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The Pseudoprefixation Effect in Visual Word Recognition: A True—Neither Strategic Nor Orthographic—Morphemic Effect

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The question of how word morphology is coded and retrieved during visual word recognition has given rise to a large number of empirical studies. The results, however, do not enable one to decide between alternative models of morphological representation and processing. It is argued in this paper that the contrast between pseudoprefixed words and non-prefixed control words can provide an empirical basis for deciding between hypotheses of morphology representation as sublexical or lexical. This contrast has been used in the three lexical decision experiments reported here, which show that decision times for pseudoprefixed words are significantly slower than for non-prefixed control words. This pseudoprefixation effect strongly supports the hypothesis that morphology is coded and processed sublexically during word recognition. The experimental conditions employed allow both strategic and strictly orthographic explanations for the pseudoprefixation effect to be dismissed.

Readers who know and understand the word *morpheme* would certainly understand a word like *polymorphemic* even if they never had encountered it before, probably by deriving its meaning from the meaning of its component parts—*poly-*, *morphem-*, and *-ic*. Moreover, mature readers are often aware of the compounding parts of quite familiar polymorphemic words, such as *unusable*, perhaps because the lexical information that becomes available upon the recognition of the word *unusable* contains information about its morphemic composition in addition to information about its formal, semantic, and syntactic properties. On this basis, the morphemic structure of the word *unusable* could be either automatically accessed together with the other kinds of lexical information or only optionally retrieved as complementary information needed only in certain circumstances. But there is still another possible explanation for this awareness. It might be that the morphemic

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decomposition, operating as a prerequisite for the interpretation of novel forms like *poly-morphemic* is also a preliminary operation for the recognition of even the most familiar polymorphemic words. According to this hypothesis, *unusable* would only be recognized after the entire letter string had been decomposed into its morphemic subunits, *un-*, *-us-*, and *-able*.

The last hypothesis appears to be the least plausible intuitively. Yet it is the one that has given rise to the greatest number of studies on the question of how the internal structure of words is represented in memory and of what this knowledge is useful for. Indeed, in the form of the prelexical morphological decomposition (PMD) hypothesis formulated by Taft and his colleagues (Taft, 1979a, 1981, 1985, 1988; Taft & Forster, 1975; Taft, Hambly, & Kinoshita, 1986), it has played a central role in this field for almost 20 years. The reason probably lies in the strength of two of its basic assertions: that the recognition process for familiar polymorphemic words include a *mandatory* affix-stripping stage and that this stage is a *preliminary* stage of lexical recognition.

This proposal of a preliminary and mandatory affix-stripping stage derives from the assumption that the code used by the visual recognition device to gain access to the lexicon does not correspond to the complete stimulus string but, rather, to the isolable stem in that stimulus string. This does not mean, however, that the entire word must then be integrated by rule during recognition. The PMD model (cf. Forster, 1976) distinguishes two levels of representation—sublexical and lexical—each of which codes information in its own format. Matching between visual and lexical codes takes place at the sublexical level in the "peripheral file", where word-stem representations (more precisely, the first syllable of the stem—see Taft, 1979b, 1985, 1986, 1987; Taft & Forster, 1976) operate as access codes to the subsequent level, the central system or "master file". The procedure used to isolate this access code is left-to-right parsing. Once a satisfactory match is achieved between the stimulus and the access code, complete information for the form is retrieved from the master file where *lexical* representations code all the information about a word's form, meaning, syntax, and so on and where form specification is in a whole-word format.

There is now sufficient evidence to suggest that the morphemic structure of a word is indeed represented somehow or other in the mental lexicon. In lexical decision experiments, nonwords composed of a stem and/or an affix segment give rise to longer rejection latencies than do nonwords composed of a non-stem and/or a non-affix segment (Caramazza, Laudanna, & Romani, 1988; Taft et al., 1986; Taft & Forster, 1975). In priming experiments, shorter recognition time has repeatedly been noted for a target word preceded by a morphologically related prime word (Feldman & Moskovljević, 1987; Forster, Davis, Schoknecht, & Carter, 1987; Fowler, Napps, & Feldman, 1985; Grainger, Colé, & Segui, 1991; Henderson, Wallis, & Knight, 1984; Napps, 1989; Napps & Fowler, 1987; Stanners, Neiser, Hernon, & Hall, 1979; Stanners, Neiser, & Painton, 1979). Finally, in a lexical decision task, the time needed to recognize prefixed (Taft, 1979a) or suffixed (Burani & Caramazza, 1987; Colé, Beauvillain, & Segui, 1989; Taft, 1979a) words has been found to depend on the frequency of occurrence in language of the stem present in these words when the surface frequency (the frequency of the whole form) is controlled for. When the stem frequency is controlled for, a surface-frequency effect is observed (Burani & Caramazza, 1987; Taft, 1979a).

All these observations are consistent with the PMD hypothesis in that they may be interpreted as suggesting that a morphemic decomposition occurs at a stage of processing that isolates a representation corresponding to a morphemic stem unit. They are, however, also compatible with competing models in which word morphology plays a central part in organizing and accessing word representations without requiring *prior* decomposition of the stimulus string. For instance, the augmented addressed morphology (AAM) model proposed by Caramazza and his colleagues (Caramazza et al., 1988; Caramazza, Miceli, Silveri, & Laudanna, 1985; Laudanna, Badecker, & Caramazza, 1989, 1992; Laudanna & Burani, 1985, 1995; Laudanna, Burani, & Cermele, 1994) and what will be called here the "separate-but-related-entries" (SRE) models (Colé et al., 1989; Lukatela, Carello, & Turvey, 1987) both allow word morphology to be retrieved during lexical access, while that access proceeds on the basis of the whole-word form description.

