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Morphology and Meaning in the English Mental Lexicon

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The authors investigated the lexical entry for morphologically complex words in English. Six experiments, using a cross-modal repetition priming task, asked whether the lexical entry for derivationally suffixed and prefixed words is morphologically structured and how this relates to the semantic and phonological transparency of the surface relationship between stem and affix. There was clear evidence for morphological decomposition of semantically transparent forms. This was independent of phonological transparency, suggesting that morphemic representations are phonologically abstract. Semantically opaque forms, in contrast, behave like monomorphemic words. Overall, suffixed and prefixed derived words and their stems prime each other through shared morphemes in the lexical entry, except for pairs of suffixed forms, which show a cohort-based interference effect.

The mental lexicon, the listener's mental representation of what words sound like and what they mean, stands at the heart of the spoken language comprehension process. The phonological properties of lexical items form the immediate target of the early stages of speech analysis, while the syntactic and semantic attributes associated with these items form the basis for subsequent processes of parsing and interpretation. It is therefore a critical question for a theory of language comprehension to specify the basic units in terms of which the lexicon is organized. Are lexical representations word based, or are they organized along morphological lines, so that the morpheme rather than the phonetic word is the primary unit of representation? What is the unit in terms of which word candidates and their competitors are specified in the lexical access process as well as in subsequent processes of integration with higher levels of processing (Marslen-Wilson, 1989; Tyler & Marslen-Wilson, 1986)?

To answer these questions, it is necessary to study the representation and access of morphologically complex words that are made up of two or more constituent morphemes. These allow us to dissociate word- and morpheme-based theories of representation as well as their associated theories of lexical access. In particular, are morphologically complex words represented as unanalyzed full forms or does the representation reflect their morphological structure? Is the word *happiness*, for example, represented as a single, unanalyzed unit, or is it represented as the morphemes {happy}[1] and {-ness}, where the morpheme {happy} may also participate in the representation of other words, such as *happily* or *unhappy*?

The psychological literature on the representation and access of morphologically complex words is conflicting and inconclusive, with both *full-listing* and *morphemic* hypotheses well supported. Full representation of polymorphemic words has been argued, among others, by Butterworth (1983), Bradley (1980), Kempley and Morton (1982), and Lukatela, Gligorijevic, Kostic, and Turvey (1980), whereas morpheme-based theories of representation have been proposed, for example, by Jarvella and Meijers (1983), Taft and Forster (1975), Taft (1981), and MacKay (1978). Going along with these conflicting proposals about representation are equally conflicting proposals about access. On a morphemic view, affixes are stripped away from base forms (Kempley & Morton, 1982; Taft, 1981), and the base form is used to access the lexicon. On a full-listing account, morphologically complex words are not decomposed into their constituent morphemes before access (Henderson, Wallis, & Knight, 1984; Manelis & Tharp, 1977; Rubin, Becker, & Freeman, 1979). Intermediate between these two camps are the partial decomposition theories, reflecting the claim that different types of morphological processes do not have uniform consequences—so that, for example, derived forms are accessed as full forms, whereas inflected forms are activated through their stems (e.g., Stanners, Neiser, Hernon, & Hall, 1979). Other proponents of mixed theories include Caramazza, Laudanna, and Romani (1988) and Stemberger and MacWhinney (1986).

There is good reason for this lack of consensus in current research. It reflects, we believe, the absence of a unified treatment of the complete set of linguistic and psychological factors

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[1] We use the convention of curly brackets {. . .} to indicate reference to abstract morphemes in a word's lexical entry.

that determine the properties of lexical representations and how they are accessed (Caramazza et al., 1988; Hall, 1992; Henderson, 1985, 1989). In the next section of this article, we attempt to lay out what these various factors are. We then go on to report some initial experiments carried out within this framework, looking at the access and representation of derivationally suffixed and prefixed words in English.

Issues in the Representation and Access of Morphologically Complex Words

A psycholinguistic theory of morphologically complex words has to start with the question of how such words are represented in the mental lexicon. In answering this question, it is crucial, first of all, to distinguish claims about the *lexical entry* for a given word from claims about its *access representation*. We take the lexical entry to be the modality-independent core representation of a word's syntactic and semantic attributes as well as its abstract phonological properties. We distinguish this from the modality-specific access representation, which provides the perceptual target for lexical access, defining the route whereby information in the sensory input is linked to a given lexical entry.

This distinction between access representations and lexical entries is not a new one in theories of the mental lexicon and can be found in models as disparate as Forster's (1976) early search models and Morton's (1969) logogen model. Despite this, psycholinguistic research into morphologically complex words has often failed to maintain this distinction, making it hard to sort out whether claims and evidence for full-listing or morpheme-based accounts apply to the access representation, the lexical entry, or both. In fact, it is perfectly possible for a full-listing hypothesis to hold true for the access representation, whereas the associated lexical entry is organized on a morphemic basis. The Augmented Addressed Morphology theory (Caramazza, Miceli, Silveri, & Laudanna, 1985; Laudanna & Burani, 1985) is one example of this.

Language and Modality

To provide a systematic answer to the question of how words are cognitively represented and accessed we have to develop an account that, at least initially, is *language specific*. Current psycholinguistic research has looked not only at English but also at languages with morphological systems as disparate as Italian (e.g., Laudanna, Badecker, & Caramazza, 1989), Dutch (e.g., Bergman, Hudson, & Eling, 1988; Schriefers, Zwitserlood, & Roelofs, 1991), Serbo-Croatian (e.g., Lukatela et al., 1980), and Chinese (Zhou, 1992; Zhou & Marslen-Wilson, 1991). It is important to study morphology cross-linguistically, but results from one language cannot be directly interpreted as evidence about the organization of the lexicon in another language. Laudanna et al. (1989), for example, reported some intriguing findings of inhibitory relations between homographic stems in Italian. However, this is a result that can only be interpreted metaphorically, at best, in a theory of English morphology, which does not have abstract bound stems in the same way as Italian. No doubt there are universal properties of morphological representation and access in the mental lexicon, but to find out what they are we have to begin by constructing systematic accounts of individual languages. Crucially, what we cannot do is investigate fragments of the morphological system in a number of different languages and then hope to combine the results into a single language-independent theory of morphological processing and representation.

Second, the account needs to be *modality sensitive*. What holds for the access of lexical representations from written words may not hold for access from the speech signal (and vice versa). One difference is the sequential delivery (and interpretation) of stimulus information in the auditory domain, with the consequences this has for the processing of prefixed as opposed to suffixed words (with their different ordering of stem and affix). Another important difference is in the presence of cues to morphological structure in one modality but not in the other—for example, the prefix in *return* and in *rebuild* is spelled in the same way but is pronounced differently. The pronunciation of *re-* with a full vowel in *rebuild* but not in *return* is a cue to morphological structure that is available to the listener but not to the reader. Thus, although the lexical entry itself may be modality independent, different access routes can give different pictures of its properties as well as having different properties themselves.

In this research, we investigate morphologically complex spoken words in English. With respect to the morphological forms themselves, there are two sets of properties that need to be kept analytically separate because they each have different consequences for the organization of the lexical entry and access to it. These properties relate to the linguistic characterization of morphologically complex words, in terms of affix type and the position of the affix with respect to the stem, and in terms of the transparency of the relationship between the stem alone and the stem in the affixed form.

Morphological Category

The first set of properties concern the basic linguistic characteristics of the affixes involved: whether they are derivational or inflectional morphemes and whether they are prefixes or suffixes. These distinctions are often ignored or conflated in psycholinguistic research, despite their salience in the linguistic analysis of the morphological structure of English. Inflectional morphology has a primarily grammatical function: for example, the suffixes that mark tense and number on a verb (as in *jump/jumps/jumped*), the suffixes that mark plural on nouns (as in *dog/dogs*), and the comparative suffixes attached to adjectives (as in *dirty/dirtier/dirtiest*). These suffixes usually do not change the form of their stems, although there are alternations like *teach/taught* or *wear/wore* that do have phonological consequences.

Derivational morphemes alter the meaning and often the syntactic form class of the base forms to which they are attached, as in *manage/management, nation/national,* and *able/unable*. Over time these forms may become semantically opaque (i.e., noncompositional in meaning), as in *department* or *delight*. In English, the derivational morphology includes both prefixes (such as *re-, ex-,* and *pre-*) and suffixes (such as *-ment, -ness,* and *-ence*), whereas the inflectional morphology is confined to suffixes. Derivational prefixes rarely change the phonological form of their stems, but some classes of derivational suffixes do trigger morphophonemic alternations that affect their stems (as in *chaste/chastity* and *decide/decision*).

The sequential order of stems and affixes (whether the word is suffixed or prefixed) is also important. In suffixed words, which seem to be preferred cross-linguistically (Cutler, Hawkins, & Gilligan, 1985), the stem is heard first, giving the listener immediate access to the syntactic and semantic information associated with it. In prefixed words, not only is access to the stem delayed but also the initial segments of the word are relatively less informative because of the large number of words typically sharing each prefix. This ordering difference, therefore, may have consequences both for how morphological factors affect the lexical entry and for the way it is accessed.

Semantic and Phonological Transparency

The second set of properties that need to be taken into account involve the nature of the relationship between the stem and the affixed form. These are the properties of phonological and semantic transparency, which interact with morphological type to determine the psycholinguistic organization of the lexical entry and its associated access representation. These factors are potentially crucial in determining how the linguistic analysis of the morphological properties of a language like English can be translated into psychological claims about full listing and decomposition at different levels of the mental lexicon. Despite this, these factors have never been systematically treated in psycholinguistic analyses of lexical access and representation.

The factor of *semantic transparency* is important in determining how a morphologically complex word can be most naturally represented at the level of the lexical entry. A morphologically complex word is semantically transparent if its meaning is synchronically compositional. Words like *happiness* or *unhappy* are semantically transparent because their meaning is directly derivable from the meaning of their stem {happy} together with their respective affixes {-ness} and {un-}. It is implausible that the lexical entries for words like this should not be related, in some way, to the lexical entry for the stem *happy*.

In contrast, even though they also contain recognizable affixes, words like *release* or *department* are not semantically transparent (although at some earlier point in the history of the language they may have been). At the level of the lexical entry, therefore, these words should not be represented in the same way as semantically transparent items. If *department* were represented as {depart} + {ment}, this would have to be a different {depart} than the phonologically identical stem of words like *departure*. Similar considerations apply for semantically opaque prefixed forms like *release* because the composition of {re-} and {lease} gives the wrong meaning. The mental representation of these forms may indeed be morphologically structured, but, if so, this will be on morphological grounds alone. Whether or not there is a purely morphological layer of structure to the lexicon remains an open question (Emmorey, 1989; Napps, 1985, 1989).

These claims about independent or shared representations in the lexical entry will also have consequences for how access representations are organized, in ways that may interact with the distinction between prefixes and suffixes (Hall, 1987, 1992). For example, if it is true that *happiness* and *happily* share the lexical entry for *happy*, it is possible that access is through a representation of the stem rather than through the full derived form. In contrast, for a prefixed word (like *unhappy*), where the initial segments of the word do not map directly onto the phonological representation of the stem, access to the lexical entry may be through a full-form access representation, as our earlier research suggests (Tyler, Marslen-Wilson, Rentoul, & Hanney, 1988).

Issues of semantic transparency and compositionality are less significant for the inflectional morphology, which is fully meaning preserving. The different inflectional variations of, say, *jump* are normally assumed to share the same lexical entry. There would be extraordinary redundancy in the mental lexicon if *jumps*, *jumped*, and *jumping* each had separate lexical entries, each containing a complete representation of the semantic and syntactic properties of the stem *jump*.

The second factor of *phonological transparency* also has consequences for both the access representation and the lexical entry. We refer to a morphologically complex form whose stem has the same phonetic shape in its affixed and unaffixed versions as phonologically transparent: For example, the stem *friend* is phonetically identical in isolation and when it occurs in the suffixed form *friendly*. There are degrees of phonological transparency, depending on how different the stem is in isolation or in its affixed form. Cases like *pirate/piracy* are more transparent than cases like *sign/signal*. We refer to cases that are relatively nontransparent, like *sign/signal*, as phonologically opaque. Phonological opacity can be found in both inflectional forms (*leave/left* and *teach/taught*) and in derived suffixed forms (*vain/vanity* and *deceive/deception*).

Cases like these, where the morphological combination is semantically transparent but phonologically opaque, provide the best argument for distinguishing an access representation from the lexical entry. A sequential access process seems to require separate access representations of lexical form. Both *teach* and *taught*, for example, need to be available as targets for the lexical access process. The stored phonological representation of the stem {teach} could not be directly accessed by the input *taught* because *teach* would never be part of the cohort of word candidates that were active when *taught* was being heard (Marslen-Wilson, 1987; Marslen-Wilson & Zwitserlood, 1989). Yet, at the level of the lexical entry, we would expect both *teach* and *taught* to map onto the same entry for the abstract stem {teach}. Similar considerations may hold true for any inflected or derived surface form that deviates in a phonologically unpredictable way from the form of the stem before the recognition point for that stem.

Experimental Issues

In the previous section, we sketched out a list of factors that need to be taken into account in thinking about the access and representation of morphologically complex words. These are all factors that, individually, have been taken up in previous research. However, it is only when they are all put together that one can begin to ask suitably focused questions about the access and representation of lexical form. We report here a series of six experiments, which make a start on the complex problem of unraveling the consequences of semantic, phonological, and morphological factors for the structure of lexical representations in speakers of English. We restrict ourselves to English derivational morphology and begin, in Experiments 1, 2, and 3, with derived suffixed words because these allow for the widest range of contrasts along the parameters of phonological and semantic transparency. In Experiments 4 and 5, we turn to English prefixing morphology, while in Experiment 6, we look at the relationship between prefixed and suffixed forms.

Experimental Task

In this research, we use a task, *cross-modal immediate repetition priming*, that has not been used extensively in previous research of lexical representation. This is a task in which the subject hears a spoken prime (e.g., *happiness*) and immediately at the offset of this word sees a visual probe (e.g., HAPPY) that is related in some way to the prime.[2] The subject makes a lexical-decision response to this probe, and response latency relative to a baseline condition is used to measure any priming effect. This effect may be either facilitatory or inhibitory. The baseline here would be the subjects' responses to the same probe following an unrelated spoken prime (e.g., *careful*). If the access of a derived form involves access to its stem, then this should have consequences for the representation of the stem in the mental lexicon, which in turn should affect immediate responses to the stem when it is itself presented as a stimulus.

Most research in the literature uses delayed rather than immediate repetition and intramodal rather than cross-modal probes. There are three reasons why we chose the immediate repetition cross-modal task instead:

1. *On-line probes.* The task is a more direct measure of the processing events we are interested in. These take place on-line as part of the access and identification of the word being heard. Immediate repetition priming allows us to probe these events as near as possible to the time that they are occurring. This is not to say that the processing consequences of accessing a particular form do not have a time-course; it may also be necessary to use delayed repetition priming as well to get a full picture of what is going on. However, the right place to start is the immediate processing consequences of hearing a derived form.

2. *Episodic effects.* A second consideration is the problem of episodic effects in delayed repetition. The issue here is whether delayed repetition priming reflects changes in the state of the lexical entry originally primed, which is the rationale for using the task to investigate the structure of the mental lexicon, or whether it is due to some other process, possibly strategic in nature, involving the subject's memory that a particular event occurred (e.g., Forster & Davis, 1984; Jacoby & Dallas, 1981). Although strenuous efforts have been made to minimize possible episodic effects (e.g., Fowler, Napps, & Feldman, 1985), there is still, in our opinion, a cloud that hangs over delayed repetition that is difficult to dispel completely.

3. *Probing the lexical entry.* Our primary interest here is in the structure of the modality-independent lexical entry. The use of a cross-modal probe means that if there are any priming effects, then they will have to be mediated through this level of the system and not through lower level overlap in modality-specific access pathways and representations. If hearing *happiness* has some consequences for responses to the visual probe HAPPY, this cannot be because the auditory input has affected the early stages of featural analysis of the visual probe. In contrast, an auditory prime followed by an auditory probe may very well cause priming effects that are due to low-level overlap in the shared processing pathways. This is especially likely to occur in an immediate priming task.

Derivationally Suffixed Words in English

Our first question is about the organization of the lexical entry for derived suffixed words in English. Is the lexical entry morphological structured, and, if so, how does the representation of a derived form reflect the semantic and phonological transparency of its constituent stem and affix morphemes?

There is relatively little work on derived suffixed forms in English, and what work there is has chiefly been in the visual domain.[3] Of this, the most relevant is the pioneering work of Bradley (1980), using frequency effects in a visual lexical-decision task to ask whether suffixed words are accessed as full forms or through some sort of stem-based representation. Bradley investigated four types of suffixed words: those with the affixes, [*-ness*], [*-er*], [*-ment*], and [*-ion*]. For the first three of these, which are all affixes that do not change the phonological form of their stems, the results suggested stem-based access and representation. Frequency effects for pairs of items with these suffixes followed the frequency of the stems rather than the frequency of the forms themselves. This contrasted with the results for words ending in the affix [*-ion*], which does induce phonological changes in the form of the stem (e.g., *decide/decision*). Here there was no significant stem-based frequency effect, suggesting that such forms are not accessed through their stems in the same way as more phonologically transparent words might be. Bradley's results are not completely clear-cut, and they are in the visual domain. Nonetheless, they suggest that morphological factors do affect the access and representation of suffixed words in English and that this may interact with phonological transparency.

Looking at the broader repetition priming literature, it is often difficult to separate out the effects for derivational as opposed to inflectional suffixes. Where the two morphological types have been kept separate, conflicting results seem to be obtained. In early research using a long-lag repetition paradigm, Stanners et al. (1979) found that derivationally suffixed forms were less effective in priming their verb stems than regularly inflected forms of these verbs. They interpreted this as evidence that derived forms are separately represented in memory from their stems, whereas inflected forms are not. Subsequent work by Fowler et al. (1985), also using delayed repetition priming but with better controls for episodic effects, found equally strong priming for derived and inflectional forms, irrespective

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[2] We use capital letters to indicate the visual probes used in the cross-modal priming task.

[3] Under the influence of Taft and Forster's (1975) affix-stripping hypothesis, a high proportion of the research in English has been on the perception of derivationally prefixed words. Much of the remainder has been concerned with the contrast between strong and weak forms in the verb inflectional morphology (e.g., the difference between *jumps/jumped* and *teach/taught*).

of the phonological or orthographical transparency of the morphological relationship. Most relevant for us, they found parallel effects for auditory and visual primes. Unfortunately, because they do not take into account the variable of semantic transparency it is hard to interpret their results in the auditory studies, where inflectional and derived forms of varying degrees of phonological and orthographic transparency were combined together as primes and targets. Nonetheless, this is work that supports the view that the morphological structure of derived suffixed words in English is reflected in the organization of the mental lexicon and that this has consequences for lexical access.

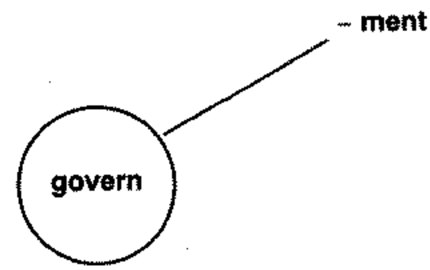

Figure 1. A preliminary stem + affix model of the lexical entry for the semantically transparent suffixed word *government.*

Experiment 1

The first experiment in this series lays the foundation for the rest, asking whether the on-line repetition priming task will provide evidence for a level of morphologically structured lexical representation that abstracts away from the surface phonetic properties of word forms belonging to morphologically related families. This is a question both about the properties of lexical representations and about the suitability of the task for investigating these properties. To answer this, we have to set up an experimental situation that covaries the phonological and morphological relationship between the auditory prime and the visual probe.