Within the AAM model, the orthographic input lexicon represents entries not for polymorphemic words but only for affixes and stems. However, in addition to this morphemically organized representational level, another representational level operates as an addressing system where the stimulus string is matched by passive and parallel activation of its letters to internal units that code stems and affixes as well as whole-word forms. The code or codes that reach a preset activation threshold first are those used to address the corresponding entries in the orthographic input lexicon. It is further assumed that, for familiar words, the whole-form addressing code reaches this threshold first. In this way, the decomposed addressing procedure, while taking place in parallel with the whole-form addressing procedure, actually contributes to lexical access only when the stimuli are novel or rare affixed words.

As the PMD and the AAM models both assume two distinct representational levels, the former coding words in a morphemic format and the latter in a whole-form format, they are both able to account for the morphemic effects obtained in visual recognition experiments. Longer rejection latencies for morphemically composed nonwords result from interference caused by addressing a stem representation in the access file according to the PMD model or from addressing decomposed lexical entries in the orthographic input lexicon according to the AAM model. Likewise, morphological priming effects may be interpreted within the PMD model as the product of repeated access to a representation—the access code—shared by both the prime and the target words, whereas within the AAM model facilitation originates from activation of the same morphemic entries in the orthographic input lexicon. The stem-frequency and the surface-frequency effects would be localized at one of the two representational levels assumed in both models: the stem-frequency effect at the level coding morphemic units—that is, the peripheral file in the PMD model and the orthographic input lexicon in the AAM model—and the surface-frequency effect at the level coding whole-word units—that is, the master file in the PMD model and the addressing system in the AAM model.

Morphological priming effects and stem-frequency effects can even be accounted for in the context of models that do not assume any level of representation in a morphemic format. Indeed, SRE models assume that word morphology is coded in the internal lexicon in such a way that no decomposed representation is needed (cf. Colé et al., 1989; Feldman & Fowler, 1987; Lukatela et al., 1987; Segui & Zubizarreta, 1985; Stanners, Neiser, Hernon, & Hall, 1979). Beyond their specificity, all SRE models share the idea that affixed words are stored in the lexicon as whole-word forms only and that their morphological structure is reflected—that is, implicitly coded—by the mere organization of the morphological family to which they belong. Accordingly, each affixed word form is stored as a separate entry in the lexicon, but this entry is not completely independent. In fact, the organization is such that the visual processing of a given word accesses a set of candidates corresponding to the morphological family. Morphological priming effects can thus be explained as follows: during the prime presentation, the rise in the activation level of the prime word also raises the activation level of all morphologically related words, which facilitates the subsequent processing of one of these related words. Moreover, if every time a word-unit is activated its activation spreads to all morphologically related units, then the result would be a permanent lowering of the activation threshold for all these related units (or a rise in the rest activation level, depending on the model chosen). In this way, all the units belonging to a given morphological family would eventually "behave" as if they had the same frequency—a mechanism that would lead to stem-frequency effects.[1]

In addition to these theories, which are equally able to account for the morphological effects reported in the literature, there is the morphological race (MR) model (Frauenfelder & Schreuder, 1992), which appears to be less able to accommodate the findings of morphological priming and stem/ surface-frequency effects. Like the AAM model, the MR model assumes that morphologically complex words are accessed via two independent routes that start simultaneously and race in parallel: a direct route that employs access representations of the full word and a parsing route that employs access representations of stems and affixes. But, unlike the AAM model, in which the outcome of the race between the direct access to the full form and access via morphemic constituents is fixed (the direct access is assumed to be faster for all words already encountered), the MR model assumes that it is the surface frequency and the phonological and semantic transparency of a morphologically complex word, its parsability, that determines which route will be faster and win the race for a given presentation of a particular word. Word forms with a high surface frequency and opaque word forms will be recognized by the direct route, whereas the parsing route is more apt to win the race with word forms that are transparent and low in frequency. Typically, these will be word forms containing productive affixes. A further assumption of the model is that the resting activation levels of the access representations of the stem and affix will be increased *only* when the parsing route wins the race. In this way, the activation level of a stem- or affix-access representation is determined only by the number of successful parsings of words with that stem or affix and not by the number of times a word form with this affix has occurred. In such a context, a morphological priming effect would not occur when either the prime or the target word (or both) is of high surface frequency. As a high-frequency word prime would be recognized via the direct route, the resting activation of its stem form will not be increased after prime exposure. Hence, even if the target word, being a transparent and low-frequency form, is accessed by the parsing route, its recognition could not be facilitated

[1] However, modeling surface frequency effects in such a context would require additional assumptions, such as, for example, distinct residual activation effects according to the direct or indirect activation of the unit.

by the prior presentation of the prime. The same holds true if the prime is to be recognized by the parsing route and the target, being of high frequency, by the direct route. Likewise, the stem-frequency effect should emerge only when the parsing route wins the race—that is, for lower-frequency words that are transparent.[2]

Thus, according to the MR model, the morphological priming and the stem-frequency effects should interact with the surface frequency of the target and with the semantic and phonological transparency of the target. I am not aware of a study reporting such interactions. The only experiments I know of in which both the stem frequency and the surface frequency were manipulated are those of Colé et al. (1989), who found no significant interaction between the stem-frequency effect and the word frequency.[3] Moreover, reliable morphological priming effects were observed with phonologically opaque complex words (Marslen-Wilson, Komisarjevsky Tyler, Waksler, & Older, 1994; Stanners, Neiser, Hernon, & Hall, 1979). More generally, the studies reporting morphological priming (e.g. Grainger et al., 1991; Marslen-Wilson et al., 1994; Stanners, Neiser, Hernon, & Hall, 1979; Stanners, Neiser, & Painton, 1979) and stem-frequency effects (Andrews, 1986; Burani & Caramazza, 1987; Taft, 1979a) generally used different kinds of morphologically complex words, including semantically and phonologically opaque words, though they were mainly low-frequency complex words. Finally, some features of the MR model have clearly not been confirmed: surface-frequency effects have been observed for low-frequency complex target words when the stem frequency was held constant (Burani & Caramazza, 1987; Taft, 1979a), and there is no lexical level in the MR model at which this effect could arise.