This in turn requires us to define the notions *morphological relationship* and *phonological transparency.* The definitions we give hold for all the experiments reported here.[4]

Morphological Relatedness

This was defined on linguistic and historical grounds. A derived form and a free stem (such as the pair *happiness/happy*) were classified as morphologically related if they met the following criteria:

1. The derived form had a recognizable affix (as listed by Quirk, Greenbaum, Leech, & Svartvik [1985] or Marchand [1969]).
2. When the affix was removed, the resulting (underlying) stem was the same as the paired free stem.
3. The pair of words shared the same historical source word (or *etymon*), as determined by the Oxford Dictionary of English Etymology (1983) or the Longman Dictionary of the English Language (1983).[5] This was a final check to exclude pairs that had coincidentally homophonic stems.

Table 1
Sample Stimuli Used in Experiment 1 (Suffixes)

Condition	Example
1: [+Morph, +Phon]	*friendly/friend*
2: [+Morph, −Phon]	*elusive/elude*
3: [+Morph, −Phon][a]	*serenity/serene*
4: [−Morph, +Phon]	*tinsel/tin*

Note. Morph = morphological; Phon = phonological.
[a] In Condition 3, the surface form of the stem in isolation does not correspond to its underlying representation (see text).

Phonological Transparency

Pairs of items were defined as having a phonologically transparent relationship on the following basis:

1. The stem was fully contained within the derived word in a form that was phonologically identical to the realization of the stem as a free form.
2. The stem was followed (or preceded) by a clearly identifiable separable affix, as in pairings like *happiness/happy* or *unable/able.*
3. A pair of items was classified as phonologically transparent even if resyllabification had taken place. This refers to the potential change in the prosodic status of the final segment in the stem when it occurs in the derived form (e.g., the final /t/ in {excite} is syllable-final in the free stem but is syllable-initial when it occurs in the derived form *excitable.*
4. In general, a pair was designated as not having a phonologically transparent relationship if there was any vowel or consonantal alternation between the stem and the derived word (as in *sane/sanity* or *delete/deletion*).

On the basis of these definitions we constructed the four types of stimuli illustrated in Table 1. In Condition 1, the auditory prime (always a derived suffixed word) was morphologically (Morph) related to the visual target (always a free stem), and this relationship was phonologically (Phon) transparent. (Examples of this are pairs like *friendly/friend* or *government/govern.*) We refer to this type of prime–target relationship as [+Morph] and [+Phon]. We predict that we should obtain priming here on the basis of the preliminary model of lexical representation illustrated in Figure 1. This simply states that the lexical entry for semantically transparent forms like *government* consists of the stem morpheme {govern} and a link to the suffix {-ment}. The same stem morpheme also functions as the lexical entry for the morphologically simple form *govern.* We assume that the recognition of the word *government* involves the access of the stem morpheme and the associated affix. This changes the state of the stem morpheme such that when the

[4] Because semantic transparency was not a factor in Experiment 1, we reserve the definition of this until later.

[5] We also tried to enforce the additional constraint that pairs of items defined as morphologically related should have come into English through the same Indo-European daughter language, preferably at around the same time historically.

visual probe GOVERN is immediately presented, mapping onto the same morpheme but through a different perceptual route, the lexical-decision response to this probe is facilitated.

This is an account of priming based on shared morphemes in the lexical entry. What we need to exclude is the possibility that any priming effect obtained in Condition 1 is simply due to the surface phonetic overlap between prime and target. When the subjects hear a [+Phon] prime like *government*, where *govern* is a transparent part of the input, it is possible that the prime activates two different lexical form representations (for *govern* and for *government*) and that it is this residual activation of *govern* that produces priming when GOVERN is presented for lexical decision.

Conditions 2 and 3 address this concern by presenting the subjects with prime–target pairs that are still morphologically related [+Morph] but where this relationship is no longer phonologically transparent [−Phon]. In Condition 2, we used cases like *tension/tense* or *elusive/elude*, where the phonetic form of the stem is different in isolation from what it is in the derived form. If priming in this task is just due to the phonetic overlap between prime word and target word, then there should be less priming in Condition 2 than in Condition 1. However, if priming is due to events at the level of the lexical entry, then changes in the surface relationship between forms should have no effect. If *friendly* primes lexical decisions to FRIEND because they share the same morpheme in the lexical entry, then the same will be true of any pair with the same morphological relationship, irrespective of any variation in the phonetic realization of the shared morpheme in different contexts.

In Condition 3, we go a step further, using pairs like *vanity/vain* or *gradual/grade*, where not only does the stem have a different phonetic form in isolation but also the underlying representation of the stem (as determined by standard linguistic analysis) is not identical to its surface form. Thus, for example, the underlying phonological representation of the stem {vain}, which surfaces as [veyn] when heard in isolation but as [væn] in the context of {-ity}, is assumed to be /vÆn/, where Æ indicates an underlying vowel unspecified for tenseness (Myers, 1987). This has the effect of increasing the abstractness of the relationship between the stem and the phonetic form of the derived word.[6] Again, if priming of the stem depends just on the phonetic overlap between prime and target, then priming should be reduced here relative to Condition 1. If priming is due to shared morphemes in the lexical entry, then there should be no effect.

Finally, in Condition 4, subjects respond to pairs such as *termite/term* or *planet/plan*, where there is no morphological relationship [−Morph] but where the target is transparently contained within the prime phonologically [+Phon].[7] If phonetic overlap between prime and target is able to produce priming in the cross-modal immediate repetition task, then we should get as much priming as in Condition 1. If priming here is just due to shared morphemes in the lexical entry, then there should be no effect at all for any of these [−Morph, +Phon] pairs.

Summary

Experiment 1 was designed to assess the role of morphological structure in the lexical entry and to evaluate the appropriateness of cross-modal repetition priming as an experimental task. To do this it asked four questions: (a) Would a derived suffixed form prime its stem? (b) Could the priming be attributed to phonological as opposed to morphological relatedness? (c) Would the degree of phonetic identity between stem and derived form affect priming? (d) Would priming be affected when the stem's underlying representation was not identical to its surface representation?

Method

Materials

We selected 120 prime–target pairs, falling into the four conditions outlined in Table 1.[8] Ninety of the pairs, forming Conditions 1, 2, and 3, consisted of a derivationally suffixed form and its associated free stem. These were morphologically related according to the definition given earlier. They were also all judged to be semantically transparent by a panel of four judges. The pairs were matched across conditions for frequency, number of syllables, and grammatical category.

In Condition 1, the prime–target pairs were phonologically transparent in that the stem had the same phonetic form when it appeared in isolation and when it was part of the derived word (e.g., *delightful/delight*). Conditions 2 and 3 consisted of derived-stem pairs that were phonologically opaque in that the stem had a different phonetic form in isolation compared with when it appeared in the derived word (e.g., *tension/tense*). In Condition 3, the surface form of the stem in isolation also diverged from its assumed underlying representation (e.g., *serenity/serene*). Thirty more pairs, in Condition 4, consisted of words that were not morphologically related but that overlapped phonetically (e.g., *tinsel/tin*).

Because we were using a cross-modal task here, it was necessary to place constraints on the orthographic properties of the visual probes:

1. We excluded heterographic homophones, such as *steak/stake*.
2. Final silent ⟨e⟩ was not considered to be a problem: Stems that were contained within the derived word up to but excluding a silent ⟨e⟩, as in *excitable/excite* (Condition 1) or *gravy/grave* (Condition 4), were allowed.
3. Regular spelling alternations, such as the ⟨y⟩ ↔ ⟨i⟩ alternation in *happy/happiness*, were also permitted. These constraints also applied in all the subsequent experiments.

For each of the 120 prime words, we selected a control (or baseline) word that matched the prime in frequency,[9] number of syllables, and form class. Frequency was computed here, as throughout, on the principle that inflectional variants of the same stem should be counted to-

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[6] In making use of linguistic concepts of representation in this way, we are not necessarily assigning a strong psychological reality to abstract phonological analyses. Nonetheless, we have found in earlier research (e.g., Lahiri & Marslen-Wilson, 1991) that phonological concepts of abstractness in underlying representation are successful in predicting performance in lexical access tasks. This suggests a useful degree of functional isomorphism between current phonological accounts and listeners' mental representations of lexical form.

[7] Strictly speaking, these pairs are not phonologically transparent in the sense defined earlier because the prime does not necessarily terminate in a recognizable affix. They are, however, [+Phon] in the sense crucial for the comparison here—namely, that the prime transparently contains the target.

[8] A full listing of the stimulus materials for this and the five following experiments is obtainable from William Marslen-Wilson. For reasons of space the materials could not be included with this article.

[9] The mean frequencies of the primes, controls, and targets, respectively, were as follows: Condition 1—19, 20, and 60; Condition 2—30, 33, and 49; Condition 3—16, 16, and 47; and Condition 4—14, 15, and 53.

gether (e.g., *jump/jumps/jumped*) but that derivational variants should not. None of the control items was either morphologically, semantically, or phonologically related to the targets. The priming effect in the immediate repetition task is measured by comparing response time to the target word following the related (test) prime with response time following the control word.

Fillers. An important consideration in priming tasks, especially those using immediately adjacent primes and targets, is to deter the subjects from developing strategies based on expectations about likely relations between primes and targets. One way of combating this, which we followed here, is to keep the stimulus onset asynchrony (SOA) between prime and target as short as possible. It is equally important to construct the filler materials so as to (a) significantly dilute the proportion of related items encountered by the subject in the experiment as a whole and (b) to obscure the regularities in the test items. To this end we constructed 180 additional filler pairs, falling into three categories:

1. Thirty fillers consisted of real-word/nonword pairs (e.g., *donkey/donk*, *bishop/bish*) in which the target was fully contained within the prime. Thirty more fillers consisted of real-word/nonword pairs in which there was a partial overlap between the prime and the nonword target (e.g., *usage/usetern*, *forgery/forticle*). These two sets of fillers ensured that not all prime–target pairs that overlapped phonetically had real-word targets.

2. Thirty fillers consisted of morphologically unrelated real-word pairs (e.g., *penniless/edge*, *lucky/accept*). We included these items to increase the percentage of morphologically unrelated real-word pairs in the stimulus set.[10]

3. To balance the number of real-word and nonword targets, 90 additional real-word/nonword pairs were constructed with no phonological relationship between prime and target (e.g., *volunteer/soad*, *vinegar/bline*).

This gave a total of 150 real-word/real-word pairs and 150 real-word/nonword pairs. The fillers and test items were pseudorandomly distributed throughout the list, with the same order of test and filler items in each of the two versions. Each version contained a total of 370 pairs—50 practice pairs, which were followed by 20 "warm-up" pairs, and the 300 test and filler pairs.

Design and Procedure

The test items were divided into two versions. These were balanced so that all the targets appeared once in each version: half preceded by the prime and half preceded by the control word.

The primes (both test and control) were recorded by a female native speaker of English. They were then digitized and stored on a Cambridge Electronic Design (CED) Winchester disk, with reference points noted for their onsets and offsets. This allowed us to control the timing relations between the prime and the visually presented target. The prime was presented binaurally to the subject and, immediately at the offset of the prime, the target word was displayed on a CRT screen in front of the subject. The subject's task was to press one response key if the target was a real word and another if it was a nonword.

The exact sequence of stimulus events within each trial was as follows (the same procedure was followed in all subsequent experiments). A fixation point was displayed on the CRT screen in front of the subject for 1,000 ms. This was followed by a short (100-ms) warning tone, which was immediately followed by the auditory prime word. At the acoustic offset of this word, the visual probe was presented (unmasked) for 200 ms. Subjects were allowed 3,000 ms, from the time of probe presentation, in which to respond. At the end of this period there was a pause of 500 ms and then a new trial was initiated (marked by the reappearance of the fixation point). To ensure that subjects attended to the auditory prime, they were occasionally asked, after they had made the yes–no response, to write down the word they had just heard. This happened on about 15% of the trials. On these trials the intertrial interval was increased by 9 s.

Subjects

We tested 25 subjects from the Medical Research Council (MRC) Language and Speech Group subject pool. Twelve subjects were tested on Version 1 and 13 subjects on Version 2.

Results and Discussion

We excluded 4 subjects (2 from each version) because of high error rates in the lexical-decision task. Two items were also excluded, one because of experimenter error and one because of high error rates. This left a total of 21 subjects and 118 items.

For the analysis of reaction times (RTs), all errors (2.9%) and extreme values (0.8%) were removed from the data set (extreme values were defined as any responses of less than 100 ms or more than 950 ms). We then computed midmean values for each subject and each item in each condition, giving the overall results shown in Table 2. The midmeans were then entered into two analyses of variance (ANOVAs), with the factors of Condition (1–4) and Prime Type (test or control), one with subjects and the other with items as the random variable. F'_{min} values were then computed.[11]

First, there were significant main effects of both Prime Type, $F'_{min}(1, 84) = 9.99, p < .01$, and Condition, $F'_{min}(3, 169) = 7.45$, $p < .01$. Responses were slower overall to control than to test items and varied between conditions. Second, there was a significant Prime Type × Condition interaction, $F_1(3, 60) = 7.64$, $p < .001$; $F_2(3, 114) = 3.40$, $p < .05$; although $F'_{min}(3, 173) = 2.35$, $p < .10$. This was because the prime word had strong facilitatory effects in the three [+Morph] conditions, but had no effect in Condition 4. Here the target also overlaps phonetically with the prime, but there is no morphological relationship between them. These effects are illustrated in Figure 2, which plots the test–control difference scores for the four conditions. Responses to target probes were facilitated in Condition 1, $t(29) = 3.304$, $p < .01$, Condition 2, $t(29) = 4.077$, $p < .01$, and Condition 3, $t(29) = 2.508$, $p < .05$, but not in Condition 4 ($t < 1$), where, if anything, responses tended to be slower following the prime.

A separate analysis of the errors, conducted on the item error means, showed an effect only of Condition, $F_2(3, 114) = 5.84$, $p < .01$. This is because there were more errors overall (7.6%) in Condition 4 [−Morph, +Phon] than in the other three conditions (1.1%, 2.8%, and 1.7%, respectively). There was no effect of Prime Type nor any interactions with Condition. This sug-

[10] In any one experimental version, the subject would encounter a maximum of 45 morphologically related target–prime pairs: This is 30% of the real-word/real-word pairs and 15% of the total set of test trials.

[11] Our policy regarding statistical reports is as follows: F_1, F_2, and F'_{min} are always computed, if appropriate. We consider an effect significant if both F_1 and F_2 meet the .05 criterion. If F'_{min} is also significant, we report only this because it makes for easier reading. When F_1 and F_2 are both significant but F'_{min} (a conservative test) is not, we report all three. In a few cases, such as error analyses, where the subject data is too patchy to warrant statistical analysis, we report F_2 only.

Table 2
Mean Lexical Decision Times and Error Rates in Experiment 1 (Suffixes)

Condition	Example	Test M	Test Error rate	Control M	Control Error rate	Difference
1: [+Morph, +Phon]	*friendly/friend*	539	1.1	583	0.3	44*
2: [+Morph, −Phon]	*elusive/elude*	563	2.8	623	2.9	60*
3: [+Morph, −Phon]	*serenity/serene*	572	1.7	608	1.3	36*
4: [−Morph, +Phon]	*tinsel/tin*	647	7.6	638	7.6	−9

Note. Morph = morphological; Phon = phonological.
* $p < .05$.

gests that some of the visual probes in Condition 4, although matched in frequency to the probes in the other conditions, were more difficult to identify.

Overall, the results give a clear answer to the questions being asked in this experiment. They show that derived suffixed forms do prime their stems in the cross-modal immediate repetition priming task and that this effect cannot be attributed in any simple way to surface phonetic overlap between prime and target (or to any postaccess strategies based on this). Phonetically related but morphologically unrelated pairs, like *principal/prince* or *cabbage/cab*, do not prime each other, whereas morphologically related pairs do prime, irrespective of the degree of surface phonetic overlap. The amount of priming in Condition 1 [+Morph, +Phon], where the morphological relationship is phonetically transparent, is not significantly greater (at 44 ms) than the 36-ms effect in Condition 3 [+Morph, −Phon], where there is a much more opaque relationship between the phonetic form of the prime and the target (and their underlying representations). The strongest priming is obtained in Condition 2, also [+Morph, −Phon], but this does not differ significantly from the amount of priming in the other two [+Morph] conditions.

In two further analyses, we looked more closely at the stimuli in the two [+Phon] cases to make sure that the contrast between Condition 1 [+Morph, +Phon] and Condition 4 [−Morph, +Phon] was indeed due to the difference in morphological relatedness and not to some other phonological difference. First, we looked at resyllabification. We assumed earlier that resyllabification did not reduce phonological transparency, where resyllabification is defined as a change in the prosodic status of the final segment of the stem when it was followed by a derivational suffix. A consonantal final segment will become syllable-initial, roughly speaking, when the suffix begins with a vowel (as in *self/selfish* but not in *harm/harmless*). In fact, most of the stems in Condition 1 did resyllabify (22 out of 30) and similarly for the pseudostems in Condition 4 (23 out of 29). Looking at these resyllabification cases on their own, the priming results were unchanged: −13 ms in Condition 4 and 41 ms in Condition 1.

In a second analysis, we checked the amount of phonetic overlap between prime and target in the two conditions. In Condition 4, almost all of the probes were monosyllabic (26 out of 29), as opposed to a much lower proportion in Condition 1 (17 out of 30). This reflected the difficulties we had in finding word pairs that were [−Morph] but where there was more than a one-syllable overlap (as in *cellar/celery*). In contrast, the stems in derivational forms are very often bisyllabic. It is unlikely that this difference affected the results because if we look at just the monosyllabic target–stem and target–pseudostem cases, the priming pattern stays unchanged (at −11 ms in Condition 4 and 44 ms in Condition 1). Nonetheless, one issue to be taken up in later experiments is the amount of overlap in the [−Morph, +Phon] control conditions compared with [+Morph] conditions.

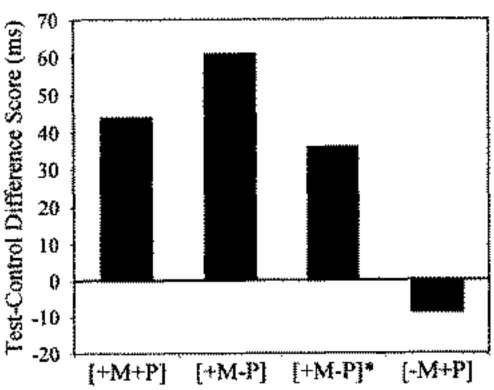

Figure 2. Priming effects for Experiment 1, showing the test–control difference scores for Condition 1 [+M, +P], Condition 2 [+M, −P], Condition 3 [+M, −P]*, and Condition 4 [−M, +P]. M = morphological; P = phonological.

Experiment 2

Experiment 1 shows that derivationally suffixed words prime their free stems in a cross-modal repetition priming task and that this effect cannot be attributed to surface phonetic overlap between prime and target. Experiment 2 investigates a variety of issues raised by these results.