Morphological studies thus have to deal with the problem of competing hypotheses concerning the access codes used in recognizing complex words. In addition, they cannot ignore the argument that the morphemic effects reported so far are insufficient to reject the hypothesis that word morphology plays no role in word recognition. Two interpretations of morphemic effects have been proposed in this context.

One interpretation is that the morphological processing revealed by these effects is merely an optional operation during word recognition. All words would be represented and directly accessed as whole forms in the lexicon, but representational units in morphemic format, together with regularities that emerge from them (word-formation rules), would be coded in the lexicon as optional (Aitchison, 1987) or supplementary (Butterworth, 1983) information. This information might be used in everyday life when

[2] Furthermore, the strength of this effect is assumed to depend upon both the properties of the target and those of the morphologically related words. As the related words of high frequency should be recognized via the direct route, the resting level of activation of their stem will not be affected by their frequency of occurrence; it will be increased only when the parser recognizes the lower-frequency related words. In other words, high-frequency complex words do not contribute to the activation level of their component morphemes. Therefore, for a stem-frequency effect to arise, not only should the target word be of low frequency and transparent but so should the related words.

[3] Proponents of the MR model might object that the words employed in the high-frequency condition should be viewed as medium-, not high-frequency words (they belonged within the frequency range of the 5000 to 8000 most frequent words of the corpus). The MR model is, however, silent about exactly which frequency range is to be considered as a "high"-frequency range; furthermore, it does not make clear predictions about the outcome of the race for "medium"-frequency complex words.

unfamiliar affixed forms are encountered or when familiar affixed forms are, for one reason or other, temporarily inaccessible—when, in other words, whole-word access fails. The morphemic effects reported would be caused by an overrepresentation of affixed items in the stimulus list that induced subjects to adopt a special procedure of accessing morphological information that is otherwise not accessed (Andrews, 1986; Nagy, Anderson, Schommer, Scott, & Stallman, 1989; Rubin, Becker, & Freeman, 1979). There are data to support this position: Andrews (1986; Experiments 1 and 3) found that stem frequency correlated with decision times for suffixed (derived) words only when they were presented within an experimental list also containing compound words, and Seidenberg (1984; cited by Seidenberg, 1989) found a significant effect of stem frequency on recognition times for prefixed words only when a large proportion of stimuli were prefixed. Note, however, that Burani and Caramazza (1987) found a root-frequency effect for suffixed Italian words presented in an experimental list that included neither any compound words nor a high proportion of derived words.

Another interpretation is that apparent morphemic effects result from the co-occurrence of particular orthographic properties with morphological properties (Seidenberg, 1987, 1989). Given its structure of connections (cf. the McClelland & Rumelhart, 1981, the Seidenberg, 1989, or the Seidenberg & McClelland, 1989, models), the lexical network automatically exploits these particular orthographic properties, referred to by Seidenberg as "orthographic redundancy"—that is, information about the distribution of letter sequences in written language. In particular, there is a general tendency for letters within a prefix (or syllable) to co-occur more often than letters straddling the boundary between the prefix and the stem (or between syllables). Thus, intra-morphemic (or intra-syllabic) bigrams often have a higher frequency in written language than do inter-morphemic bigrams. In this way, the morphemic (or syllabic) structure of words *generally* happens to be "marked" by the presence of a *bigram trough pattern* at the morphemic (or syllabic) boundary. These facts are exploited in such a way by the network that sublexical units corresponding to morphemes (or syllables) may emerge in the course of processing even though no such units are in fact explicitly coded or analysed by the system.

In summary, the various morphemic effects reported to date do not provide a basis for deciding between competing models of morphological representation and processing. The first point these data cannot answer is whether morphology is represented at a sublexical or a lexical level. In the former case, sublexical morphemic representations serve as access codes, which implies a *preliminary* decomposition stage in lexical access (the PMD model and, for some categories of complex words only, the MR model); in the latter, a whole-word access procedure allows retrieval of morphological information, which is either explicitly (as in the AAM model, where lexical entries are coded in a morphemic format) or implicitly (as in the SRE models, where whole-word forms are grouped together along shared morphological properties) coded in the lexicon proper. The second point at issue is whether access to morphological information during word processing results from an *obligatory* or automatic device (the PMD, AAM, and SRE models) or merely an *optional* or strategic one (e.g. Butterworth, 1983) that could be triggered by experimental conditions (Andrews, 1986; Rubin et al., 1979). Finally, uncertainty remains about the actual nature of the morphemic effects observed, as some other confounding factor, correlated with morphological structure, might well be responsible for them (Seidenberg, 1987, 1989).

The present experiments were designed to address these questions by comparing response times in a lexical decision task for pseudoprefixed and control words. Pseudoprefixed words are words that start with a prefix-like string but are not truly prefixed (e.g. *religion*). As pseudoprefixed words are, in fact, monomorphemic words, they will be compared with control words that are also monomorphemic but do not have a potential prefix. In my view, such a comparison could provide evidence regarding the validity of competing hypotheses about the access unit—morpheme, whole-word form, or both—used for recognizing morphologically complex words. These competing hypotheses clearly do make different predictions about the outcome of this comparison. According to the PMD hypothesis, pseudoprefixed words should take longer to process than control words. The reason for this is that the affix-stripping process operates "blindly" with a left-to-right parsing procedure under the PMD hypothesis. It will, therefore, strip the pseudoprefix string, like any true prefix string, in order to isolate the word stem. Of course, the access code for the letter-string remaining after affix-stripping in pseudoprefixed words—the pseudostem—cannot be found in the peripheral file. A second search must then proceed on the basis of the whole stimulus representation, which will cause a processing delay.[4] In contrast, if familiar complex words were accessed via whole-word form access units (as is held by the SRE models) or even via both whole-form and morpheme access units (as in the AAM and MR models), no time cost would be incurred in lexical access by pseudoprefixed words. These words, being monomorphemic, would be accessed like any other monomorphemic word.