Semantic and Morphological Structure

Is the priming that we observed in the [+Morph] conditions in Experiment 1 due to shared morphemes in a morphologically structured mental lexicon, or was it due to the semantic relationships between the morphologically related pairs? All of the

[+Morph] pairs in Experiment 1 were judged to be semantically transparent, whereas the [−Morph] pairs clearly were not. It is possible, therefore, that the lexical relationships we are tapping into are semantic in nature and not necessarily morphological at all. The words *government* and *govern*, for example, share many semantic properties, and it may be by virtue of this relationship, rather than any specifically morphological relationship, that priming is obtained.

We can investigate this by covarying semantic and morphological relatedness. In Experiment 1, we obtained priming for pairs that were both morphologically and (we assumed) semantically (Sem) related, that is, [+Sem, +Morph]. Will we also obtain priming for [−Sem, +Morph] pairs, which are morphologically but not semantically related? This raises the issue of whether there are grounds for supposing that there is morphological structure in the lexicon independent of semantic structure.

The clearest arguments here are linguistic in nature. In his influential treatise on morphology, Aronoff (1976) argued that morphological relations can be identified that involve morphemes that have no clear semantic interpretation. These are cases like the bound morpheme {-mit}, which only occurs as an element in words like *permit, transmit*, and *submit*. Although these words do not share a common meaning, they are linked by a common phonological rule, which generates the forms *permission, transmission*, and *submission*, and which is specific to verbs containing the root {-mit}. This suggests, according to Aronoff, that phonetic strings can be identified as morphemes independent of semantic considerations. Some experimental support for this is provided by the work of Emmorey (1989), who found priming effects for pairs like *submit/permit* or *conceive/deceive* in an intramodal repetition priming task.[12] Using somewhat different tasks, researchers such as Henderson et al. (1984) and Napps (1985, 1989) have also argued for the separability of morphological and semantic factors in determining lexical relations.

Returning to English derivational suffixes, there are plenty of cases where morphological links can be established between pairs of words but where the relationship is no longer semantically transparent. These are pairs like *authority/author* or *responsible/response*, which meet the linguistic and etymological criteria for morphological relatedness defined earlier, but where the meaning of the complex form can no longer be derived from the simple composition of the meanings of the stem and the affix. For cases such as this, where the historical relationship between stem and derived form remains phonologically recoverable, it is possible that synchronic processes of morphological analysis could identify the potential constituent morphemes without requiring semantic support. These processes might operate, for example, as part of a perceptual parsing procedure applied to all input strings (e.g., Caramazza et al., 1988).

Automatic morphological decomposition during lexical access, accompanied by morphemic representation independent of semantic support, is also, of course, central to the view of lexical representation and access proposed by Taft and Forster (e.g., Taft, 1981; Taft & Forster, 1975). Words like *submit* and *deceive* are primarily represented in terms of their bound root morphemes ({-mit} and {-ceive}), and all potential affixes are stripped off in a preliminary parsing procedure that prepares the input string for lexical access.

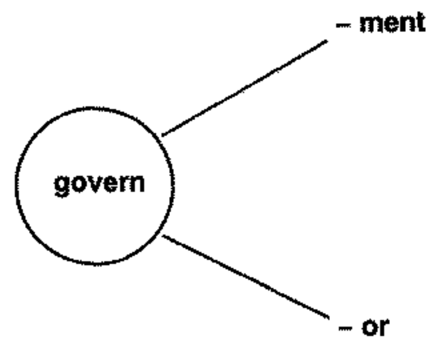

Figure 3. The stem–affix model expanded to show two suffixes (*-ment* and *-or*) sharing the same stem (*govern*).

In Experiment 2, we contrast priming for suffixed [−Sem, +Morph] pairs, such as *authority/author*, with priming for [+Sem, +Morph] pairs of the type used in Experiment 1, such as *friendly/friend* or *predictable/predict*. This requires a synchronic definition of semantic transparency. Derived forms are normally transparent when they first come into the language, in the sense that the meaning of the form can be directly established from the composition of the stem (or root) with its affix. The problem is to determine whether this still holds synchronically, that is, for current users of the language. The only reliable way of doing this is to consult groups of current users. For the purposes of this and subsequent experiments, therefore, we have resorted to an operational definition of [±Sem], classifying morphologically complex words as semantically transparent or opaque on the basis of a pretest, where individuals are asked to judge the relatedness of a derived form and its free stem.[13]

Morphological Relations

The second direction we take in Experiment 2 is the development of the model sketched out in Figure 1. Assuming, for the moment, that the effects in Experiment 1 were morphological in nature, then we can explain the results in terms of shared morphemes in the derived form and the free stem. Facilitation is due to repeated activation of the same region (the shared morpheme) in the lexical representation.

If this account is correct, then it leads to further predictions involving the relationship between two derived suffixed forms, such as *governor* and *government*. The model is expanded in Figure 3 by adding another link to {govern} so that it is now shared not only by the free stem *govern* and the derived form *government* but also by the derived form *governor*. This predicts that derived forms sharing the same stem should prime each other. In each case, access to the lexical entry involves the same re-

[12] Emmorey's results are not completely clear-cut. We discuss this further when we come to our own experiment involving prefixed bound morphs (Experiment 5).

[13] See Derwing (1976) and Smith (1988) for examples of earlier studies using rating techniques to measure the synchronic transparency of morphologically complex forms.

gions in the lexical representation. When the probe GOVERNOR follows the prime *government*, responses should be facilitated in the same way, and for the same reasons, that the probe GOVERN is facilitated.

The issue of semantic transparency is potentially important here because it is unlikely that two forms will share the same stem if there is not a semantically transparent relationship both between the two derived forms and between each form and its hypothesized shared stem. In line with the contrasts outlined earlier, between [+Morph] and [+Sem] derived–stem pairs, we investigate the effectiveness as primes of derived–derived pairs that are either [+Sem, +Morph], as in *confession/confessor*, or [−Sem, +Morph], as in *successful/successor*.

Phonological and Semantic Controls

The design for Experiment 2 can be seen, so far, as a two-way factorial, with the factors of Semantic Transparency [±Sem] and Morphological Type (derived–derived vs. derived–stem). We need to append to this design two further control conditions, evaluating the roles, respectively, of purely semantic and of purely phonological links between primes and targets.

In conjunction with the [+Sem, +Morph] and [−Sem, +Morph] pairs, we need to test pairs like *idea/notion*, which are semantically related but have no morphological or phonological relation [+Sem, −Morph, −Phon].[14] The reason for this is to establish whether the task is sensitive to purely semantic links between prime and target. There is plenty of research showing priming between associatively related primes and targets in cross-modal tasks, going back to the original research by Swinney (1979), but none of this research, as far we know, has separated out semantic from associative effects in the way that has been attempted for intramodal priming (e.g., Fischler, 1977; Lupker, 1984; Moss, Ostrin, Tyler, & Marslen-Wilson, 1992). Because the [+Sem, +Morph] pairs in Experiment 1 were not associates of each other, associative priming is unlikely to be the basis of the priming effects. This additional test will tell us whether semantic relations prime cross-modally.

The final issue is the question of phonological overlap between prime and target in the [−Morph, +Phon] control conditions. In Experiment 1, the average amount of overlap in Condition 4 (*tinsel/tin*) was less than for the comparison Condition 1 (*delightful/delight*).[15] Because it is crucial that priming is not found for [−Morph, +Phon] pairs, we decided to repeat this test for a new set of items where the amount of phonological overlap between prime and target was more precisely matched to the amount of overlap for the morphologically related pairs.

Method

Materials

The design of the experiment required six sets of prime–target pairs, four of them organized along the factorial dimensions of Semantic Transparency and of Morphological Type (derived–stem vs. derived–derived), with the other two falling into the semantic and phonological control conditions (see Table 3). For the four factorial sets, we proceeded by constructing the largest sets we could find that met the morphological relatedness criteria and then subjected these to a semantic relatedness pretest. Morphological relatedness was defined as before, with minor extensions to cover the derived–derived pairs: Both members of the pair were required to have a recognizable affix, and when this was removed, the resulting stems[16] (or roots for bound-root pairs) were required to be etymologically identical in their mode of entry into the language.

Candidate pairs for the two derived–stem conditions were relatively easy to find, and 30 of each were entered into the pretest. Derived–derived pairs were more difficult to find, especially those potentially falling into the [−Sem] condition. We therefore expanded the derived–derived category to include pairs sharing a bound root. These are pairs like *fragile/fragment*, where the root {frag-} never occurs as a free form. This allowed us to compile a list of 24 candidates for each condition, equally divided into bound-root and free-stem forms.

For Condition 5, a candidate set of 42 synonym pairs, such as *clumsy/awkward* or *sorrow/grief*, were selected from published lists of synonyms. The reason for choosing synonym pairs was because we wanted to match the high degree of overlap in semantic features that presumably holds between morphologically related words sharing the same stem. For Condition 6, we scoured the language looking for morphologically and semantically unrelated words that shared their first two syllables (such as *arsenal/arsenic* and *serial/serious*) and where the first syllable could not be interpreted as a prefix. These are quite uncommon, but we managed to find 40 candidates for the pretest.

Semantic relatedness pretest. The 190 candidate test pairs, together with 35 completely unrelated pairs (such as *kennel/solution* or *vinegar/inspiration*), were then tested for semantic relatedness. The 225 word pairs, together with 10 practice items, were presented to the subjects in the form of a test booklet. Each page contained 20 word pairs, each followed by a 9-point scale ranging from *very unrelated* (1) to *very related* (9). Subjects were asked to decide, for each pair, how "related in meaning" they thought the two words were. They were given a synonym pair (*happy/cheerful*) and a [+Sem, +Morph] pair (*friendly/friendship*) as examples of words that should be scored as very related in meaning. They were also reminded that pairs like *treaty/treatment*, although they look as if they might contain the same word, are in fact unrelated in meaning and should be scored low on the scale. They were warned, finally, that some of the words in the lists might be unfamiliar to them. If this was the case, then they should not attempt to rate the relatedness of the pair. This gave us some feedback about the familiarity of the items in the experiment.

Fifteen subjects successfully completed the pretest. In evaluating the rating scores for the candidate items for the six test conditions, we took as baselines the mean score of 1.08 for the unrelated controls (*kennel/solution*) and the mean score of 8.34 for the synonyms. The subjects were clearly using the entire scale, and it was possible to select subsets of items for each test condition that were well separated in average relatedness and where there was no overlap in the distributions for [−Sem] and [+Sem] conditions. No pair with a rating of less than 6.8 was included in any of the [+Sem] conditions, and no pair with a rating higher than 4.0 was included in the [−Sem] conditions.

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[14] The other stimulus types in this (and subsequent) experiments are made up of stimuli that for the most part are phonologically transparent. For clarity of exposition we do not state this explicitly for every stimulus type. The [Phon] variable is only specified when this is relevant to the contrast being tested.

[15] In Experiment 1, the average amount of overlap for Condition 4 was 3.3 segments, compared with 4.3 segments for Condition 1. Note, however, that Conditions 1 and 4 were matched in the sense that in each of them the probe was transparently and completely contained within the prime.

[16] In the experiments presented here, the stems were nearly always roots. The exceptions (e.g., the stem *absorb* can be analyzed as having the prefix {ab} and the root {-sorb}) were judged to be synchronically monomorphemic.

Table 3
Sample Stimuli Used in Experiment 2 (Suffixes)

Condition	Morphological type	Example
1: [−Sem, +Morph]	derived–stem	*casualty/casual*
2: [+Sem, +Morph]	derived–stem	*punishment/punish*
3: [−Sem, +Morph]	derived–derived	*successful/successor*
4: [+Sem, +Morph]	derived–derived	*confession/confessor*
5: [+Sem, −Morph, −Phon]	NA	*idea/notion*
6: [−Sem, −Morph, +Phon]	NA	*bulletin/bullet*

Note. Sem = semantic; Morph = morphological; Phon = phonological; NA = not applicable.

Association pretest. A second pretest was carried out to obtain associates of the synonym pairs in Condition 5. This was to ensure that there was no associative relationship between prime and target in this condition, on the assumption that any nonmorphological links between pairs in the [+Morph] conditions would be semantic rather than associative in nature. Morphologically related words that are semantically transparent are not normally given as responses in free association tasks.

In this second pretest, we prepared two lists, each of which contained half of the set of 42 pairs of synonyms. Ten subjects were given each list and were asked to read each word on the list and write down the first word that came to mind. All synonyms that were given as associates by more than 1 subject were discarded. This left us with 26 pairs of synonyms.[17]

Table 4 summarizes the outcome of the selection procedures; the different *N*s across conditions reflect the need to use as many pairs as possible that meet all the selection criteria. The highest proportion of candidates had to be discarded in the derived–derived bound-root pairs so that only seven of these could be included in each of the derived–derived conditions. Almost all the pairs met the criteria for phonological transparency, but because the [+Phon] variable had so little effect in Experiment 1, we felt it was justifiable to include pairs where there were minor phonological changes in the form of the stem, for example, *succession/successful.* The test pairs were matched as far as possible across conditions for frequency, suffixes used, and amount of phonological overlap between members of the pair. In particular, the average segmental (4.3) and syllabic (1.5) overlap between prime and target in Condition 6 (*bulletin/bullet*) closely matched the average overlap for the other [+Phon] conditions (at 4.5 and 1.5, respectively). Note that the amount of overlap in Condition 6 is now the same as in the [+Morph, +Phon] condition in Experiment 1, where significant priming was obtained.

Each of the 120 test pairs was paired with a control word, which was matched to the prime word in frequency, number of syllables, and form class.[18] None of the control words was morphologically, semantically, or phonologically related to either the prime or the target. In addition, we constructed 120 filler pairs in which the target was a nonword. Thirty of these pairs consisted of real-word/nonword combinations in which the first member of the pair was a derived form and the second was a pseudoderived form with an apparent morphological relationship to its partner (e.g., *respectful/respition*). Another 30 pairs had comparable pseudoderived–stem relations (e.g., *computation/compuse*). There were also 60 pairs (e.g., *nourishment/demper*) with no phonological or orthographical relation between them. In addition, 50 practice items were constructed for use at the beginning of each list as well as 20 warm-up items preceding the test list.

Design and Procedure

Two versions of the materials were made, each version containing half of the real-word pairs. Items were balanced across versions so that each target appeared only once in each version. In one version, it appeared with its prime and in the other version, with its control word. The real-word pairs were pseudorandomly interspersed with the real-word/nonword pairs.

The materials were recorded, digitized, and presented to the subjects following the same procedures as in Experiment 1.

Subjects

Twenty-two paid subjects were tested, having been selected from the MRC Language and Speech Group subject pool. Eleven subjects were run on each version.

Results and Discussion

One subject from Version 1 and 2 subjects from Version 2 were dropped from the analyses because of long and variable RTs. Two items were also dropped because of high error rates (over 30%); both of these were from Condition 1. Extreme and missing values (0.3%) and errors (3.1%) were also omitted. Midmeans were then calculated for each subject and each item in each condition. Table 5 shows the mean RTs for each condition.

The set of derived–derived pairs included words that consisted of both free and bound morphemes. In a preanalysis, we evaluated whether this factor had any effect. We conducted two ANOVAs that included bound–free stem as a variable and found no main effect ($F'_{min} < 1$) of this nor any sign of interaction with any other factor. We therefore dropped the bound–free variable in subsequent analyses.

The error data were then entered into a two-way ANOVA, on the arc-sine transformed item means, with the factors Condition (1–6) and Prime Type (test or control). There was a significant main effect of Condition, $F_2(5, 111) = 2.33$, $p = .046$, but no effect of Prime Type nor any interaction. The effect for Condition reflects the higher overall error rate (at 5.6%) for Condition 6 [−Sem, −Morph, +Phon] than for any of the other conditions (averaging 2.5%).

We then carried out separate two-way ANOVAs, on subjects and on items, with Condition (1–6) and Prime Type (test or control) as the factors. There was a significant effect of Prime Type,

[17] Twenty-four out of the 26 items in the final set were not given as associates by any of the subjects.

[18] The mean frequencies of primes, controls, and targets, respectively, were as follows: Condition 1—44, 23, and 45; Condition 2—22, 14, and 27; Condition 3—41, 38, and 33; Condition 4—26, 24, and 26; Condition 5—52, 34, and 23; and Condition 6—13, 10, and 31.

Table 4
Properties of Stimulus Sets in Experiment 2 (Suffixes)

Condition	Morphological type	*N*	Mean relatedness[a]
1: [−Sem, +Morph]	derived–stem	16	2.6
2: [+Sem, +Morph]	derived–stem	18	7.9
3: [−Sem, +Morph]	derived–derived	16	2.0
4: [+Sem, +Morph]	derived–derived	16	7.6
5: [+Sem, −Morph, −Phon]	NA	26	8.5
6: [−Sem, −Morph, +Phon]	NA	28	1.3

Note. Sem = semantic; Morph = morphological; Phon = phonological; NA = not applicable.
[a] 1 = *very unrelated;* 9 = *very related.*

with RTs to target words being faster when they followed primes rather than control words, $F'_{min}(1, 37) = 3.59$, $p < .01$. There was also a significant effect of Condition, $F'_{min}(5, 185) = 3.8$, $p < .01$, but no overall interaction between Prime Type and Condition ($F'_{min} < 1$). Before moving on to a separate analysis of Conditions 1–4, we carried out post hoc tests on the semantic and phonological control conditions (Conditions 5 and 6).

For the synonyms in Condition 5 [+Sem, −Morph, −Phon], the test–control difference of 27 ms is significant, $t(25) = 2.453$, $p = .021$, indicating that semantic links alone can produce priming in the cross-modal task. This does not mean that the effects we obtain in [+Sem, +Morph] conditions are therefore not morphological in nature, but it certainly permits the development of a semantic account of our results so far. This result can also be interpreted as more evidence that the cross-modal task taps into the lexical entry because it is presumably only at this level that semantic information is represented in the lexicon and can therefore form the basis for a priming effect.

In the other control condition [−Sem, −Morph, +Phon], we looked at the effects of purely phonological overlap between primes and targets, with the amount of overlap now closely matched to the [+Morph] conditions. Despite this, there was still no priming effect, with a 2-ms difference between test and control. The response to BULLET is the same whether it is preceded by *bulletin* or by an unrelated control. Whatever the source of priming in the other conditions, it is undoubtedly not due to surface phonetic similarities between primes and targets.

The results of Conditions 1–4, which form a factorial subpart of the design, were entered into separate three-way ANOVAs, with the factors Morphological Type (derived–derived or derived–stem), Prime Type (test or control), and Semantic Transparency ([±Sem]). There were significant main effects of all three factors, with overall RTs being slower for derived–derived than for derived–stem targets, $F'_{min}(1, 75) = 4.35$, $p < .05$, for opaque than transparent targets, $F'_{min}(1, 75) = 7.72$, $p < .01$, and for test than control stimuli, $F'_{min}(1, 94) = 4.37$, $p < .05$. Although the interaction between Semantic Transparency and Prime Type was not significant ($F'_{min} < 1$), there was an unexpected Morphological Type × Prime Type interaction, $F_1(1, 37) = 7.109$, $p < .01$; $F_2(1, 60) = 5.046$, $p < .05$; but $F'_{min}(1, 97) = 2.95$, $p > .10$.