Rubin et al. (1979) also measured the time cost of pseudoprefixation in their experiments, but they used truly prefixed words instead of monomorphemic words as the control condition. However, comparing pseudoprefixed and prefixed words is not likely to enable one to decide between competing access hypotheses.[5] The observation that prefixed words are recognized faster than pseudoprefixed ones could be accounted for by two properties being intermingled within the contrast tested. First, a prefixed word contains more morphemes than does a pseudoprefixed word. Thus, proponents of the AAM or the SRE models might argue that more morphemic entries, or more word units, would be activated in the presence of prefixed words and that this is why their recognition is facilitated by comparison to pseudoprefixed words. Second, access time for prefixed

[4] I would stress that only *pseudoprefixation* and not *pseudosuffixation* could constitute a critical test for the PMD hypothesis. As affix-stripping is assumed to operate via a left-to-right parsing procedure, it will terminate as soon as a stem is located—thus before any suffix is encountered. Therefore, pseudosuffixation would not be expected to cause any temporal delay in processing.

[5] In addition, the pseudoprefixed/ prefixed word comparison is problematic as a test of the PMD hypothesis. According to this hypothesis, prefixed words are recognized after the following steps: (1) strip off the prefix; (2) search for the stem in the peripheral file; (3a) test whether the prefix + stem form is represented in the master file. The operations needed for the recognition of pseudoprefixed words would be, once Step (2) has failed, the following: (3b) search for the whole form in the peripheral file; (4) search for this code in the master file. As the time needed to perform Steps (3a) and (3b) is unknown, it is difficult to draw rigorous temporal predictions from this contrast. However, pseudoprefixed words involve the same decisions about the same tests as do other monomorphemic words (3b and 4) plus two extra tests (1 and 2).

words might well be influenced by the stem frequency, which is, of course, higher than the surface frequency. Shorter access times for prefixed words may thus reflect a stem-frequency effect rather than a pseudoprefication effect, and the former is interpretable within a lexical system that does not include any morphemically decomposed access units or representation.[6] On the contrary, if only monomorphemic words are involved in the comparison, one could avoid any lexical effects that may be due to these two factors (the number of morphemes in the word and the stem frequency). Thus, if a pseudoprefixation effect occurs in such conditions, one could dismiss any whole-word access explanation proposed in the context of the AAM or SRE models.

Furthermore, the pseudoprefixation test could also decide whether access to decomposed forms is optional or mandatory if the likelihood of strategic effects induced by the composition of the stimulus list is manipulated. If affix-stripping were merely an optional device and whole-word access were instead usual, pseudoprefixed words would incur a time penalty only when affix-stripping is likely to constitute an efficient strategy for the task, as would be the case in a stimulus list saturated with prefixed words.

Two previous studies tested the time cost of pseudoprefixation against control words that were also monomorphemic words, in a lexical decision task. The findings were, however, contradictory. Henderson et al. (1984; Experiment 2) found no evidence for a pseudoprefixation cost in English, whereas Bergman, Hudson, & Eling (1988; Experiment 1) did find longer processing times for Dutch pseudoprefixed words in comparison with other monomorphemic words.[7] There are many possible reasons for these contradictory results, apart from the fact that they were obtained from different languages. First of all, a number of lexical and orthographic properties such as syntactic category, frequency of the initial letter string, initial orthographic structure, sequential frequency of bigrams, and prefix productivity were not controlled in these experiments, so they may well not be comparable. For example, it is unclear whether the material was comparable as regards the number of pseudoprefixed words starting with a string that was homographic with a productive or a non-productive prefix. This factor might interact with pseudoprefixation. As productive prefixes are more likely to be represented as independent units in the lexical system than are non-productive prefixes (for justification, see, for example, Baayen, 1994; Pillon, 1993), letter strings corresponding to a productive prefix are more likely to be stripped during lexical access. Second, the two experiments are not comparable as regards the composition of the stimulus list. In the experiment by Henderson et al., the

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[6] In an attempt to control this potential stem-frequency effect in a lexical decision task (Experiment 1) and in a naming task (Experiment 2), Taft (1981) used prefixed words whose stems did not appear in other prefixed words (e.g. *intrigue, replica*). In both tasks, he found longer processing times for pseudoprefixed words than for prefixed words. However, several authors have been reluctant to consider these words as true prefixed words (Henderson, 1985; Henderson et al., 1984; Smith, Meredith, Pattison, & Sterling, 1984), as they do not conform to the usual operational criterion for deciding whether or not a word is prefixed—that is, that the putative stem enters in the formation of at least one other word.

[7] Taft (1981; Experiment 3) also obtained a pseudoprefixation effect with monomorphemic control words, but it was in a naming task. It is not clear, therefore, which of the various components involved in the naming task (visual input lexicon or phonological output lexicon) was responsible for the pseudoprefixation effect obtained. Furthermore, no attempt was made in this experiment to control the regularity of spelling–sound correspondences.

proportion of potentially prefixed items (prefixed or pseudoprefixed words and nonwords) in the stimulus list was 28%, whereas Bergman et al. found a pseudoprefixation effect when three context conditions were combined—namely, conditions where the stimulus list contained 100%, 50%, and 25% of potentially prefixed items. Bergman et al. did not report statistical results for the Pseudoprefixation × Context Conditions interaction, but the pseudoprefixation effect in the 100% condition was almost double that in the 25% condition. Finally, one may add that Henderson's material contained only 10 items per condition, which might be responsible for the negative outcome.