As Figure 4 makes clear, there is no priming in either of the derived–derived conditions. Even in the [+Sem, +Morph] condition, where prime and target have a mean relatedness of 7.6, there is only a 2-ms difference between test and control. Hearing *excitable* does not facilitate responses to EXCITEMENT. This is an important result because it suggests that semantic relatedness is not the only factor controlling responses in this task. The derived–derived [+Sem] pairs are just as strongly semantically related as the derived–stem [+Sem] pairs, which show a healthy priming effect of 35 ms, $t(17) = 3.563$, $p = .002$, but they do not prime each other.

The other feature of Figure 4 is the weak and nonsignificant effect for the derived–stem [−Sem] pairs (Condition 1). The size of the effect, at 15 ms, is not only much smaller than the 35-ms effect for the [+Sem] set but also more variable across items.

Table 5
Mean Lexical Decision Times and Error Rates in Experiment 2 (Suffixes)

		Test		Control		
Condition	Morphological type	*M*	Error rate	*M*	Error rate	Difference
1: [−Sem, +Morph]	derived–stem	544	1.6	559	4.0	15
2: [+Sem, +Morph]	derived–stem	504	1.8	539	2.5	35*
3: [−Sem, +Morph]	derived–derived	578	4.6	582	1.8	4
4: [+Sem, +Morph]	derived–derived	540	2.5	542	0.5	2
5: [+Sem, −Morph, −Phon]	NA	558	0.8	585	4.0	27*
6: [−Sem, −Morph, +Phon]	NA	593	5.0	595	6.0	2

Note. Sem = semantic; Morph = morphological; Phon = phonological; NA = not applicable.
* $p < .05$.

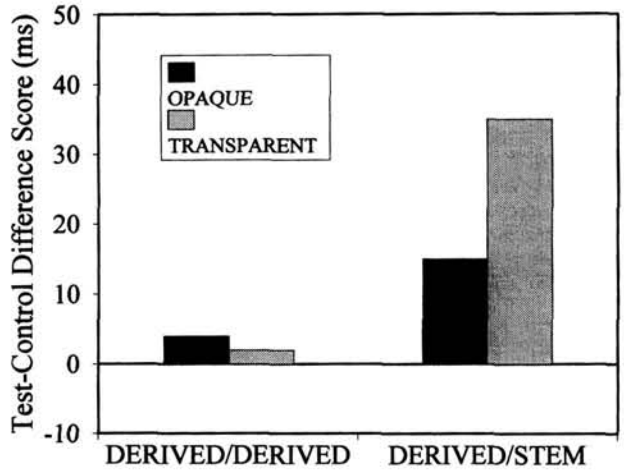

Figure 4. Priming effects for Experiment 2, showing the test–control difference scores for suffixed semantically opaque and transparent prime–target pairs in the derived–derived and derived–stem conditions.

Only 8 out of 14 items show priming in Condition 1, as opposed to 16 out of 18 for the derived–stem [+Sem] pairs. This is also a potentially important result because it suggests that morphologically related words will only be linked in the mental lexicon if there is a synchronically transparent semantic relationship between a derived form and its free stem.

Before proceeding further with the interpretation of Experiment 2, we decided that it was necessary to replicate two of the main results: the failure of derived–derived pairs to prime and the weakness of the priming effects for semantically opaque derived–stem pairs. We were concerned, first, with the heterogeneous nature of the derived–derived pairs, split into two small groups of bound and free stems. We also felt that questions could be raised about the applicability of the transparent–opaque distinction to bound roots like {dent-} (in *dentist/dental*) or {mort-} (in *mortal/mortify*). The fact that *dental* is rated as being highly related to *dentist* will only have consequences for morphological relatedness if bound roots function as structural elements in the mental lexicon in the same way as free stems. Finally, the effects for the derived–stem opaque pairs were not clear-cut: They showed some signs of priming, the number of items was small (the two items dropped because of high error rates both came from this group), and the effects were variable across items.

Experiment 3

The purpose of Experiment 3 was to put the investigation of the effects of morphological type and semantic transparency on a firmer empirical basis. To do this we planned to increase the number of items in each condition, to use only derived–derived forms based on free stems, and to reduce between-item variability by using a stronger within-word design, allowing the same derived form to be used as a prime in both derived–stem and derived–derived conditions. A word like *attraction*, for example, could be used as a prime both for its stem *attract* and for the related derived form *attractive*.

In addition to these methodological changes, we also introduced a new type of prime–target combination. This was intended as a further test of the model in Figure 3. We had predicted from this that derived forms sharing the same stem should prime each other. The results of Experiment 2 suggest that this prediction fails. Another, closely related, prediction of the model is that a stem should prime a derived form. If the access of *government* activates the morpheme {govern}, and this is why we get derived–stem priming, then the converse should also hold. Hearing *govern* should activate the corresponding morpheme, and this should facilitate responses to the probe GOVERNMENT. If this prediction fails as well, this will throw into doubt the shared morpheme account of the results so far.

Method

Materials

The stimuli for Experiment 3 fall into five categories; four of these are the same as Conditions 1–4 in Experiment 2: namely, the factorial combination of Semantic Transparency ([±Sem]) with Morphological Type (derived–derived or derived–stem). As the starting point for the new set of materials, we took the already pretested stimuli from Experiment 2, leaving out any bound-morph pairs and any pairs with high error rates. We then undertook an extensive search for additional materials, especially in the derived–stem opaque conditions and in the two derived–derived conditions, that met the criteria for morphological relatedness applied in Experiments 1 and 2. The results of this search were then entered into a semantic relatedness pretest, following the same procedures as for Experiment 2.

The relatedness pretest contained 93 potential [+Sem, +Morph] test pairs, all with free stems. We added to these, as controls and fillers, 20 each of the synonym pairs (*agile/nimble*), the unrelated pairs (*kennel/solution*), and the [−Morph, +Phon] pairs (*arsenal/arsenic*) from the previous pretest to provide the same anchor points as before for the 9-point rating scale. These materials were tested on 28 subjects, selected from the MRC Speech and Language Group subject pool. We then combined the successful pairs from this test with the surviving materials from Experiment 2 to construct the new stimulus sets.

The first priority was to reduce sources of variation in the design by finding sets of morphologically related words that could be paired across conditions. This only proved to be practicable within [±Sem] conditions, spanning Morphological Type. Thus, we could find triplets like *observation/observant/observe*, where *observation/observant* and *observation/observe* were separately judged to be highly related (mean of 8.0 and 7.9, respectively) and where *observation/observant* would form a prime–target pair in the derived–derived [+Sem, +Morph] condition and *observation/observe* would form a test pair in the derived–stem [+Sem, + Morph] condition. Conversely, triplets with low ratings of relatedness, such as *organize/organic/organ*, could form the basis for matched prime–target pairs in the derived–derived and derived–stem [−Sem, +Morph] conditions (i.e., *organize/organic* and *organize/organ*). This means that, across Morphological Type, we are measuring the effects of the same primes on different targets.

Not surprisingly, these triplets were hard to find. We managed to construct 24 such sets, equally divided between [+Sem] and [−Sem]. This meant that there were 12 prime–target pairs in each condition that shared a prime with a test pair in the neighboring Morphological Type condition. We then added to these as many other stimulus pairs as met the criteria to bring up the numbers in each condition. The four stimulus sets were matched, as far as possible, for amount of prime–target

Table 6
Properties of Stimulus Sets in Experiment 3 (Suffixes)

Condition	Morphological type	Example	N	Mean relatedness[a]
1: [−Sem, +Morph]	derived–stem	*casualty/casual*	20	2.6
2: [+Sem, +Morph]	derived–stem	*punishment/punish*	28	7.8
3: [−Sem, +Morph]	derived–derived	*successful/successor*	20	2.0
4: [+Sem, +Morph]	derived–derived	*confession/confessor*	20	7.3
5: [+Sem, +Morph]	stem–derived	*friend/friendly*	28	7.6

Note. Sem = semantic; Morph = morphological.
[a] 1 = *very unrelated*; 9 = *very related*.

phonological overlap, word frequency, and type of suffix.[19] No [+Sem] pair had a relatedness rating of less than 6.2, and no [−Sem] pair had a rating higher than 4.5. An overview of the materials is given in Table 6.

This table also contains the fifth stimulus category. This is the [+Sem, +Morph] condition with the stem–derived, prime–target order, as in *harm/harmless* or *predict/predictable*. Ideally, this should have been accompanied by a [−Sem, +Morph] stem–derived condition (as in *depart/department*). This was not possible because most of the pretested [−Sem] pairs we had found were already being used in the rest of the experiment. We therefore had to postpone running this condition (see Experiment 6).

Each of the 116 test words was paired with a control word, which was matched to the prime word in frequency, number of syllables, and form class. None of the control words was morphologically, semantically, or phonologically related to either the prime or the probe.

Fillers. We included a variety of filler items. First, to maintain a similar testing environment to Experiment 2, we added two sets of real-word/real-word fillers. These were 20 [−Morph, +Phon] pairs, such as *admiral/admiralty*, and 20 synonym pairs, such as *agile/nimble*. In addition, we included three types of fillers involving nonwords: 30 of them were of the type *donkey/donk*, where a morphologically simple real word was paired with a nonword that was fully contained within the real word. Another 36 fillers were of the type *consumption/constern*, where the prime word was a complex word and was paired with a nonword that shared some initial phonemes. The third type of filler consisted of 90 pairs such as *selection/nad*, where there was no phonological similarity between the real-word prime and the nonword target. This gave a total of 156 real-word/real-word pairs and 156 real-word/nonword pairs. We also constructed 50 practice items and 20 warm-up pairs, which preceded the test list.

Design and Procedure

The use of the stimulus triplets required a four-version design so that each target from a triplet (e.g., *observant* and *observe*) could be presented to different subjects in both test and control conditions (i.e., either preceded by *observation* or by an unrelated control word). The single pairs of triplets in each condition, which only require a two version design, then had to be superimposed on this. We did this by splitting the single pairs so that half of them appeared in Versions 1 and 2 and the other half in Versions 3 and 4. This increased the between-subject variance for this part of the design but meant that each stimulus pair had equal exposure across conditions.

The materials were recorded, digitized, and presented to the subjects following the same procedures as in Experiments 1 and 2.

Subjects

To further increase the power of the design, the number of subjects per version was increased. Fifteen subjects were tested on Versions 1 and 2, 16 on Version 3, and 17 on Version 4, giving a total of 63 subjects. As before, all subjects were recruited from the MRC Language and Speech Group subject pool.

Results and Discussion

Five subjects were dropped from the analyses because of slow and variable responses, leaving 13 subjects in Version 1, 14 in Version 2, 16 in Version 3, and 15 in Version 4. Three items were also dropped for similar reasons. Extreme and missing values (0.2%) and errors (3.3%) were also omitted. Midmeans were then calculated by subject and by item within conditions. Table 7 shows the mean RTs for each condition.

The error data, after arc-sine transformation, were entered into a two-way ANOVA, run on the item means, with the factors of Condition (1–5) and Prime Type (test or control). The only significant effect was of Prime Type, $F_2(1, 111) = 5.01, p = .027$, with an average of 2.6% errors following test words as opposed to 4.2% following control words. There was no main effect of Condition ($F_2 < 1$) nor any interaction with Prime Type.

Turning to the RT data, we carried out two preliminary analyses. The first of these was a pair of two-way ANOVAs with the factors Prime Type (test or control) and Condition (1–5). There was a main effect of Prime Type, $F'_{min}(1, 165) = 9.08, p < .05$, with faster overall responses following test primes than control primes. There was a weaker effect of Condition, $F_1(4, 228) = 13.469, p < .001$; $F_2(4, 115) = 2.455, p < .05$; but $F'_{min}(4, 153) = 2.08, p > .05$, and a Condition × Prime Type interaction, $F_1(4, 57) = 5.87, p < .001$; $F_2(4, 116) = 2.773, p < .05$; but $F'_{min}(4, 217) = 1.88, p > .05$. This indicates that test–control differences vary across conditions. The largest effect was for the stem–derived stimuli (Condition 5), which show a strong priming effect of 52 ms, $t(27) = 3.64, p < .001$.

In a second, preliminary analysis, we ran item and subject ANOVAs on Conditions 1–4 with Stimulus Type (triplet or nontriplet) as an added variable. This was to determine whether the triplet stimuli (matched across Morphological Types) behaved differently from the single pairs. There was no trace of an effect anywhere in the analyses, indicating that the two sets of data could be grouped together.

[19] The mean frequencies of the primes, controls, and targets, respectively, were as follows: Condition 1—18, 28, and 56; Condition 2—41, 28, and 30; Condition 3—21, 18, and 24; Condition 4—25, 18, and 22; and Condition 5—54, 46, and 26.

Table 7
Mean Lexical Decision Times and Error Rates in Experiment 3 (Suffixes)

		Test		Control		
Condition	Morphological type	*M*	Error rate	*M*	Error rate	Difference
1: [−Sem, +Morph]	derived–stem	575	1.7	574	3.0	−1
2: [+Sem, +Morph]	derived–stem	554	2.0	595	4.8	41*
3: [−Sem, +Morph]	derived–derived	611	5.0	614	3.9	4
4: [+Sem, +Morph]	derived–derived	580	2.7	591	4.8	11
5: [+Sem, +Morph]	stem–derived	578	1.8	630	5.0	52*

Note. Sem = semantic; Morph = morphological.
* $p < .05$.

We then conducted three-way item and subject ANOVAs on the complete data set for Conditions 1–4, with the factors of Prime Type (test or control), Morphological Type (derived–derived or derived–stem), and Semantic Transparency ([±Sem]). There were significant main effects of Morphological Type, $F'_{min}(1, 106) = 5.02$, $p < .05$, and of Prime Type, $F'_{min}(1, 134) = 2.76$, $p = .07$, with RTs being slower to targets following control primes and slower overall in the derived–derived conditions. There was no Morphological Type × Prime Type interaction, $F_{min}(1, 101) = 1.24$, $p > .10$, but a marginal Semantic Transparency × Prime Type interaction, $F_1(1, 57) = 3.71$, $p = .06$; $F_2(1, 85) = 3.64$, $p = .06$; $F'_{min}(1, 134) = 1.84$, $p > .10$.

The pattern of effects, as laid out in Figure 5, is very similar to what we found in Experiment 2 (see Figure 4). There are no priming effects in either of the derived–derived conditions and a clear difference between the two derived–stem conditions. Priming is now unambiguously absent in the [−Sem] derived–stem conditions, with a test–control difference of 1 ms, but clearly present in the [+Sem] condition, with a strong 41-ms effect, $t(27) = 3.51$, $p = .002$.[20] This pattern is also reflected in the effects for individual items. Priming is not a stable phenomenon for the derived–derived or the [−Sem] derived–stem sets, with 10 items showing priming and 9 not, compared with the robust 19/9 split for the [+Sem] derived–stem set.

The results of Experiment 3, therefore, confirm the effects in Experiment 2. Suffixed derived–derived pairs do not prime each other, even when they share free stems rather than bound stems and even when they are strongly semantically related. Suffixed derived–stem pairs prime strongly when they are semantically related but not when the semantic relationship between them is synchronically opaque. This pattern holds for the triplets, where the same prime is used across conditions, as well as for the complete data set.

Finally, in the new condition added here, semantically related stem–derived pairs show robust priming effects. This not only fits in with the predictions of the shared-morpheme account of [+Sem, +Morph] priming but also rules out the possibility that derived–derived pairs fail to prime because derived forms are in some way unsuitable as probes. If anything, the priming effects are stronger and more consistent for the stem–derived pairs than for the derived–stem pairs.

The similarity in priming effects between [+Sem] derived–stem and stem–derived pairs also allows us to address the possible role of strategic factors in the immediate repetition task. As we noted earlier, subjects might develop expectancies based on the properties of the prime. As previous research in the visual domain has shown (Neely, 1991), these strategies are time dependent and emerge only at longer SOAs. Although the target here is presented at prime offset, it could be argued that the effective SOA may be quite long because the listener will often be able to identify the prime word before all of it has been heard, therefore allowing time for strategic effects to appear. However, if this is so, then priming should be reduced in the stem–derived case, relative to the derived–stem case, because not only will stem primes always be shorter than their associated derived forms but also, because many of the stems are monosyllables, they are unlikely to be identifiable until all of the word has been heard (e.g., *train, ripe, calm*, and so on). For these stimuli, with effectively zero SOA, there would be no time for conventional strategies to be applied. The finding that the priming effects are just as strong, if not stronger, for the stem–derived pairs, suggests that we can reject a strategy-based account of our results and interpret them instead as reflecting the automatic effects of underlying activation processes.

Theoretical Implications

Experiment 3 completes our preliminary investigation of derived suffixed words in English. It is therefore appropriate to take theoretical stock at this point. The results of this first series of experiments allow us to draw three main conclusions:

1. The level of representation tapped into by the task is abstract in nature. Phonetic overlap between primes and targets does not by itself produce priming, and the amount of priming is not affected, for morphologically related forms, by variations in the phonological transparency of the relation between prime and target.

2. Semantic relatedness between a prime and a target is a necessary but not sufficient condition for priming to occur. Semantically unrelated pairs, whether morphologically related or not, do not prime reliably.

[20] The results for the triplet stimuli on their own are very similar, with a significant 42-ms effect in the derived–stem [+Sem] condition and no significant effects elsewhere.

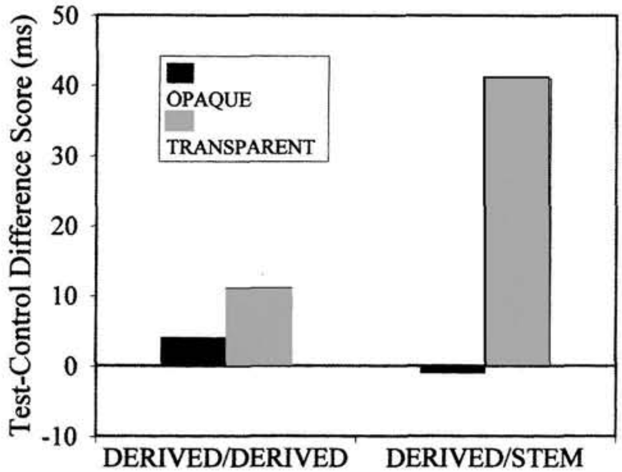

Figure 5. Priming effects for Experiment 3, showing the test–control difference scores for suffixed semantically opaque and transparent prime–target pairs in the derived–derived and derived–stem conditions.

3. The type of morphological relation between a prime and a target affects whether or not priming is obtained. Derived forms prime their free stems, and free stems prime related derived forms. Derived forms, however, do not prime each other, even if they are semantically related and share the same stem.

To accommodate these results we need to expand the model sketched in Figure 3, where the evidence for abstractness confirms that we are dealing with abstract stems at the level of the lexical entry. First, we need separate models for [−Sem, +Morph] words and for [+Sem, +Morph] words. A word like *department* will be represented at the level of the lexical entry as if it was a morphologically simple stem: It can enter into combination with other morphemes (as in *departmental* or *interdepartmental*), but by itself it has no internal structure. In particular, it does not share the stem {depart} with words like *departure.* This has a separate representation, consisting of the free stem {depart}, linked to the affix {-ure}. These arrangements are illustrated in Figure 6.

This proposal reinterprets semantic relatedness in terms of its consequences for morphological structure in the mental lexicon. The reason that [+Sem, +Morph] pairs show priming, and [−Sem, +Morph] pairs do not, is because the listener does not mentally represent words as sharing the same stem, and therefore as morphologically related, unless there are semantic grounds to do so. This, in turn, is a developmental claim. The structure of the adult lexicon reflects individuals' experience with the language as they learn it. An item like *department,* although it has a phonetically transparent morphological structure on the surface, will not be analyzed during language acquisition into {depart} + {ment} at the level of the lexical entry because the semantic criteria for such an analysis have not been met.

One consequence of this view is that [+Sem, −Morph] pairs like *agile/nimble* show priming for quite different reasons from [+Sem, +Morph] pairs. Synonym pairs, like other semantically but not associatively related words, have separate lexical entries that are linked in some way in the lexicon. These links form the basis for semantic priming effects. Morphologically related pairs, in contrast, prime because they share the same morpheme and, in that sense, the same lexical entry. There is evidence in the literature to support this distinction because semantically and morphologically based priming seem to have a different time-course, with semantic priming dissipating much more rapidly (e.g., Henderson et al., 1984; Napps 1985, 1989).

The second challenge to the model is the absence of priming between [+Sem] suffixed pairs. This is evidence against a purely semantic account of the results so far. However, it also presents difficulties for the shared morpheme account of priming in the [+Morph] cases. If hearing the derived form *government* activates {govern}, and it is this residual activation that facilitates responses to the probe GOVERN, then why does *government* not facilitate responses to GOVERNOR, with which it shares the same stem? What makes this seem especially puzzling is that *govern,* as a prime itself, should facilitate responses to both GOVERNOR and GOVERNMENT (given the stem–derived results in Experiment 3). Why should the residual activation of {govern} in the one case facilitate responses to a suffixed probe and in the other case not? Our answer is sketched out in Figure 7.

We propose that hearing a semantically transparent suffixed form like *government* has two immediate processing consequences. It activates the stem morpheme {govern}, but at the same time it inhibits other suffixed forms sharing the same stem. This is because forms like *government* and *governor* are mutually exclusive competitors for the same lexical region: the shared stem. The combination of the morpheme {govern} with the affix {-ment} defines a lexical item with a distinct meaning and identity in the language, and this is incompatible with the simultaneous combination of {govern} with a different affix to give a different lexical item. Figure 7 reflects this by proposing an inhibitory link between the two suffixes {-ment} and {-or}, rather than between the two lexical items *government* and *gov-*

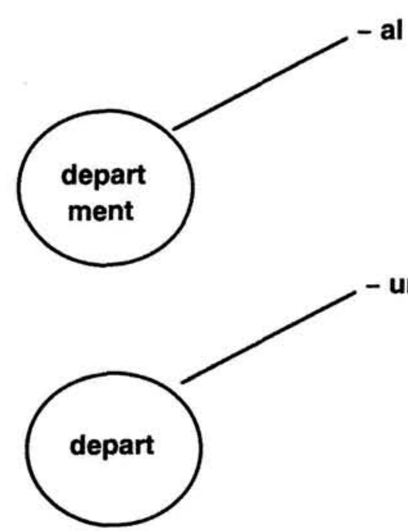

Figure 6. Lexical entries for a cognitively monomorphemic word (*department*), shown here in combination with the affix *-al,* and for a morphologically complex form (*departure*).

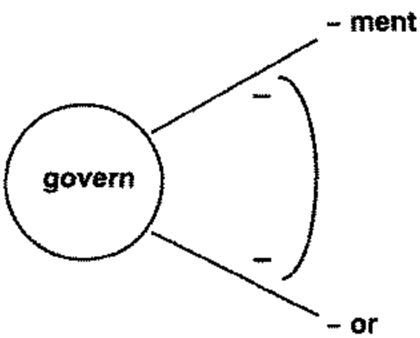

Figure 7. The stem–affix model for semantically transparent suffixed forms, expanded to show inhibitory links between suffixes attaching to the same stem.

ernor. This is to avoid the problem of having the stem morpheme being simultaneously activated (as part of *government*) and inhibited (as part of *governor*).

The consequence of this inhibitory relationship between affixes[21] is that when a suffixed form is heard, it will temporarily inhibit the combination of the stem with all other suffixes. Thus, when a related suffixed form immediately follows, recognition will be slowed, even though the stem morpheme is in an activated state. In contrast, when the stem itself follows as a target, there is no inhibitory effect to counter the facilitatory effects of the activated state of the morpheme in question because recognition of the stem does not involve any of its connections to suffixes. Similarly, when the stem functions as the prime, this will change the state of the shared-stem morpheme, but it will not affect the state of any of its links to suffixes. Thus, when a suffixed form follows as target, the effects of stem activation will facilitate recognition without any counterbalancing inhibitory effects.

This modified model, with inhibitory links between suffixes, can accommodate all the results so far. It explains why semantically transparent suffixed forms prime their free stems and why derived forms, in turn, can be primed by their stems but not by other related suffixed derived forms. What it immediately raises, however, is the question of how the representation and access of prefixed forms fits into this framework. Will there be the same distinction between derived–stem and derived–derived pairs? Will there be priming at all, given that items are now heard in affix–stem order rather than stem–affix order? Will semantic transparency play such a central role in determining whether a pair shows priming or not? These and other questions were the subject of the next two experiments.

Experiment 4

Much of the experimental work on English derivational morphology has focused on prefixed forms, responding in one way or another to Taft and Forster's (1975) affix-stripping hypotheses about the access and representation of morphologically complex words. The problem for us about this work is, first, that almost all of it is in the visual domain and, second, that none of it has systematically distinguished between semantically transparent and opaque derived forms (the issue of phonological transparency does not arise here because derivational prefixes in English do not normally change the phonological form of the stems with which they combine).

The difficulty with visual presentation is that it does not impose the same temporal ordering on the perceiver's acquisition of information about the word as does the auditory modality. A prefixed word in the visual domain provides the reader with simultaneous information about both the stem and the affix so that a stem-based access strategy, of the type proposed by Taft and Forster (1975), is in principle just as plausible as an access strategy that starts with the prefix and works from left to right across the word. A spoken prefixed word, in contrast, presents the prefix first, with the onset of the stem following at a delay of 2–300 ms or more. Here a stem-based access strategy has obvious temporal costs associated with it, and, indeed, in some earlier work using spoken words (Tyler et al., 1988), we found evidence that access was initiated from word onset.

A potentially more serious problem is the failure to distinguish systematically among prefixed words according to the semantic transparency of the relationship between the derived form and its constituent morphemes. The reason this is a serious problem is that if our arguments in the first half of this article are correct, then only derived words whose morphemic composition is semantically transparent will be represented in the mental lexicon as morphologically complex, that is, as an abstract stem with associated affixes. This means that any research on derivational morphology that used semantically opaque prefixed forms may not, in fact, have been studying words that are morphologically complex at the level of the lexical entry.

The issue here is not that prior researchers have never distinguished between synchronically prefixed and nonprefixed forms but that attempts to do so have been based on inappropriate criteria (Smith, 1988). Taft and Forster (1975), for example, classified certain historically prefixed forms as synchronically unprefixed on the basis that the prefix had become semantically opaque. The *re-* in *rebel*, for example, no longer has any implications of "again," so that *rebel* is classified as pseudoprefixed. This prefix-based criterion leads to forms such as *replenish* and *repugnant* being classified as synchronically prefixed. Our view is that the semantics of the stem are equally, if not more, important so that *replenish* and *repugnant*, compared with transparent cases like *refill* or *remarry*, will not be represented in the mental lexicon in morphologically decomposed form because their "stems" (*-plenish or -pugnant*) have no synchronic semantic interpretation on the basis of which the meaning of the derived form could be computed.

The first priority here, therefore, is to repeat for the prefixing morphology the investigation of the effects of semantic transparency that we carried out in Experiments 2 and 3, using free stems and the same type of relatedness pretest. Our prediction is that only [+Sem] pairs will show priming, given the results for the suffixing morphology and our interpretation of them. If

[21] The theoretical options for representing the mutually exclusive relationship between two related suffixed forms are still very open. The inhibitory effect might not, for example, be located in the suffixes themselves but rather in the connections between the stem and its various suffixes.

morphological structure in the mental lexicon reflects the synchronic recoverability, during acquisition, of the meaning of derived forms from the meaning of their component morphemes, then this should apply just as much to prefixed forms as to suffixed forms. Transparent [+Morph] pairs like *disobey/obey* should prime, but opaque [+Morph] pairs like *release/lease* should not.

We combine this, as before, with the variable of morphological type, asking whether derived–derived and derived–stem prefixed pairs show the same effects as suffixed words. The issue here, especially for the derived–derived [+Sem] pairs, such as *reappear/disappear*, is whether these will prime or not. One possibility is that prefixes are mutually inhibitory, just like suffixes, so that there will be no priming between prefixed pairs. The other possibility is that because prefixed pairs sharing the same stem are not cohort competitors (Marslen-Wilson, 1987) in the same way as comparable suffixed pairs, they will not need to inhibit each other, and therefore priming will be permitted. The form *misjudge*, for example, will access the stem {judge} through the linked affix {mis-}. Because the initial syllable [mis-] is used to enter the lexicon, the route to {judge} through {pre-} will not be activated and therefore will not need to be suppressed.

Method

Materials

The design of the experiment required four sets of prime–target pairs, organized along the factorial dimensions of Semantic Transparency ([±Sem]) and Morphological Type (derived–stem vs. derived–derived). As in Experiments 2 and 3, we proceeded by constructing the largest sets we could find that met the criteria for morphological relatedness. These were analogous to those for Experiments 1–3, requiring that prefixed forms should have identifiable separable prefixes and that the stem of the derived form should historically be identical to the free stem (or to the stem of another derived prefixed form). The four sets of candidate pairs were then entered into a semantic relatedness pretest, following the same procedures as for Experiments 2 and 3. The test booklet also included candidate pairs for use in Experiment 5; these are described later. This gave a total of 220 pairs.

The first relatedness pretest was run on 15 subjects. When this did not produce enough stimuli in some of the test categories, a further pretest, with 60 new pairs, was run on 12 subjects. Combining the results of the two tests, we were able to construct a stimulus set consisting of 18 pairs in each category. No [+Sem] pair had a mean rating less than 6.5 and no [−Sem] pair had a rating higher than 3.9. In choosing the [+Sem] derived–derived pairs, we excluded pairs like *proclaim/exclaim*, in which the meanings of the whole forms were synonymous or close to synonymous. This was to reduce the possibility that any priming could be attributable to semantic links between the members of the pair. Thus, from the set of derived–derived pairs that satisfied our rating criteria on the pretest, we chose only those pairs whose members had decompositional meanings and that were semantically related by virtue of sharing a common stem.

The four stimulus sets were matched, as well as possible, for frequency and for type of prefix. Acceptable [+Sem] derived–derived forms were hardest to find, and the mean frequencies, especially of the target word, were lower than in the other conditions.[22] For each of the 72 test pairs we selected a control word, which was matched to the prime word in frequency, number of syllables, and form class. A sample set of stimuli is listed in Table 8.

Fillers. We constructed 144 pairs of filler items, which were designed to obscure the regularities of the test pairs. These fell into three main categories:

1. Thirty-six fillers were real-word/real-word pairs, where the two words were unrelated and where either the prime, both the prime and the target, or neither were prefixed. This was to reduce the proportion of potentially related prime–target pairs in the experiment.
2. Sixty real-word/nonword fillers had prefixed real-word primes followed either by nonword pseudostems, as in *recruit/cruit*, or by prefixed or unprefixed nonwords, as in *unusual/mismune*. This was to ensure that not all prime–target pairs with phonological overlap, or where the prime and target both started with a prefix, had real-word targets.
3. Forty-eight additional fillers consisted of unprefixed real words followed by unprefixed nonword targets.

Taken together with the 72 test items, this yielded a total of 108 real-word/real-word pairs and the same number of real-word/nonword pairs. Each test version consisted of these 216 test and filler pairs, preceded by 50 practice items and 20 warm-up items.

Design and Procedure

Two versions of the materials were made in which each version contained half of the real-word pairs. Items were balanced across versions so that each target appeared only once in each version. In one version, it appeared with its prime and in the other version with its control word. The real-word pairs were pseudorandomly interspersed with the real-word/nonword pairs.

The materials were recorded, digitized, and presented to the subjects following the same procedures as in Experiment 1–3.

Subjects

We tested 26 subjects, 13 subjects for each version, and all subjects were recruited from the MRC Language and Speech Group subject pool.

Results and Discussion

Five subjects were dropped because of slow and erratic performance. This left 10 subjects for Version 1 and 11 subjects for Version 2. One item had to be dropped because of experimenter error, and three more items were dropped because of high error rates (more than 35%).[23] For the remaining data, the percentage of errors was 2.8%. These were removed from the data set together with extreme outliers (0.2%). The error data were then entered, after arc-sine transformation, into a two-way ANOVA on item means, with the factors of Condition (1–4) and Prime Type (test or control). The only significant effect was for Condition, $F_2(3, 64) = 3.25$, $p = .027$. Errors were more frequent (at 5.5%) in the derived–derived [+Sem] condition, possibly because the targets here were relatively low in frequency. There was no main effect of Prime Type, $F_2(1, 64) = 2.08$, $p < .10$, nor any interaction.

[22] The mean frequencies of the primes, controls, and targets, respectively, were as follows: Condition 1—51, 37, and 100; Condition 2—9, 13, and 109; Condition 3—20, 16, and 59; and Condition 4—13, 9, and 8.

[23] Unfortunately, all the missing items came from the derived–derived [+Sem] category, leaving only 14 pairs for the analysis. Target words in this category were relatively lower in frequency than in the other sets, and this may have led to higher error rates.

Table 8
Stimulus Properties in Experiment 4 (Prefixes)

Condition	Morphological type	Example	N	Mean relatedness[a]
1: [−Sem, +Morph]	derived–stem	*restrain/strain*	18	2.8
2: [+Sem, +Morph]	derived–stem	*insincere/sincere*	18	8.6
3: [−Sem, +Morph]	derived–derived	*depress/express*	18	2.5
4: [+Sem, +Morph]	derived–derived	*unfasten/refasten*	18	7.4

Note. Sem = semantic; Morph = morphological.
[a] 1 = *very unrelated*; 9 = *very related*.

Turning to the RT data, midmeans were then calculated over items and subjects and entered into two three-way ANOVAs, with the variables of Morphological Type (derived–derived or derived–stem), Semantic Transparency ([±Sem]), and Prime Type (test or control). Table 9 gives the overall means for each condition.

There was a significant main effect of Morphological Type, with derived targets being responded to more slowly than stem targets, $F'_{min}(1, 83) = 11.27$, $p < .01$. This presumably reflects the greater length of the derived targets because of the presence of a prefix. There was no main effect of Transparency ($F'_{min} > 1$) nor of Prime Type, $F'_{min}(1, 82) = 2.45$, $p > .10$, but there were two significant two-way interactions. The first, between Morphological Type and Transparency, $F'_{min}(1, 77) = 4.78$, $p < .05$, primarily reflects item differences between conditions: Transparent targets are faster than opaque targets in the derived–stem condition, but opaque targets are faster in the derived–derived condition. The second interaction, between Transparency and Prime Type, $F'_{min}(1, 69) = 5.63$, $p < .05$, reflects the main finding here, that [+Sem] test items are faster than controls, whereas [−Sem] test items tend to be slower, irrespective of Morphological Type. This is brought out in Figure 8, which plots the test–control difference scores across conditions.

These results give a clear answer to the questions being asked in this experiment. First, there is a strong effect of Semantic Transparency, with only the [+Sem] prime–target pairs showing facilitation. As we predicted, [+Sem] pairs like *disobey/obey* prime, but [-Sem] pairs like *release/lease* do not. In this respect, the effects for the prefixes parallel those we found for suffixes. In another respect they are very different. The prefixed [+Sem] derived–derived targets are strongly facilitated, $t(13) = 3.27$, $p < .01$, with 12 out of 14 pairs showing the effect. If anything, the effect is stronger than for the [+Sem] derived–stem pairs, where the 31-ms difference is only marginally significant, $t(17) = 1.86$, $p = 0.08$. Thus, unlike the suffixed [+Sem] pairs, which showed no reliable priming, prefixed pairs like *unwind/rewind* do prime each other. This is consistent with the view that a prefixed form such as *rewind* is not activated as a possible competitor when a related prefixed form, such as *unwind*, is being heard and therefore is not inhibited or suppressed. Hearing *unwind* activates the stem {wind}, and this facilitates subsequent responses to *rewind*.

These priming effects between derived prefixed forms are a further argument against an interpretation of our results so far in terms of semantic priming between related whole-word forms. On this type of account, the absence of priming between derived–derived suffixed pairs (as opposed to stem–derived suffixed pairs) might be explained in terms of a failure of mediated associative priming, where *governor* can only prime *government* through the form *govern*. This would also predict a failure of priming for the derived–derived prefixed pairs, where a similar mediated relationship would hold between prime and target. The fact that we do find strong priming here, as opposed to the derived–derived suffixed pairs, seems to rule out a general account of these results solely in terms of semantic links between different lexical entries.

However, to accommodate these results, we need to expand the model in two ways. Prefixed [−Sem, +Morph] forms, such as *mistake* or *disclose*, are represented as monomorphemic items, just like [−Sem, +Morph] suffixed words, such as *sweater* or *emergency*. The [+Sem, +Morph] prefixed forms, such as *insane* or *refasten*, are represented in the same way as [+Sem, +Morph] suffixed forms, as abstract stems linked to prefixes. Where the same stem is shared by two or more prefixed forms, we assume that there are no inhibitory links between prefixes. This is the kind of arrangement illustrated in Figure 9.[24]

Despite certain graphic similarities, note that this model is quite different from the "satellite" model proposed by Lukatela and colleagues (e.g., Lukatela et al., 1980). The satellite model is only concerned with inflectional morphology, and it is a full-listing rather than a decompositional model. Complete representations of all the different inflected forms of a given noun (e.g., *dinare, dinaru, dinara, dinari*) are arranged around the nucleus of the nominative singular form (e.g., *dinar*). This is probably the antithesis of the type of model sketched in Figure 9. Furthermore, although we do not touch on inflectional morphology in the research reported here, work now in progress suggests that a decompositional account is also appropriate for English inflectional relations.

We now turn to Experiment 5, which continues our investigation of prefixed forms.

Experiment 5

The results of Experiment 4 lay the foundation for our treatment of English derivational prefixes. They leave unanswered,

[24] The suffixes indicated here are assumed to be suffixes that can immediately follow the stem (as opposed to suffixes that can only follow the stem when it has another suffix added, like the *-al* in *governmental*).

Table 9
Mean Lexical Decision Times and Error Rates in Experiment 4 (Prefixes)

		Test		Control		
Condition	Morphological type	*M*	Error rate	*M*	Error rate	Difference
1: [−Sem, +Morph]	derived–stem	542	3.1	543	2.0	1
2: [+Sem, +Morph]	derived–stem	503	1.7	534	2.0	31*
3: [−Sem, +Morph]	derived–derived	576	0.6	554	3.0	−22
4: [+Sem, +Morph]	derived–derived	576	3.4	635	7.0	60**

Note. Sem = semantic; Morph = morphological.
* $p < .10$. ** $p < .05$.

however, a range of questions about the access and representation of these forms.