Moreover, the failure to match pseudoprefixed and control words against other variables may have yielded false positive or false negative results, depending on the variables involved. Thus syntactic category (and concreteness, which might be correlated with it) might be confused with the contrast tested. As pseudoprefixed words might be less often concrete nouns than are the control words, they may require longer decision times (for the role of semantic factors in lexical decisions, see Chumbley & Balota, 1984; Jastrzembski, 1981; Seidenberg & McClelland, 1989; Whaley, 1978). Initial consonant/vowel patterns might also be confused with the contrast tested. For instance, pseudoprefixed words are more likely to start with relatively infrequent C/V patterns than are control words. According to Smith (1988), infrequent initial C/V patterns might disrupt syllabic or higher-level non-morphological parsing processes and thus slow down recognition times. In addition, he found that the pseudoprefixation effect reported by Taft (1981; Experiment 1) was no longer significant when this factor (with the four levels: C–C–V, V–C–V, V–C–C, and C–V–C) was added as a covariate in an analysis of covariance. Finally, a pseudoprefixation effect might be an artefact of the presence of a bigram-trough pattern at the pseudoprefix/pseudostem boundary, which would cause a pseudoprefix unit to emerge in the course of recognition without it being coded in the mental lexicon (cf. Seidenberg, 1987, 1989). On the other hand, the failure to match the frequency of initial strings present in the pseudoprefixed and the control words may result in a negative outcome for the pseudoprefixed test. The initial strings of pseudoprefixed words (i.e. prefix-like strings) are generally more familiar than are the non-prefix-like strings present in other monomorphemic words. The frequency of an initial bigram might influence the speed of response in a lexical decision task, either at the level of the decision processes (because the perceived familiarity of the stimulus may lower the decision criterion; cf. Balota & Chumbley, 1984) or at the level of the recognition process itself (cf. Taft, 1979b, 1985, 1987; Taft & Forster, 1976). Accordingly, a delay in the recognition of the pseudoprefixed words could not be detected because, in another respect, recognition or decision processes would be facilitated by prefix-like bigrams being more familiar than non-prefix-like bigrams.

In the three experiments reported in this paper, an attempt was made to match the pseudoprefixed and the control words against the syntactic category, the frequency of the first bigram, and the initial consonant/vowel pattern. In the first experiment, the conditions were designed to measure the possible effects of the stimulus-list composition on the emergence of a pseudoprefixation time cost. As a pseudoprefixation cost was obtained in this experiment, the second one sought to ascertain whether it was the result of the presence of a bigram-trough pattern at the pseudomorphemic boundary, which some authors (Seidenberg, 1987, 1989; Seidenberg & McClelland, 1989) have argued is responsible for all apparent morphemic effects. The third experiment was intended to replicate the findings of the other two with experimental conditions that were the least favourable for the emergence of a pseudoprefixation effect.

The pseudoprefixed words used in these experiments were selected from French words with one of three prefix-like strings: *dé*, *re*, and *in*. The choice of such a restricted set of initial strings reduces the generalizability of the results, but the aim of the experiments was not to search for evidence that could apply to *all* kinds of prefixes. As Laudanna and Burani (1995) emphasized, prefixes do not constitute a homogeneous class, and theoretical proposals, as well as experimental research, should consider their diversity. A conglomerate of characteristics such as affix length, frequency, and productivity and the ratio between truly prefixed and pseudoprefixed words for a given prefix-like string might influence the likelihood of linguistically defined prefixes being represented as access units. Although it was beyond the scope of this study to find out which characteristics are relevant for a prefix to act as a processing unit, the issue could not be ignored. Hence, I chose to test competing access hypotheses with a restricted set of prefix strings presenting a number of common characteristics, so that the significance of the findings could be evaluated more specifically. The three prefix-like strings selected present the following characteristics: (1) they are two letters long; (2) they are homographic with a productive French prefix, productive prefixes being defined as those that are part of a word-formation rule that is currently used by French speakers for coining new complex words[8]; (3) these initial strings are more often present in truly prefixed words than in pseudoprefixed words, the percentage of truly prefixed word types relative to the total number of prefixed and pseudoprefixed word types containing a given initial string, as evaluated by two independent raters, being 59–72% for *dé*, 61–68% for *re*, and 56–57% for *in*.[9]

EXPERIMENT 1

This first lexical decision experiment applied the test that I have argued is critical for the PMD hypothesis—namely, the time cost of pseudoprefixation. Its purpose was twofold: to measure the pseudoprefixation cost in more controlled conditions than in the experiments of Henderson et al. (1984) and Bergman et al. (1988), and to look at the possible interaction of the pseudoprefixation effect with the list composition by presenting sub-

[8] No empirical measure has been applied to distinguish between productive and non-productive word formation rules. However, there is a general agreement among French linguists and lexicographers on considering *dé-*, *re-*, and *in-* among the prefixes the most often used by French speakers to coin new words (see, for example, the extensive linguistic study of the French derivational morphology by Corbin, 1987; see also the lexicographic studies on French neologisms by Clémenceau, 1992; Dugas, 1990, 1992; Goose, 1975). The other French productive prefixes are Greek and Latin particles such as *extra-*, *super-*, *ultra-*, *archi-*, *hyper-*, *pré-*, *post-*, *mini-*, *maxi-*, *micro-*, *macro-*, *pseudo-*, *néo-*, *inter-*, and *mono-*, and prefixes such as *sur-* and *sous-*, which can also be free prepositional forms. As these strings are nearly always used in written French words with a hyphen between them and the lexical root to which they are attached, they obviously could not be used in the experiments. Furthermore, there are virtually no words bearing these strings that could be unambiguously classified as a pseudoprefixed word.

[9] These estimates were performed by Rohr & Pillon (1996), on the basis of the approximately 36,000-word database BRULEX (Content, Mousty, & Radeau, 1990). The total number of word types sharing the initial strings *dé-*, *re-*, and *in-* was 1214, 682, and 1251, respectively.

jects with the same critical words in two experimental conditions. In the "non-prefixed" condition, the critical words were presented within a stimulus list composed and ordered so as to prevent, or at least to render useless, any strategic decomposed-access procedure. Conversely, the stimulus list used in the "prefixed" condition was composed and ordered so as to favour a decomposed-access procedure.