Morphological Type

Having established that prefixed derived–derived pairs behave differently from their suffixed counterparts, it is important to add to this an investigation of the stem–derived order as well, for both semantically transparent and opaque cases. Given the model developed in Figure 9, we expect [+Sem, +Morph] pairs, such as *sincere/insincere*, to show priming, whereas [−Sem, −Morph] pairs like *lease/release* should not.

Bound Stems

Prefixed words with bound stems, such as *submit* or *include*, where the stems {-mit} and {-clude} cannot appear as independent words, have figured prominently in research into English morphology, and it is necessary to look at them here, using the cross-modal immediate repetition task. First, a central component of the original Taft and Forster (1975) hypothesis, and of its subsequent restatements (Taft, 1981, 1988), is the claim that

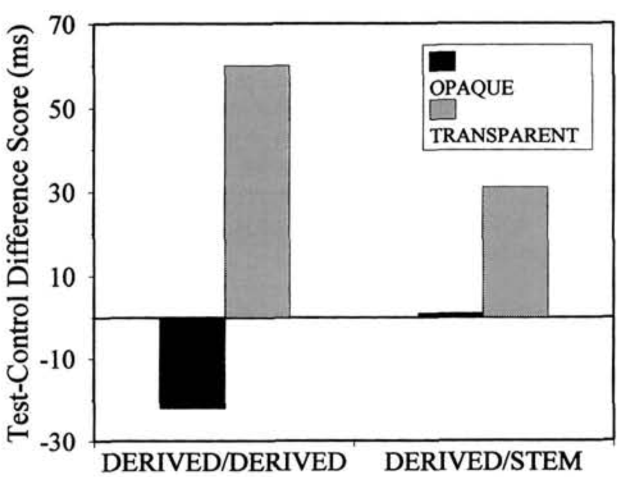

Figure 8. Priming effects for Experiment 4, showing the test–control difference scores for prefixed semantically opaque and transparent prime–target pairs in the derived–derived and derived–stem conditions.

words like *dialect, revive*, or *insult* are stored simply as nonword stems, such as {-lect}, {-vive}, or {-sult}, and that access to these requires stripping off their affixes. If this is correct, then prefixed items sharing the same bound stem, such as *include/conclude* or *submit/permit*, should prime each other in the immediate repetition priming task for exactly the same reason as the prefixed pairs sharing a free stem in Experiment 4. It is evident from the treatment of bound stems in the psycholinguistic literature that semantic transparency is not at issue, so the fact that pairs of this sort are semantically opaque should not affect priming. According to our model, however, [−Sem, +Morph] bound-stem pairs should not prime. As we noted earlier, our approach requires that both affix and stem be synchronically semantically interpretable for the listener to represent a potentially complex form as morphologically decomposed at the level of the lexical entry.

Because effects for prefixed bound stems are typically compared with pseudoaffixed words, such as *deliver* or *remember*, we also include these in the stimulus set. These can be defined as [−Morph, +Phon] pairs, where the prime appears to be made up of a free stem and a prefix but is in fact either unprefixed or not historically related to the target. Again, there is no reason for us to expect priming here.

The second reason for looking at bound stems is that there is previous research (Emmorey, 1989) using an intramodal immediate priming task, which does find facilitation for prefixed bound-stem pairs. Emmorey used auditory presentation of pairs of words like *succeed/proceed* or *conceive/deceive*, where words were defined as being morphologically related (Aronoff, 1976) if they both could undergo the same morphological rule: *conceive* and *deceive*, for example, become *conception* and *deception* with the addition of {-ion}. However, although Emmorey found large facilitatory effects, she also found priming effects in phonological control pairs like *shadow/widow*, which have no morphological relationship. It is necessary to look at similar stimuli in the cross-modal task because surface phonetic overlap seems to play a very small role here.

Phonological Controls

The final requirement for Experiment 5 is to make sure that we have appropriate controls for nonmorphological priming based on phonological overlap between prime and target. In Experiment 1, we had [−Morph, +Phon] pairs like *principle/*

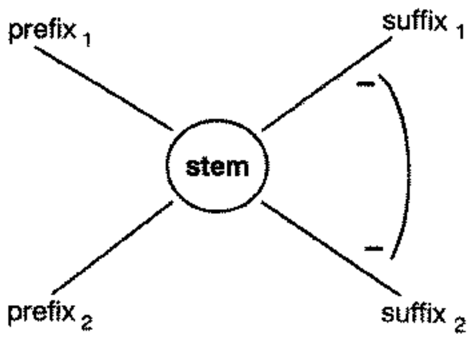

Figure 9. The expanded stem–affix model of the lexical entry for semantically transparent prefixed and suffixed forms sharing the same stem, with inhibitory links between suffixes but not between prefixes or between prefixes and suffixes.

prince, where the probe was entirely and transparently contained in the prime. These stimuli were comparable in overlap, from word onset, with the [+Morph, +Phon] suffixed pairs. To provide the appropriate comparison for the prefixed pairs, we need prime–target pairs where the initial syllable of the prime is not a prefix and where the final syllable is a real word: for example, *fertile/tile* or *trombone/bone*.

Apart from the need to control for phonological priming, there is research by Shillcock (1990), using a cross-modal associative priming task, that reports that a stimulus like *trombone* facilitates lexical-decision responses to RIB (an associate of *bone*). This effect was restricted to monomorphemic two-syllable words, where lexical stress fell on the second syllable. One interpretation of this result is that the lexical entry for *bone* is being activated by the final syllable of *trombone*.[25] If so, then we should also get priming in the immediate repetition task, where priming is based on repeated access of the same morphemes in the lexical entry. This possibility is not excluded by the model so far because it permits parallel access of different lexical entries by the same speech inputs. The evidence from the [−Sem] stimuli in Experiment 4, however, where sequences like *release/lease* do not prime, suggests that we should not find priming here either.

Method

Materials

There were six different stimulus sets constructed for Experiment 5. Two of these, the [+Sem] stem–derived pairs, were simply the corresponding derived–stem pairs from Conditions 1 and 2 in Experiment 4, presented to the subjects in reverse order. There was one other [+Morph] set, the prefixed bound-stem pairs. Twenty-four of these were pretested (as part of the pretest described in Experiment 4) and 18 were selected for testing. All items in this set had separable prefixes, bound stems (i.e., stems that cannot appear as isolated words), and both members of a pair shared the same phonological rule. The bound-stem pairs were all semantically opaque.

The other test stimuli were not morphologically related. The pseudoaffixed set consisted of pairs like *device/vice* or *dispatch/patch*. These are words that appear to have a separable common prefix followed by a free stem but where the prime is either historically unprefixed (*dispatch*, for example, came into the language in the 16th century from the Italian *dispacciare*) or where the stem is not historically related to the target. The 18 pseudoaffixed pairs were also included in the pretest for semantic relatedness and were all highly opaque.

The final set of phonological controls were (with two three-syllable exceptions) all two-syllable monomorphemic words, where the first syllable was not a possible prefix in the language and where the stem included in the prime was phonologically identical to the target. These were split into two groups: 14 pairs with weak–strong stress patterns (as in *ordeal/deal*) and 14 with strong–weak prosody (e.g., *mildew/dew*). This was to control for the possibility that a final syllable's prosodic status (strong or weak) determines its effectiveness in activating lexical representations (Shillcock, 1990). All pairs were pretested and found to be semantically opaque.

For each of the 100 test pairs, we selected a control word, which was matched to the prime word in frequency, number of syllables, and form class.[26] A sample set of stimuli is listed in Table 10.

Fillers. One hundred thirty-six fillers were constructed, falling into three main categories:

1. There were three sets of 12 real-word/real-word pairs, where prime and target were unrelated, consisting either of prefixed–unprefixed pairs, unprefixed–prefixed pairs, or unprefixed–unprefixed pairs.
2. There were 40 real-word/nonword pairs, where the prime was a prefixed real word, followed either by a nonword stem (as in *indulge/dulge*) or by prefixed or unprefixed unrelated nonwords.
3. There were 96 additional pairs, where an unprefixed real word was followed by either a related prefixed nonword (as in *grade/begrade*) or by an unrelated prefixed or unprefixed nonword.

This gave a total of 136 real-word/real-word pairs and 136 real-word/nonword pairs. We also constructed 50 practice pairs and 20 warm-up pairs. The materials were digitized and made into two lists as described in the earlier studies.

The same design and procedure were followed as in Experiment 4.

Subjects

Twenty-four subjects were tested, 12 on each version. All were recruited from the MRC Speech and Language Group subject pool.

Results and Discussion

Six subjects were dropped, either because their responses were slow and variable or because they had an error rate of more than 10%, leaving 9 subjects for each version. Four test pairs were also dropped because of high error rates (more than 35%). For the remaining data, the percentage of error was 3%. These and extreme outliers (0.2%) were removed from the data set. The error data were then entered into a two-way ANOVA on item means, with the factors of Prime Type (test or control) and Condition (1–6). There were no significant main effects or interactions.

Midmean RTs were then calculated over items and subjects and entered into a two-way ANOVA, with the factors Condition

[25] An alternative interpretation is that associative priming is mediated at a lower level in the lexical access system so that the lexical entry is not necessarily implicated.

[26] The mean frequencies of the primes, controls, and targets, respectively, were as follows: Condition 1—100, 103, and 51; Condition 2—109, 108, and 9; Condition 3—32, 62, and 15; Condition 4—53, 109, and 73; Condition 5—52, 64, and 139; and Condition 6—9, 45, and 146.

Table 10
Stimulus Properties in Experiment 5 (Prefixes)

Condition	Morphological type	Example	*N*	Mean relatedness[a]
1: [−Sem, +Morph]	stem–derived	*strain/restrain*	18	2.8
2: [+Sem, +Morph]	stem–derived	*sincere/insincere*	18	8.6
3: [−Sem, +Morph]	bound stems	*submit/permit*	18	2.4
4: [−Morph, +Phon]	pseudoprefixed	*dispatch/patch*	18	1.4
5: [−Morph, +Phon]	initial stress	*mildew/dew*	14	1.2
6: [−Morph, +Phon]	final stress	*trombone/bone*	14	1.2

Note. Sem = semantic; Morph = morphological; Phon = phonological.
[a] 1 = *very unrelated*; 9 = *very related.*

(1–6) and Prime Type (test or control). Table 11 gives the overall test and control means per condition.

There is clearly no priming for most conditions, and this is reflected in the outcome of the analysis, where none of the main effects or the interaction are significant (apart from the hint of an interaction between Condition and Prime Type in the item analysis, $F_2(5, 96) = 1.92$, $p = .09$. In the two [+Morph] stem–derived conditions, where the [−Sem] targets (as in *stall/install*) are 28 ms slower than the controls, $t(16) = 1.85$, $p = .08$, whereas the [+Sem] targets (as in *agree/disagree*) are 29 ms faster, $t(16) = 1.89$, $p = .07$, the contrast in Semantic Transparency causes a significant 57-ms shift in the priming effect, $t(16) = 2.71$, $p = .01$, consistent with the results in the earlier experiments.

There are two main points to be made here. The first is the absence of priming in the phonological control and pseudoprefixed conditions. Whether the match between the prime and a pseudostem is from word onset (as in Experiments 1 and 2) or in terms of the final syllable of the prime, there is no sign that phonological overlap between two words is sufficient to produce priming in this task. This is consistent with the view that the task taps into processing events at the level of the lexical entry and that when priming is obtained it is because of residual activation of regions of lexical representation shared by prime and target.

The result is, however, inconsistent with Shillcock's (1990) report that *trombone* facilitates responses to RIB. One possible reason for this is that the effect is insufficiently robust to replicate easily. Another is that associative priming does not necessarily tap into lexical representations at the level of the lexical entry (Moss, 1991; Moss & Marslen-Wilson, 1993), which is where we expect to pick up facilitation of the probe BONE. If associative links are links between word forms, then *bone* may be activated sufficiently to coactivate its associates without this being mediated through morphemic representations in the lexical entry.

The second point concerns the absence of priming for the bound-stem conditions, which is in contrast with the strong priming obtained for the parallel [+Sem] conditions (the derived–derived pairs in Experiment 4). This result suggests that the effect Emmorey (1989) obtained was at least partly due to phonetic overlap effects, with these operating more strongly in an intramodal repetition task. In the context of the results here, using a cross-modal repetition task, the failure of bound prefixed forms to prime is more evidence for the claim that there is no facilitation where there is no synchronic semantic basis for representing a word form as morphologically complex. Even if the listener does pick up during acquisition the distributional regularities in bound stems—for example, that the syllable *clude* is shared by several prefixes, as in *include, conclude, exclude, occlude,* and *preclude*—this is no more than a relic of word-formation processes that are no longer productive. To represent these forms as sharing the stem {-clude} would not give the right semantics because the potential stem here has no consistent semantic interpretation. Instead, each form will be represented as if it was monomorphemic, like *department* or *elbow.* Otherwise, *exclude* should prime *conclude* as effectively as *unwind* primes *rewind.*

The results also raise two other possibilities. One is that stem–derived priming is less robust for prefixes than for suffixes, and the other is that there may be some interference effects for [−Sem, +Morph] prefixed pairs. These are questions that will need to be pursued in subsequent research.

Experiment 6

The results of Experiment 5 are consistent with the model we proposed on the basis of the first prefix experiment (see Figure 9). In this model, there are inhibitory links between suffixes sharing the same stem but not between prefixes. This reflects the competitor environment during lexical access, where suffixed forms sharing the same stem are both active as competitors, whereas prefixed forms presumably are not. This implies that there should not be inhibitory links between suffixed and prefixed forms. Just as *misjudge* does not have *prejudge* as a cohort competitor, *judgment* should not be a competitor either. Similarly, *judgment* should not be activated as a competitor of either of the prefixed forms.

This leads to the prediction that suffix–prefix pairs should prime each other as, indeed, should prefix–suffix pairs. Our argument throughout has been that [+Morph] priming in the cross-modal task is due to residual activation of a stem morpheme shared by prime and target. Because this activation should not be canceled out by inhibition for prefix–suffix and suffix–prefix pairs, such as *disagree/agreement* or *kindness/unkind,* these should prime each other. The amount of priming, furthermore, should be symmetrical. We would only expect

Table 11
Mean Lexical Decision Times and Error Rates in Experiment 5 (Prefixes)

		Test		Control		
Condition	Morphological type	*M*	Error rate	*M*	Error rate	Difference
1: [−Sem, +Morph]	stem–derived	627	7.9	599	4.4	−28*
2: [+Sem, +Morph]	stem–derived	594	4.8	623	6.2	29*
3: [−Sem, +Morph]	bound stems	587	3.4	598	3.4	11
4: [−Morph, +Phon]	pseudoprefixed	577	2.1	564	3.2	−13
5: [−Morph, +Phon]	inital stress	558	6.1	561	3.1	3
6: [−Morph, +Phon]	final stress	578	2.6	566	3.7	−12

Note. Sem = semantic; Morph = morphological; Phon = phonological.
* $p < .10$.

asymmetry if, for example, suffixes inhibited all affixes attached to a given stem, rather than just other suffixes.

We also include in Experiment 6 the missing suffixed [−Sem, +Morph] stem–derived condition from Experiment 3. This is necessary not only to complete the design for the suffix experiments but also to provide the proper contrast with the prefixed stem–derived pairs in Experiment 5. The suffixed [+Sem] stem–derived pairs, such as *dismiss/dismissal*, primed very strongly. We predict that suffixed [−Sem] stem–derived pairs, such as *apart/apartment*, will not prime at all because *apartment* should not be represented as {apart} + {ment}, where the stem {apart} is shared with the word *apart*. The absence of synchronic semantic interpretability should block the formation of a morphologically complex lexical entry.

Method

Materials

The design of the experiment required three stimulus sets: the two suffix–prefix, prefix–suffix sets and the stem–derived [−Sem] suffixed set. The stem–derived set did not require additional pretesting and could be selected directly from the [−Sem] suffixed materials already tested for semantic relatedness in Experiments 2 and 3. Twenty such pairs were selected together with 20 matched control words.

The mixed-affix stimulus sets required extensive pretesting because we needed to select prime–target pairs where not only the two test items were related but also where each item was itself related to its stem. This required three separate pretests: For example, for a candidate pair like *connection/disconnect*, the first pretest would ask subjects to judge the semantic relatedness of *connection/connect*, the second would test *disconnect/connect*, and the third would test *connection/disconnect*. There were 120 items in each version of the pretest, with 69 potential candidates included. Forty-two subjects were tested on the three versions.

Our initial criterion for acceptance in the stimulus set was a relatedness score of 7.0 or above in all three pretests for a given mixed-affix pair. This gave a total of 20 prefix–suffix and 20 suffix–prefix pairs. To increase the number of items we then relaxed the criteria to include pairs where each member of the pair had a relatedness of 7.0 or more to their joint stem but where the relatedness of the pair to each other did drop below 7.0. This brought the numbers for each set up to 25. For each prime word, a control word was selected, which was matched in frequency, number of syllables, and form class.[27] A sample set of stimuli is listed in Table 12.[28]

Fillers. Ninety filler pairs were constructed, falling into three categories:

1. There were two sets of 10 real-word/real-word pairs, consisting of unrelated suffix–prefix or prefix–suffix pairs (as in *misfortune/argument*).

2. There were 48 suffixed or prefixed real words followed by a suffixed or prefixed nonword. In 28 of these the pseudostem of the nonword was phonologically related to the real word (as in *scandalous/miscand*), and in 20 it was unrelated (as in *booklet/incruve*).

3. There were 22 additional monomorphemic unrelated real-word/nonword pairs.

This gave a total of 70 real-word/real-word pairs and 70 real-word/nonword pairs, which were combined with 50 practice pairs and 20 warm-up pairs. The materials were digitized and made into two test versions in the same way as in the earlier studies. The same design and procedure were followed as in Experiments 4 and 5.

Subjects

We tested 43 subjects, 23 subjects on Version 1 and 20 subjects on Version 2. All were recruited from the MRC Speech and Language Group subject pool.

Results and Discussion

Three items were omitted from the analyses because they elicited more than 35% errors. Five subjects were removed because of their high error rate and slow and variable performance. This left 19 subjects on each version. Errors (3.5%) and extreme outliers (0.2%) were also removed from the data set. The remaining data were used to compute subject and item midmeans. The overall results for each condition are given in Table 13.

The midmean data were entered into two separate two-way ANOVAS on subjects and on items, with the factors Condition

[27] The mean frequencies of the primes, controls, and targets, respectively, were as follows: Condition 1—9, 11, and 55; Condition 2—74, 76, and 24; and Condition 3—84, 114, and 41.

[28] The relatedness scores given in Table 12 are for the relatedness of the two affixed forms to each other. We also have relatedness scores for the relationship of each affixed form to its stem, and these tend to be higher than the between-item scores, averaging over 8.0.

Table 12
Stimulus Properties in Experiment 6 (Suffixes and Prefixes)

Condition	Morphological type	Example	*N*	Mean relatedness[a]
1: [+Sem, +Morph]	prefix–suffix	*distrust/trustful*	25	7.5
2: [+Sem, +Morph]	suffix–prefix	*judgment/misjudge*	25	7.5
3: [−Sem, +Morph]	stem–derived	*apart/apartment*	20	2.6

Note. Sem = semantic; Morph = morphological.
[a] 1 = *very unrelated*; 9 = *very related*.