Method

Subjects

Seventy volunteer subjects from the Université de Mons-Hainaut (Belgium) took part in the experiment. All were native French speakers.

Stimuli and Design

Thirty-six experimental words were selected, of which half were pseudoprefixed and half were controls. The 18 pseudoprefixed words (e.g. *dégoter, recruter*) were words with the prefix-like bigrams *dé* or *re*. The letter-strings occurring after this pseudoprefix had all the properties of a pseudostem—that is, (1) it did not have any meaning; (2) it was not homographic with a real stem; (3) it did not appear in any other prefixed or pseudoprefixed word. The 18 control words (e.g. *capoter, modérer*) were words whose first bigram was not a prefix-like string. The pseudoprefixed and control words were selected in pairs, so that the two words of a given pair were as similar as possible in lemma frequency (i.e. the summed frequency of all the inflected forms of a given word) and in letter and syllable length. The mean lemma frequencies of the pseudoprefixed and control words were, respectively, 206 and 197 (*Trésor de la langue francaise*, 1971),[10] a non-significant difference ($t < 1$). The mean letter length was 7.7 for the pseudoprefixed words and 7.6 for the control words (all words were between 6 and 9 letters and 3 syllables long), again a non-significant difference ($t < 1$).

The mean root frequency of the pseudoprefixed and control words was checked a posteriori, as it might also affect the response times in the lexical decision task (see, for example, Burani & Caramazza, 1987; Colé et al., 1989; Taft, 1979a). The root frequency for each experimental word was calculated by summing the lemma frequency of all the words sharing the same root; the obtained values were then submitted to a logarithmic transformation (*log* root frequency). It turned out that the mean *log* root frequency for the pseudoprefixed (mean = 2.67; *SD* = 0.77) and the control words (mean = 2.63; *SD* = 0.55) were very close to each other and that the difference was far from being significant ($t < 1$). In order to control the syntactic category, all the pseudoprefixed and the control words were verbs in the infinitive or the past participle form.[11]

[10] All the word-frequency values reported in this paper are given per 100 million. They correspond to the values reported in the *Trésor de la langue française* (1971) for the text corpus of the second half of the twentieth century. This corpus contains 23,505,451 word tokens and 71,125 word types.

[11] The surface frequency of the whole-word forms could not be controlled for the pseudoprefixed and the control words, because the frequency values for individual inflected forms are not available in French (the *Trésor de la langue française*, which is the only reliable frequency count that is available for French words, is a lemma-based frequency count). In order to circumvent this difficulty, only infinitive and past-participle forms were used for both the pseudoprefixed and the control words. Infinitive and past-participle forms are among the most frequent inflected forms of a verb; the lemma frequency of a verb might be viewed, therefore, as a good approximation of the frequency of its infinitive or past-participle form. Moreover, it seems reasonable to assume that there is no systematic difference between pseudoprefixed and other monomorphemic verbs as to the actual ratio between the frequency of the infinitive/ past-participle form of the verb and the cumulative frequency of all its inflected forms.

The control words were chosen so that their first bigram was among the most frequent initial bigrams in French (*ma, ca, pa, ba,* and *mo*). For bigram frequencies, the tables of Content and Radeau (1988) were used, and the *textual* frequency of bigrams occurring in initial word position was considered. (In these tables, the textual frequency reported for a given bigram in the initial, medial, and final word positions corresponds to the summed frequencies of all the words containing the given bigram in the given position divided by the total number of word tokens in the corpus and multiplied by 100,000.[12]) The mean textual frequency was 986 ($SD = 221$) for the prefix-like initial bigrams and 1257 ($SD = 759$) for the non-prefix-like initial bigrams, a non-significant difference, $t(19.86) = 1.46$, two-tailed, $p > .1$. Moreover, I matched the initial spelling patterns across the pseudoprefixed and the control words by selecting only words with an initial C–V–C string. However, the initial spoken syllabic pattern was not perfectly matched for the pseudoprefixed and the control words. All the pseudoprefixed words contained an initial C–V syllable, whereas only 13 out of the 18 control words presented this initial C–V syllabic pattern; the 5 remaining control words presented a C–V–C initial syllable.[13] Finally, the overall orthographic redundancy of the experimental words was checked a posteriori. It was indexed by calculating the geometric mean of the textual frequencies of all the bigrams composing a word. The textual frequency for each bigram was taken from Content & Radeau's tables in function of word position (initial, medial, or final). On average, the pseudoprefixed words had a lower orthographic redundancy (mean = 500; $SD = 215$) than did the control words (mean = 617; $SD = 325$), but this difference was not significant, $t(34) = 1.27$, two-tailed, $p > .1$.

Two lists were constructed by mixing the 36 experimental words with different kinds of filler items in function of the access procedure to be induced. In the first list ("non-prefixed" condition, NP), 110 filler monomorphemic words (of various frequencies, lengths, and syntactic categories) were mixed with the 36 experimental words. In the second list ("prefixed" condition, P), 110 prefixed filler words were mixed with the same 36 experimental words. Note that, in previous studies, the composition of the list was likely to facilitate the processing of the prefix-like strings because the same prefix-like strings were repeated in various prefixed or pseudoprefixed words and nonwords (conversely, the initial bigrams of control words were generally not). In order to control for this possible bias, only filler words (monomorphemic and prefixed) whose initial bigram differed from the initial bigrams of experimental words were selected. Furthermore, 8 monomorphemic words starting with strings present in control words (*ca, ma, pa*) were added to each of the two lists. This addition was sufficient for the experimental words in the list to be arranged so that the pseudoprefixed and the control word of a given pair was *preceded* by the same number of stimuli starting with an identical prefix-like or non-prefix-like bigram.[14] The addition of the 8 monomorphemic words starting with *ca, ma,* or *pa* led to another one—that is, 8 filler pseudoprefixed words (whose first bigram was *in*), in order to equalize the number of pseudoprefixed and other monomorphemic words in the list.

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[12] In order to estimate the frequency of occurrence of bigrams in French texts, Content & Radeau considered the 30,000 word entries of the *Micro Robert* (Robert, 1986) dictionary and their corresponding frequency of occurrence in French texts as reported in the *Trésor de la langue française* (1971).

[13] In all instances but one (*mandater*), the initial spelling pattern was congruent with the initial syllabic pattern—that is, the C–V initial syllabic pattern corresponded to a C–V spelling string (e.g. *délirer, capoter*), and the C–V–C initial syllabic pattern was spelled with a C–V–C spelling string (*mastiquer*). In the control word *mandater,* the first C–V syllable (/ mɑ̃/) was spelled with a C–V–C string (*man*).

[14] By so doing, the experimental list did not include the same number of instances of each prefix-like bigram and each control bigram. Indeed, the purpose was not to control for the overall probability of encountering one or another bigram. Instead, the purpose was to control for the repetition effect produced by the *prior* presentation of a stimulus bearing a given initial bigram on the *subsequent* recognition of a stimulus bearing an identical initial bigram. Controlling for this potential bias does not require, and is not necessarily achieved by, the presentation of the same proportion of the different initial bigrams.

In this way, the NP list and the P list both comprised 162 words with which were mixed 162 nonword items, which were made up by changing two or three letters in the middle of the 162 word items. Therefore, the total number of items was 324 in each list. The NP list consisted of 272 items (136 words and 136 nonword items) that did not have a potential prefix, and 52 items (26 pseudoprefixed words and the 26 corresponding nonwords) starting with a prefix string. In contrast, the P list consisted of 52 items with no potential prefix (26 word and 26 nonword items) and 272 items starting with a prefix string (210 of which were truly prefixed words and their corresponding nonwords). Thus 84% of the items in the NP list did not have a prefix-like string, and none was a truly prefixed word; conversely, 84% of the items in list P did have a potential prefix.

Both the NP and the P lists were split into two sub-lists of 162 items. Each sub-list contained half of the items from each category (pseudoprefixed and control words, filler words and nonwords). The items were arranged in these sub-lists in a pseudorandomized order, with the following constraints. First, in order to prevent a practice effect occurring differently on pseudoprefixed and control words, each sub-list was divided into 9 fictive blocks, with a pair of experimental words (a pseudoprefixed and a control word) in each block. Second, as already noted, the potential bias arising from a repetition effect of the initial bigram was countered by inserting before the pseudoprefixed word and the control word of a given pair an equal number of items starting with the same prefix-like and control bigram as those present in the pair. For example, the pseudoprefixed/control word pair *dénigrer*/*camoufler* was placed in the list after 5 stimuli starting with *dé* and 5 stimuli starting with *ca* had already been presented (see an extract of the experimental list in Appendix A). Third, an attempt was made to maximize the potential effect of list composition: (a) the first 24 items in the two NP sub-lists were non-prefixed items, and the first 24 items in the two P sub-lists had a prefix-string (as were the 10 practice items preceding each of the sub-lists); (b) in the NP sub-lists, each pseudoprefixed word was preceded by at least 11 non-prefixed items; conversely, the same pseudoprefixed words in the P sub-list were preceded by at least 11 items with a prefix string. Finally, there were no more than 4 words or 4 nonwords in succession in a sub-list.

The subjects were randomly divided into two groups of 35 subjects each. One group received the two NP sub-lists and the other the two P sub-lists. The order of sub-lists in a given group was identical for all the subjects. Once the first sub-list had been completed, a 10-min rest period was allowed before the next one was presented.

Procedure and Apparatus

The subjects were run individually in approximately 45-min sessions. The stimuli were presented in lower case on a black-and-white video display unit controlled by an IBM personal computer. The subjects were instructed to decide, as quickly and as accurately as possible, whether or not the letter string was a word. They were told to respond by pressing one of the two buttons of a mouse with their preferred hand. They had to press the button labelled "OUI" [yes] if the letter string presented was a word and the button labelled "NON" [no] if it was not a word. The label "OUI" was set on the button for the index finger (i.e. on the left button for right-handed subjects and on the right button for left-handed subjects), and the label "NON" on the button for the middle or third finger.

The experimental sequence was as follows. At the beginning of the experimental sequence, a fixation point (*) was presented at the centre of the screen for 500 msec together with a warning tone. After a 500-msec blank interval, the item was presented in the centre of the screen until the subject responded. If the response was wrong, the feed-back message "*Erroné*" [error] appeared for 1 sec at the bottom of the screen; if the response was given after a preset time limit of 1800 msec, a message

"*Plus vite*" [faster] also appeared for 1 sec. No message was displayed for correct responses. The interval between the disappearance of the item (or of the feed-back information) and the warning tone for the following trial was 2800 msec.

Results and Discussion

The mean response times and percentages of errors for the two types of experimental words (pseudoprefixed and control words) in the two list conditions (NP and P) are given in Table 1. (The results on individual word stimuli are given in Appendix B.) Analyses of variance, by subjects and by items, were carried out only on the correct response-time data. On average, the pseudoprefixed words were responded to 60 msec more slowly than were the control words, and this main effect was significant, $F_1(1, 68) = 54.3$, $MS_e = 2141$, $p < .001$; $F_2 = (1, 34) = 4.7$, $MS_e = 13{,}772$, $p < .05$. The words were responded to 20 msec slower in the "prefixed" than in the "non-prefixed" list, but the main effect of list composition was not significant, $F_1(1, 68) < 1$, $MS_e = 27{,}978$; $F_2(1, 34) = 1.93$, $MS_e = 3688$, $p > .1$. The interaction between the type-of-word and the list-composition effects reached significance only in the subject analysis, $F_1(1, 68) = 4.57$, $MS_e = 2141$, $p < .05$; $F_2(1, 34) = 1.61$, $MS_e = 3688$, $p > .1$. Decomposing this significant interaction effect by performing separate ANOVAs by condition revealed a significant effect of the type of words both in the "non-prefixed" condition, $F(1, 34) = 25.16$, $MS_e = 1165$, $p < .001$, and in the "prefixed" condition, $F(1, 34) = 31.03$, $MS_e = 3117$, $p < .001$.