(1–3) and Prime Type (test or control).[29] There was a significant main effect of Prime Type, $F'_{min}(1, 101) = 5.36$, $p < .025$, reflecting faster overall responses following test rather than control primes, and a marginally significant effect of Condition, $F'_{min}(2, 86) = 2.96$, $p < .10$. Overall, the effects are very clear, with no priming for the stem–derived [−Sem, +Morph] suffixed pairs and significant priming for both the prefix–suffix pairs, $t(23) = 2.96$, $p < .01$, and the suffix–prefix pairs, $t(22) = 2.20$, $p < .05$. The amount of priming is equivalent in each case, at around 30 ms.

Both sets of results are consistent with the model as we have developed it so far. Stem–derived [−Sem] pairs like *apart/apartment* do not prime because they do not share a stem morpheme in the lexical entry and because priming in this task reflects events at this level of lexical representation. Suffix–prefix and prefix–suffix [+Sem] pairs do prime (in contrast with [+Sem] suffix–suffix pairs) because they share a lexical entry and because there are no inhibitory links between suffixes and prefixes. In addition, as the model predicts, priming is symmetrical: Suffixed words prime prefixed words just as well as prefixed words prime suffixed words.

General Discussion

We begin by pulling together the complete set of results for the six experiments, looking at them under a number of subheadings. We then go on to discuss some of the implications of this work for models of the mental lexicon, focusing on the contrast between word- and morpheme-based theories of the lexical entry and on the issue of access representations and the access route from the sensory input to the lexical entry.

Suffixing Morphology

The results for the experiments involving English derivational suffixes are summarized in Figure 10, averaging over identical conditions in Experiments 1–3 and including the stem–derived condition run in Experiment 6. The pattern is clear and consistent. Semantically transparent pairs prime but only if the prime–target relationship is between a free stem and a related suffixed form. Two suffixed forms do not prime each other whether semantically related or not.

This pattern of results leads to a model of lexical structure where semantically transparent, morphologically complex words are represented, at the level of the lexical entry, in decomposed morphemic form. The same stem morpheme, therefore, may be shared by members of a cluster of morphemically and semantically related words. The lack of priming between suffixed words in the same cluster is attributed to inhibitory relations between the suffixes (or between the links connecting the stem morpheme to the suffixes). This is because the same stem morpheme cannot simultaneously combine with two different derivational affixes.[30]

When the listener encounters a suffixed form, the stem will be heard first, and this will activate both the stem itself and the suffixes attached to this stem. These suffixed forms therefore become active as competing interpretations of the current input. As soon as the evidence starts to pick out one suffix rather than another, these suffixed competitors will be suppressed. This has the effect of slowing down responses to one of these competitors if it is subsequently presented as a target in the priming task.[31]

This is a stronger form of competition than we have observed elsewhere, between morphologically unrelated words belonging to the same cohort (such as *gallon/gallop*), where there is little evidence for lateral inhibitory effects (Marslen-Wilson, in press; Marslen-Wilson, Gaskell, & Older, 1991). This is because the two lexical interpretations do not conflict in the same way. Pairs like *attractive* and *attraction* are mutually exclusive, in the strong sense that the same lexical representation (the stem morpheme *attract*) cannot simultaneously be interpreted as two different lexical items, with different meanings and different syntactic properties. Hearing the word *attractive* means that the word *attraction* no longer exists as a possible candidate. In contrast, pairs like *gallop* and *gallon* do not compete for ownership of the same lexical region. If the word *gallon* is heard, the entry for *gallop* remains in the system as a possible candidate, with its activation level decaying away over time.

Prefixing Morphology

There is a different pattern for English derivational prefixes, which is summarized in Figure 11. Again, only semantically

[29] A preliminary analysis showed no difference between items where all relatedness scores were greater than 7.0 and those where relatedness between the two affixed words was less than 7.0.

[30] We refer here to the case (as in our experiments) where both suffixes are in competition for the position directly after the stem so that both affixes cannot simultaneously combine with the stem morpheme. The situation may be different where two affixes can be concatenated (as in forms like *governmental*).

[31] This inhibitory effect is likely to be quite short lived. If priming was tested at a longer delay, it is possible that facilitatory effects would be

Table 13
Mean Lexical Decision Times and Error Rates in Experiment 6 (Suffixes and Prefixes)

		Test		Control		
Condition	Morphological type	*M*	Error rate	*M*	Error rate	Difference
1: [+Sem, +Morph]	prefix–suffix	499	0.8	529	3.1	30*
2: [+Sem, +Morph]	suffix–prefix	530	2.1	561	6.2	31*
3: [−Sem, +Morph]	stem–derived	533	3.2	534	4.0	1

Note. Sem = semantic; Morph = morphological.
* $p < .05$.

transparent pairs prime, but now there is no restriction on the morphological relationship between prime and target. Prefixed pairs prime each other as well as, if not better than, pairs made up of a free stem and a prefixed form. There is also a tendency, which did not appear for the suffixed forms, for derived targets to show signs of interference in the [−Sem] conditions.

This leads to a modified model for semantically transparent prefixed words, where there is still morphemic decomposition at the level of the lexical entry but no inhibition between prefixes attached to the same stem. The same prohibition applies here against combining the same stem simultaneously with two affixes, but because competitors are defined from word onset, a prefixed input will not activate other prefixed words sharing the same stem, and therefore these will not be active competitors that need to be suppressed as part of the recognition process. The results of Experiment 6 are consistent with this competitor-based account. They show that prefixed and suffixed words sharing the same stem can prime each other. Prefixed and suffixed words in the same morphemic cluster do not share the same word onset; they will not, therefore, be coactivated as competitors.

Semantic Opacity

A consistent finding across all six experiments is that semantically opaque pairs do not prime. Unless listeners rate a derived word and its free stem or a pair of derived words sharing the same stem as being semantically related, we do not find reliable priming between them. This applies across the board, irrespective of the presence or absence in the word pairs of phonologically transparent stems and affixes. Throughout, the [+Morph, −Sem] pairs behave no differently to the monomorphemic [−Morph, +Phon] pairs used as phonological controls.

We interpret this as evidence that semantically opaque, morphologically complex words in English are represented as morphologically simple at the level of the lexical entry. From the point of view of structural decomposition in the lexicon, words like *apartment* or *discover*, despite their morphological decomposability on linguistic, etymological, and phonological grounds, appear to be represented in the same way as words like *elbow* or *celery*, which are monomorphemic on all counts and which are presumably mentally represented as such. The average listener has no access to the diachronic history of a word and will only mentally represent it as morphologically complex if this gives the right compositional semantics. Any linguistic analysis of the morphology of English must, therefore, be filtered through this synchronic criterion before it can be interpreted in terms of actual mental representations of words in the language.

If these conclusions are correct, they raise awkward questions for previous research involving derived forms in English because little of this work seems to have taken semantic opacity into account. Most stimulus sets of suffixed or prefixed derived forms are likely to have contained some forms that were not morphologically complex, especially if the criterion used to determine synchronic decomposability took into account only the semantic transparency of the affix. If research in this area has been contaminated in this way, by the inclusion of psychologically monomorphemic words in experiments looking at the effects of morphological complexity on lexical access and representation, then it is not surprising that there has been difficulty in reaching a common view on these issues.

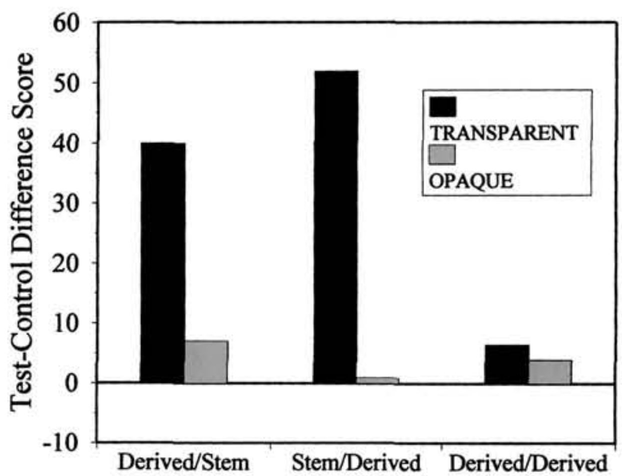

Figure 10. Priming effects for English derivational suffixes, showing test–control difference scores as a function of semantic transparency and opacity, across three types of morphological relations between primes and targets (derived–stem, stem–derived, and derived–derived).

obtained, with the longer-lasting activation of the shared-stem morpheme starting to come through.

Phonological Transparency and Phonological Overlap

In comparison with semantic factors, variations in the phonological relationship between prime and target had much less effect on subjects' responses. In Experiment 1, priming was just as strong for phonologically opaque pairs as it was for transparent pairs, as long as prime and target were morphologically and semantically related. However, for all the [−Morph, +Phon] cases, across several experiments, where there was only a phonological relationship between prime and target, there was never a significant facilitatory effect and usually there were signs of inhibition or interference.

We deal first with a possible criticism of these results: that the [−Morph, +Phon] pairs used in Experiments 1 and 2 were not the appropriate controls for the [+Morph, +Phon] pairs. This is because, unlike the morphologically related pairs, they were not always made up, phonetically, of a potential stem followed by an affix. If there was some morphological parsing process that operated at an early stage of the input process to parse the incoming string into stems and affixes, as suggested in the Taft and Forster (1975) affix-stripping model and in the Augmented Addressed Morphology model of Caramazza et al. (1988), then a [−Morph, +Phon] prime like *principal* would not be parsed into [*prince* + affix] because there is no affix *-pal* or *-ipal*. In contrast, for a [+Morph, +Phon] prime like *attractive*, the affix *-ive* can be stripped off in the preliminary parse, leaving the potential (and in this case actual) stem *attract*. This difference in parsability might lead to differences in priming effects, with *prince*, in contrast with *attract*, never going through as a candidate to the lexical level and therefore never being activated, even partially.

We can exclude this on two grounds. The first is the absence of priming for [+Morph, −Sem] pairs like *department/depart* or *university/universe*. These were comparable to the [+Morph, +Sem] pairs in their surface parseability but showed no sign of priming. Similarly, prefixed and pseudoprefixed [−Sem] pairs like *restrain/strain* or *dispatch/patch*, which are just as decomposable on the surface as [+Morph, +Sem] prefixed pairs, also do not prime each other. The second is the result of an additional test, not reported here, where we compared [−Morph, +Phon] pairs of the *principal/prince* type with pairs such as *pigment/pig* or *booty/boot*, where the pairs were also morphologically unrelated but could be parsed into potential stems and affixes (as in *pig* + *ment*). Here also there was no sign of priming.[32]

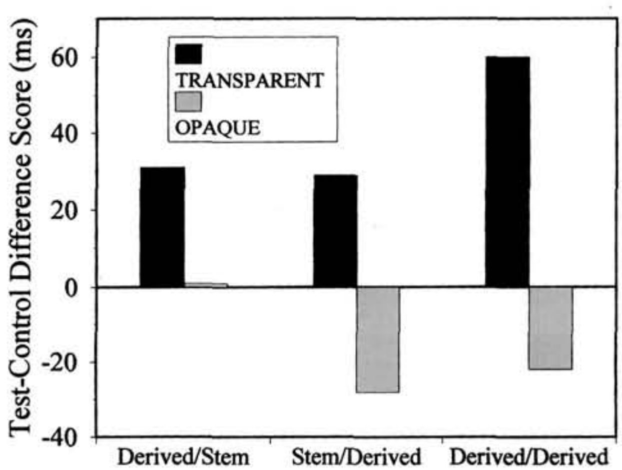

Figure 11. Priming effects for English derivational prefixes, showing test–control difference scores as a function of semantic transparency and opacity, across three types of morphological relations between primes and targets (derived–stem, stem–derived, and derived–derived).

The failure, then, of phonological opacity to prevent priming, and of phonological transparency to produce priming, tells us something both about the level of lexical representation into which the task is tapping and about the nature of competition effects in lexical access. First, however, these phonological effects rule out the possibility that the priming effects are due to surface phonetic overlap between prime and target.

If this was the case, then a prime such as *principal* would activate not only itself but also the word *prince*. The residual effects of this secondary activation would then facilitate a subsequent lexical-decision response to the visual probe PRINCE. Given that a prime like *principal* does phonologically contain the word *prince* and given a lexical access process, which allows parallel access of different word candidates (e.g., Marslen-Wilson, 1987; Zwitserlood, 1989), there is little doubt that *prince* should be activated when the prime is heard. The fact that, nonetheless, there is no facilitation of *prince* when it occurs as a visual probe a few hundred milliseconds later means that this activation dies away very rapidly: either because of the slope of the decay function or because it is actively inhibited by the subsequent mismatching input (Marslen-Wilson, in press).

This brings back into focus the question of why, nonetheless, [+Morph, +Sem] pairs like *attractive/attract* do prime. Why does hearing *attractive* not have the same consequences for the activation level of *attract* that *principal* apparently does for *prince*? Most plausibly, this is because *attractive* and *attract* share the same stem so that there are not two lexical representations competing in the same way. Words like *principal* and *prince* are represented as two separate stem morphemes, and evidence that *principal* is being heard is evidence that *prince* is not so that the pattern of activation corresponding to the *prince* interpretation will decay or be suppressed. A word like *attractive*, in contrast, is represented as the morpheme *attract* in combination with the affix *-ive*. Evidence that *attractive* is being heard, rather than *attract*, does not entail any decay or suppression of the activation of *attract*—to the contrary, because the internal representation of *attractive* is based on the representation of *attract* combined with the affix *-ive*.

The outcome of this, in the immediate repetition priming task, is that when a [+Morph, +Sem] probe is presented the shared stem morpheme will still be active, and this speeds the lexical-decision response. It is hard to see, otherwise, how the difference between morphologically related and unrelated prime–target pairs can be explained. Lexical items with similar

[32] This additional study contained two sets of 20 prime–target pairs of the [−Morph, +Phon] type, which were matched in frequency and syllable length but contrasted in whether they ended in a potential suffix. The pseudosuffixed pairs (such as *booty/boot*) showed a nonsignificant priming effect of 14 ms, and the nonsuffixed pairs (such as *furlong/fur*) showed an effect of −4 ms.

phonological forms will necessarily compete with each other unless they share the same morphology and the same semantics.

These arguments are complemented by the effects of phonological opacity on the [+Morph, +Sem] pairs, which not only seem to require a common morpheme explanation but also constrain the properties of form representations at this level of the system. The fact that *vanity* primes *vain*, or that *decision* primes *decide*, is hard to explain on a phonetic overlap account because this predicts that *vanity* should, if anything, prime *van* better than it primes *vain*. However, if *vanity* and *vain* share the same stem morpheme, then the story is exactly the same as it is for pairs like *attractive/attract* or *friendly/friend*. This in turn means that the form representation of the stem morpheme in the lexical entry must in some way abstract away from its surface phonetic form. If the stem morpheme {vain} was represented as /veyn/, then this would conflict with surface [væn], as in *vanity*, and vice versa if it was represented underlyingly as /væn/. This raises the general issue of access representations for morphologically complex words, to which we now turn.

Access Representations and Morphological Parsing

We argued at the beginning of this article that it was essential in the study of lexical representation and process to define which level or levels of the system are being investigated. We made a basic distinction between a modality-independent core representation of a word or morpheme's abstract syntactic, semantic, and phonological properties (the lexical entry)[33] and the possible modality-specific form representations that provided the access routes to these core representations. This is simply a way of making explicit the widely shared intuition that a word like *cat* has a single entry in the mental lexicon, constituting its meaning, and that this entry can be accessed in diverse ways, including the spoken word [kæt] and the written form CAT. The research reported here was designed to investigate the properties of this single lexical entry, and to do so it used a cross-modal priming task on the assumption that this would tap into events at a modality-independent level of the system.

The results are consistent with the view that there is a modality-independent lexical level and that this is structured on a morphological basis. The question we now need to address is the relationship between form representation at the level of the lexical entry and representation at the level of modality-specific access. There are two main issues here: the relationship between orthographic and phonological representations of a word form and the problem of surface opacity (or allomorphy) in the relationship between a derived form and its stem (as in the *vain/vanity* and *delete/deletion* cases).

The issue of orthography and phonology has a long and tortuous history (mainly under the heading of grapheme-to-phoneme recoding) and we do not discuss it in detail here. Our working assumption is that there is an independent orthographic route to the lexical entry so that there is something like an access representation of a word's written form. We assume, however, that the form representation in the lexical entry is an abstract phonological one from which the orthographic representation ultimately derives and onto which the orthographic access route ultimately projects. It is unclear how early the mapping from orthographic to abstract phonological representation takes place, and there is little in the data reported here that bears directly on this.

It is, however, relevant that both types of representation must deal with the problem of surface opacity (or allomorphy). If *vanity* is represented in the lexical entry as abstract {vain} + {ity}, then the system must find a way of mapping divergent surface phonological and orthographic forms onto the same underlying morpheme. For the phonological access route, there are two ways of doing this. One is to set up a phonological access representation, which represents the surface form of the word and which mediates between phonological input and lexical entry. On this account, forms such as [veyn] and [vænɪtɪ] would be separately listed in the access representation, and initial access would be to these forms. These in turn would be linked to the relevant lexical entry. This is essentially the arrangement that Forster (1976) proposed, with a lexical master file and modality-specific access files.

To deal with the evidence for morphological decomposition in the representation of [+Morph, +Sem] words, this view requires some form of morphological parsing at the level of the access representation. The purpose of these access representations is to translate between variable, complex, surface forms and their underlying morphemes. It is hard to see how this can be achieved unless these surface forms are first decomposed into their constituent morphemes. Indeed, considerations of this sort motivated the original proposal by Taft and Forster (1975) for a process of morphological parsing (in their terms affix stripping) as a preliminary to accessing lexical entries organized on a morphemic basis. Although Taft and Forster do not themselves deal with issues of surface opacity, any modality-specific input parser will have to find ways of determining the correct analysis of [−Phon] forms, such as *vanity* and *decision*, as well as the apparently more straightforward [+Phon] forms, such as *happiness* or *rebuild*.

The problem with this is that if the morphological parser has to perform morphophonological inference—if, for example, it has to deduce that [væn] in the context of [ɪtɪ] is potentially underlying {vain}, whereas [væn] in the context of [ɪʃ] (as in *vanish*) is not—then it will not only need to have access to rules of phonological alternation but also to information about the syntactic as well as phonological properties of morphemes. This is because the syntactic properties of stems and affixes are used in determining whether they can combine to form larger units. However, this would mean storing in the access representation much the same kind of information that already needs to be stored in the lexical entry, so that it is no longer clear what is being achieved by postulating this preliminary process of analysis.

The alternative view is to allow direct mapping of the phonological input onto the lexical entry, where the phonological representation is abstract in ways that make it compatible with the surface variants of a given morpheme. This is an extension to the arguments we have made elsewhere (Lahiri & Marslen-Wilson, 1991, 1992; Marslen-Wilson, in press) for the role of abstractness in explaining the perception of phonological varia-

[33] This is consistent with linguistic analyses of the lexical sign as a triplet, incorporating phonological, syntactic, and semantic information in a hierarchical feature structure (e.g., Pollard & Sag, 1987).

tion that does not involve morphological factors—for example, the nasalization of the oral vowel /æ/ in English when followed by a nasal consonant (as in *ban*). The general claim is that regular phonological alternations, which change the surface form of a word or morpheme, do not create mismatches at the lexical level because the underlying representation of the word in question is underspecified for the feature dimension (e.g., [nasal]) along which the alternation is operating.

Underspecification is a phonological concept, which we can gloss here as the hypothesis that only the marked or nondefault values of phonological features are specified in the underlying lexical representation (e.g., Archangeli, 1988). Our claim is that the lexical representations involved in the perception of language are phonologically underspecified in this sense. If, for example, underlyingly oral vowels in English are unspecified for nasality because [+nasal] is marked and [−nasal] is the unmarked default, the processing consequence of this is that the presence or absence of nasality in the phonetic input does not affect the computed goodness of fit between this input and the underlying phonological representation of this word.[34]

In the same way, phonological alternations that are morphologically triggered—for example, the *divine/divinity* and *sane/sanity* type of variation—can be argued to involve a vowel that is underlyingly unspecified for the feature that is alternating (in this case, the tense–lax distinction). The underlying representation of the morpheme {sane} on this account would be something like /sÆn/, where the capitalized vowel symbol (Æ) denotes a vowel segment unspecified for tenseness (Myers, 1987). In the appropriate environment, this vowel is realized as either [ey] or [æ], as in the surface forms [seyn] and [sænɪtɪ]. The crucial point, from the perceptual side, is that because the lexical representation is underspecified for this particular feature, both surface forms will match to it. Underlying [sÆn] will match equally well to surface [seyn] and to surface [sæn]. There is no need, therefore, to postulate an intermediate access representation to deal with surface opacity of this type.[35]

The assumption of direct mapping not only dispenses with the need for an intermediate access representation; it also dispenses with the requirement for morphological parsing before entry into a morphemically based lexicon. Whatever parsing processes do operate can do so over the domain of the central lexicon, where the syntactic and semantic properties of individual morphemes are available as well as their phonological properties, so that different morphemes can be linked together as necessary to compute the correct interpretation of the incoming word string. In our earlier research on the processing of morphologically complex words in context (Tyler & Marslen-Wilson, 1986), we proposed a parsing process of this sort, where stem and affix morphemes can interact independently with different aspects of the on-line parsing and interpretation process.

Turning to the orthographic access route, essentially the same two options present themselves: an intermediate access representation or direct mapping onto abstract underlying representations. If it is the case that the underlying abstract representation in the lexical entry is phonological in nature, then the orthographic access route will always involve some sort of recoding process. If there is an orthographic access lexicon, with pointers linking it to a Forsterian master file, then the recoding can take place at this interface. One view of this (though other variants have certainly been suggested) is that the access file would contain representations of full orthographic forms onto which the visual input is mapped during lexical access.

Again, the assumption of an initial process of access to representations of orthographic form will require some form of morphological parsing, with the same advantages and disadvantages as discussed earlier for the phonological access file. It is also possible, however, that the problems of morphological decomposition of phonologically opaque forms are somewhat different in the orthographic domain. This is because English orthography seems to have morphophonemic properties—that is, it preserves the underlying morphemic structure of complex forms more directly than in the phonetic surface form. This was pointed out, among others, by Chomsky and Halle (1968), arguing that the apparent failure of the orthography to reflect the changed vowel in pairs like *sane/sanity* or *decide/decision* in fact preserves the underlying identity of the stem morpheme in each case (see also Klima, 1972; Weir & Venezky, 1968). This would simplify the task of morphological analysis in the access process, although it would not help the parser with the question of whether to treat *vanish* as a monomorphemic form.

However, if English orthography is significantly morphophonemic, this would also allow for a more direct mapping onto the lexical level. At some point graphemes still have to be related to phonological entities, but this mapping may be primarily between graphemes and abstract underlying phonological units rather than surface phonemes or similar units. To the extent that orthographic representations can be directly linked to the lexical entry in this way, then this would allow, again, for processes of morphological parsing to be operating over the appropriate knowledge domain. It would also allow for essentially parallel access processes in the two modalities, with both routes allowing direct access to the lexical entry both for transparent cases and for phonologically regular opaque cases. This, we suggest, is the most interesting hypothesis from the point of view of future research.

One issue that this research will also have to confront is the generalizability of the results reported here, based on cross-modal immediate repetition priming, to other tasks and other combinations of presentation modality. Preliminary research in our laboratory (Zhou & Marslen-Wilson, 1993), using an intramodal version of the immediate repetition task, with auditory presentation of both target and prime, has obtained very similar results of the effects of semantic transparency and of the lack of effect of phonological opacity. This is consistent with our emphasis here and elsewhere on the abstractness of the lexical form representations in the lexical access process.

In the visual domain, there is at least a partial overlap be-

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[34] For an account of how underspecified representations might function in speech production (where defaults have to be filled in), see Keating (1988).

[35] It is important to note that this treatment of allomorphy will only apply in cases where morphologically induced alternations in surface form can be analyzed as regular phonological alternations operating on underspecified feature dimension. It is doubtful that this is the case, for example, for some of the alternations in English inflectional morphology, such as *teach/taught* or *dig/dug*.

tween our results and those reported by Grainger, Colé, and Segui (1991), using a visual masked priming technique to study derivationally affixed forms in French.[36] Grainger et al. (1991) also found an asymmetry between prefixed and suffixed forms, with significant priming for both stem–derived and derived–derived pairs with prefixed targets but no priming for derived–derived suffixed targets. Their results diverge from ours in that they also obtained no priming for stem–derived suffixed pairs. They interpret this failure of priming for suffixed targets in terms of low-level inhibitory orthographic effects, but an interpretation in terms of effects at the level of the lexical entry seems equally plausible.

More work is obviously needed here, and it will also be necessary to examine priming effects between derivationally related forms using delayed repetition tasks. The inhibitory and excitatory effects we postulate here may well have different time-courses, with, for example, inhibitory effects disappearing at longer repetition delays.

Words and Morphemes: Concluding Remarks

At the beginning of this article we asked, what is the basic unit in terms of which the lexicon is organized? Our answer, for derivational forms in English, is clearly the morpheme. This should be understood, however, as a cognitive, or psycholinguistic, concept of the morpheme, developmentally definable for each listener in terms of its synchronic semantic interpretability. This cognitive morpheme does not include all entities definable as morphemes on linguistic and diachronic grounds so that linguistically polymorphemic forms, like *apartment* or *submit*, can behave like unanalyzed simple forms, with no internal structure, as far as their mental representation is concerned. In this sense, the model may be more correctly described as stem based rather than morpheme based.

This approach falls into the class of morphemic rather than whole-word or full-listing models of lexical representation. In fact, it is hard to make functional sense of any strict full-listing theory of the mental lexicon, unless it is construed as a theory of access representations, listing the surface forms of words. At the level of the lexical entry, which has been our main concern here, it seems strongly counterintuitive to represent semantically transparent forms like *happily, happiness*, or *unhappy* as unanalyzed individual entries such that the semantics of *happy* are duplicated for each separate derivational variant. The interesting finding in our research is not so much that pairs like *happy* and *happiness* share the same morpheme but that pairs like *apart* and *apartment* do not.

This focus on the lexical entry for English derived forms, as well as the important role played by semantic factors, makes it difficult to relate, in any significant detail, the view we are developing here to most of the other morphemically structured models in the psycholinguistic literature. These tend to be concerned with inflectional morphology or deal with different languages and generally ignore semantic issues. Our approach diverges still further when we take into account the views developed in the previous section about access representations and morphological parsing. If we make the appropriate assumptions about the abstractness of lexical form representation (Lahiri & Marslen-Wilson, 1991, 1992), then morphological parsing can operate directly on the lexical entry, obviating the need to postulate a prelexical parsing procedure, operating on modality-specific access representations of surface full forms.

Nonetheless, our claim that the mental representation of English derived forms is organized on a morphemic basis is broadly consistent with a range of psycholinguistic research stretching back over two decades, and there is little doubt that some type of morphemic theory of the lexical entry must be correct. What we have tried to do in the research reported here is to put the further development of such a theory on a more systematic basis, taking fuller account of the range of linguistic and functional conditions under which listeners learn, understand, and produce morphologically complex forms in English.

[36] We thank Ken Forster for drawing our attention to this article, which was published after the research reported here had been completed.

References

Archangeli, D. (1988). Aspects of underspecification theory. *Phonology, 5*, 183–207.

Aronoff, M. (1976). *Word formation in generative grammar.* Cambridge, MA: MIT Press.

Bergman, M. W., Hudson, P. T. W., & Eling, P. A. T. M. (1988). How simple complex words can be: Morphological processing and word representations. *The Quarterly Journal of Experimental Psychology, 40*, 41–72.

Bradley, D. (1980). Lexical representation of derivational relation. In M. Aronoff & M-L. Kean (Eds.), *Juncture* (pp. 37–55). Saratoga, CA: Anma Libri.

Butterworth, B. (1983). Lexical representation. In B. Butterworth (Ed.), *Language production* (Vol. 2, pp. 257–294). San Diego, CA: Academic Press.

Caramazza, A., Laudanna, A., & Romani, C. (1988). Lexical access and inflectional morphology. *Cognition, 28*, 297–332.

Caramazza, A., Miceli, G., Silveri, M. C., & Laudanna, A. (1985). Reading mechanisms and the organization of the lexicon: Evidence from acquired dyslexia. *Cognitive Neuropsychology, 2*, 81–114.

Chomsky, N., & Halle, M. (1968). *The sound pattern of English.* New York: Harper & Row.

Cutler, A., Hawkins, J. A., & Gilligan, G. (1985). The suffixing preference: A processing explanation. *Linguistics, 23*, 723–758.

Derwing, B. L. (1976). Morpheme recognition and the learning of rules for derivational morphology. *Canadian Journal of Linguistics, 21*, 38–66.

Emmorey, K. (1989). Auditory morphological priming in the lexicon. *Language and Cognitive Processes, 4*, 73–92.

Fischler, I. (1977). Semantic facilitation without association in a lexical decision task. *Memory & Cognition, 5*, 335–339.

Forster, K. I. (1976). Accessing the mental lexicon. In E. C. T. Walker & R. Wales (Eds.), *New approaches to language mechanisms* (pp. 257–287). Amsterdam: North-Holland.

Forster, K., & Davis, C. (1984). Repetition priming and frequency attenuation in lexical access. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 10*, 680–698.

Fowler, C. A., Napps, S. E., & Feldman, L. (1985). Relations among regular and irregular morphologically related words in the lexicon as revealed by repetition priming. *Memory & Cognition, 13*, 241–255.

Grainger, J., Colé, P., & Segui, J. (1991). Masked morphological priming in visual word recognition. *Journal of Memory and Language, 30*, 370–384.

Hall, C. J. (1987). *Language structure and explanation: A case from morphology.* Unpublished doctoral dissertation, University of Southern California, Los Angeles.

Hall, C. J. (1992). *Morphology and mind.* London: Routledge & Kegan Paul.

Henderson, L. (1985). Towards a psychology of morphemes. In A. W. Ellis (Ed.), *Progress in the psychology of language* (Vol. 1, pp. 15–72). Hillsdale, NJ: Erlbaum.

Henderson, L. (1989). On mental representation of morphology and its diagnosis by measures of visual access speed. In W. D. Marslen-Wilson (Ed.), *Lexical representation and process* (pp. 357–391). Cambridge, MA: MIT Press.

Henderson, L., Wallis, J., & Knight, K. (1984). Morphemic structure and lexical access. In H. Bouma & D. Bouwhuis (Eds.), *Attention and performance X: Control of language processes* (pp. 211–226). Hillsdale, NJ: Erlbaum.

Jacoby, L., & Dallas, M. (1981). On the relationship between autobiographical memory and perceptual learning. *Journal of Experimental Psychology: General, 110,* 306–340.

Jarvella, R., & Meijers, G. (1983). Recognizing morphemes in spoken words: Some evidence for a stem-organized mental lexicon. In G. B. Flores d'Arcais & R. Jarvella (Eds.), *The process of language understanding* (pp. 81–112). New York: Wiley.

Keating, P. A. (1988). Underspecification in phonetics. *Phonology, 5,* 275–292.

Kempley, M., & Morton, J. (1982). The effects of priming with regularly and irregularly related words in auditory word recognition. *British Journal of Psychology, 73,* 441–454.

Klima, E. (1972). How alphabets might reflect language. In J. F. Kavanagh & I. G. Mattingley (Eds.), *Language by ear and by eye* (pp. 57–80). Cambridge, MA: MIT Press.

Lahiri, A., & Marslen-Wilson, W. D. (1991). The mental representation of lexical form: A phonological approach to the recognition lexicon. *Cognition, 38,* 243–294.

Lahiri, A., & Marslen-Wilson, W. D. (1992). Lexical processing and phonological representation. In G. J. Docherty & D. R. Ladd (Eds.), *Papers in laboratory phonology II: Gesture, segment, prosody* (pp. 229–254). Cambridge, England: Cambridge University Press.

Laudanna, A., Badecker, W., & Caramazza, A. (1989). Priming homographic stems. *Journal of Memory and Language, 28,* 531–546.

Laudanna, A., & Burani, C. (1985). Address mechanisms to decomposed lexical entries. *Linguistics, 23,* 775–792.

Longman Dictionary of the English Language. (1983). London: Longman.

Lukatela, G., Gligorijevic, B., Kostic, A., & Turvey, M. (1980). Representation of inflected nouns in the internal lexicon. *Memory & Cognition, 8,* 415–423.

Lupker, S. J. (1984). Semantic priming without association: A second look. *Journal of Verbal Learning and Verbal Behavior, 23,* 709–733.

MacKay, D. G. (1978). Derivational rules and the internal lexicon. *Journal of Verbal Learning and Verbal Behavior, 17,* 61–71.

Manelis, L., & Tharp, D. (1977). The processing of affixed words. *Memory & Cognition, 5,* 690–695.

Marchand, H. (1969). *The categories and types of present-day English word-formation.* Munich, Federal Republic of Germany: Beck.

Marslen-Wilson, W. D. (1987). Functional paralellism in spoken word recognition. *Cognition, 25,* 71–102.

Marslen-Wilson, W. D. (1989). Access and integration: Projecting sound onto meaning. In W. D. Marslen-Wilson (Ed.), *Lexical representation and process* (pp. 3–24). Cambridge, MA: MIT Press.

Marslen-Wilson, W. D. (in press). Issues of process and representation in lexical access. In G. Altmann (Ed.), *Cognitive models of language processes: The second Sperlonga meeting.* Hillsdale, NJ: Erlbaum.

Marslen-Wilson, W. D., Gaskell, G., & Older, L. (1991, April). *Match and mismatch in lexical access.* Paper presented at the Experimental Psychological Society meeting, Cambridge, England.

Marslen-Wilson, W. D., & Zwitserlood, P. (1989). Accessing spoken words: The importance of word onsets. *Journal of Experimental Psychology: Human Perception and Performance, 15,* 576–585.

Morton, J. (1969). Interaction of information in word recognition. *Psychological Review, 76,* 165–178.

Moss, H. (1991). *Access to word meanings during spoken language comprehension.* Unpublished doctoral dissertation, University of Cambridge, Cambridge, England.

Moss, H., & Marslen-Wilson, W. D. (1993). Access to word meanings during spoken language comprehension: Effects of sentential semantic context. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 19,* 1254–1276.

Moss, H., Ostrin, R. K., Tyler, L. K., & Marslen-Wilson, W. D. (1992, April). *Auditory associative and semantic priming.* Paper presented at the Experimental Psychology Society meeting, Oxford, England.

Myers, S. (1987). Vowel shortening in English. *Natural Language & Linguistic Theory, 5,* 487–518.

Napps, S. E. (1985). *Morphological, semantic and formal relations among words and the organization of the mental lexicon.* Unpublished doctoral dissertation, Dartmouth College, Hanover, NH.

Napps, S. E. (1989). Morphemic relationships in the lexicon: Are they distinct from semantic and formal relationships? *Memory & Cognition, 17,* 729–739.

Neely, J. H. (1991). Semantic priming effects in visual word recognition: A selective review of current findings and theories. In D. Besner & G. W. Humphreys (Eds.), *Basic processes in reading: Visual word recognition* (pp. 266–336). Hillsdale, NJ: Erlbaum.

Pollard, C., & Sag, I. A. (1987). *Information-based syntax and semantics.* Stanford, CA: Center for the Study of Language and Information.

Oxford Dictionary of English Etymology. (1983). London: Oxford University Press.

Quirk, R., Greenbaum, S., Leech, G., & Svartvik, J. (1985). *A comprehensive grammar of the English language.* London: Longman.

Rubin, G. S., Becker, C. A., & Freeman, R. H. (1979). Morphological structure and its effects on visual word recognition. *Journal of Verbal Learning and Verbal Behavior, 8,* 399–412.

Schriefers, H., Zwitserlood, P., & Roelofs, A. (1991). The identification of morphologically complex spoken words: Continuous processing or decomposition. *Journal of Memory and Language, 30,* 26–47.

Shillcock, R. (1990). Lexical hypotheses in continuous speech. In G. Altmann (Ed.), *Cognitive models of speech processing* (pp. 24–49). Cambridge, MA: MIT Press.

Smith, P. T. (1988). How to conduct experiments with morphologically complex words. *Linguistics, 26,* 699–714.

Stanners, R. F., Neiser, J. J., Hernon, W. P., & Hall, R. (1979). Memory representation for morphologically related words. *Journal of Verbal Learning and Verbal Behavior, 18,* 399–412.

Stemberger, J. P., & MacWhinney, B. (1986). Frequency and the lexical storage of regularly inflected forms. *Memory & Cognition, 14,* 17–26.

Swinney, D. A. (1979). Lexical access during sentence comprehension: (Re)consideration of context effects. *Journal of Verbal Learning and Verbal Behavior, 14,* 645–660.

Taft, M. (1981). Prefix stripping revisited. *Journal of Verbal Learning and Verbal Behavior, 20,* 289–297.

Taft, M. (1988). A morphological-decomposition model of lexical access. *Linguistics, 26,* 657–667.

Taft, M., & Forster, K. I. (1975). Lexical storage and retrieval of prefixed words. *Journal of Verbal Learning and Verbal Behavior, 14,* 638–647.

Tyler, L. K., & Marslen-Wilson, W. D. (1986). The effects of context on the recognition of polymorphemic words. *Journal of Memory and Language, 25,* 241–256.

Tyler, L. K., Marslen-Wilson, W. D., Rentoul, J., & Hanney, P. (1988). Continuous and discontinuous access in spoken word-recognition: The role of derivational prefixes. *Journal of Memory and Language, 27,* 368–381.

Weir, R. H., & Venezky, R. (1968). Spelling-to-sound patterns. In K. S. Goodman (Ed.), *The psycholinguistic nature of the reading process* (pp. 185–200). Detroit, MI: Wayne State University Press.

Zhou, X-L. (1992). *The mental representation of Chinese disyllabic words.* Unpublished doctoral dissertation, University of Cambridge, Cambridge, England.

Zhou, X-L., & Marslen-Wilson, W. D. (1991, July). *The representation and access of Chinese disyllabic words.* Paper presented at the Experimental Psychological Society meeting, Sussex, England.

Zhou, X-L., & Marslen-Wilson, W. D. (1993, November). *Auditory morphological priming for English derived words.* Paper presented at the Psychonomic Society meeting, Washington, DC.

Zwitserlood, P. (1989). The locus of the effects of sentential-semantic context in spoken-word processing. *Cognition, 32,* 25–64.

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