The results of this experiment indicate that pseudoprefixed words do indeed generate a processing delay in lexical access, whether or not they are embedded in a stimulus list favouring a decomposed access procedure. The magnitude of the slowing tended to increase when pseudoprefixed words are interspersed among many prefixed items, but this trend turned out to be non-significant in the item analysis. This non-significant trend suggests that only *some* pseudoprefixed words were responded to more slowly in the "prefixed" than in the "non-prefixed" condition. One explanation for this pattern of results could be that some pseudoprefixed words were very low-frequency words and that the "prefixed" versus "non-prefixed" condition was a between-subjects factor. It might be that some low-frequency pseudoprefixed words happened to be less familiar to the

TABLE 1
Mean Response Times in Msec and Error Percentages for Pseudoprefixed and Control Words According to List Composition (Experiment 1)

	"Non-prefixed" List		*"Prefixed" List*		*Mean*		*Δ (List effect)*
	M	*%*	*M*	*%*	*M*	*%*	
Pseudoprefixed words	823	3	861	5.4	842	4.2	−38
Control words	781	1.6	783	2.2	782	1.9	−2
Mean	802	2.3	822	3.8	812	3.1	−20
Δ (Pseudoprefixation effect)	+42		+78		+60		

"prefixed" subject group than to the "non-prefixed" subject group. Another explanation, which would not exclude the first, could be that an interference effect was generated by the structure displayed by the great majority of the nonwords presented in the "prefixed" list. Note that these nonwords were made up by changing two or three letters *in the middle* of the words presented in the same list. The prefixed nonwords made up from prefixed words often happened, therefore, to be analysable as a "prefix + string that was not a real root"—which, in fact, parallels the structure of the pseudoprefixed *words*. Thus, when presented with a stimulus displaying the "prefix + not-root string" structure, the subjects had to respond "NO" in the great majority of cases (there were 136 such prefixed nonwords against 26 pseudoprefixed words in the "prefixed" list). This might have caused some hesitation or an additional control procedure before a "YES" response to *some* pseudoprefixed words—especially to the less familiar ones—was given.

Although this potential interference effect certainly deserves further investigation, it does not weaken the observation of a 42-msec pseudoprefixation cost with a stimulus list that does not favour a decomposed-access strategy at all. In order to evaluate the robustness of this observation, the pseudoprefixation test was reapplied in the next experiment (Experiment 2) by presenting the subjects with a stimulus list containing no prefixed items at all.

Seidenberg (1987, 1989; Seidenberg & McClelland, 1989) have argued that what have been taken as "morphemic effects" were in fact artefactual effects resulting from the co-occurrence of particular orthographic properties with morphological properties: the morphemic structure of words generally happens to be "marked" by the presence of a bigram-trough pattern at the morphemic boundary. Thus the question is whether the pseudoprefixation effect observed in Experiment 1 can be attributed to systematic confusion between pseudoprefixation and the presence of a trough pattern at the pseudoprefix/ pseudostem boundary—a pattern that would have led to isolation of a sublexical unit corresponding to a pseudoprefix in the course of processing. However, how could a recognition mechanism that does not manipulate any morphemically defined units be slowed down because a sublexical unit corresponding to a pseudoprefix happens to emerge during processing? The answer is not at all clear, and Seidenberg himself did not consider the question. While he stressed, for example, that "prefixes should tend to act as processing units because of their orthographic properties" (Seidenberg, 1987: 260), he did not specify which particular effect prefixes acting as "processing units" should be expected to produce on recognition times. What the effect produced by the emergence of a sublexical unit corresponding to a *pseudoprefix* would be is thus even more unclear.

One possibility is that the pseudoprefixation cost results from interactive inhibitory activation occurring between the semantic system and the word-form level (corresponding to sublexical and lexical form units) before recognition. Such an "orthographic/ semantic" interpretation would require the assumption that some semantic information can come into play *before* lower-level recognition is complete. In such a processing context, the pseudoprefixation cost could be described as follows. Given a pseudoprefixed stimulus (e.g. *détecter*) whose pseudoprefix/ pseudostem boundary is marked by a bigram trough, the network will work so that a sublexical unit corresponding to the pseudoprefix (*dé*) emerges. The activation of this sublexical unit will perhaps then favour the partial activation of a set of "*dé*" words, and one can expect that a majority of them will be truly prefixed words (e.g. *déboucher*, *décoller*, and *dégarnir*). As many morphological relatives (all sharing the same prefix *dé*) will then be active, some common semantic specification, such as the semantic representation for the prefix *dé*, could then be retrieved from the semantic system *before* the recognition process is complete—that is, before the target pseudoprefixed word is finally identified. (Note, however, that it is not at all certain that a recognition device that does not systematically exploit morphological structure would be able to address semantic representations corresponding to morpheme units.) This semantic information would then contradict the semantic specifications attached to the target word, which would, in turn, inhibit and slow down the final selection of its form representation.

There is another way to conceive the pseudoprefixation effect as possibly artefactual that does not call for high-level interactive processes. One can assume that the emergence of sublexical units (such as syllables, which are relevant for word pronunciation) facilitates and speeds up the recognition of a given unit. With this hypothesis, the apparent pseudoprefixation effect obtained in Experiment 1 could have originated from the first syllabic boundary being accidentally less marked in the pseudoprefixed than in the control words. The artefact would be produced, in this case, by systematic confusion between pseudoprefixation and the *absence* of a trough pattern at the first syllabic boundary.

In fact, the nature of the material used in Experiment 1 makes it unlikely that the results were produced by a systematic confusion of the pseudoprefixation and the presence of a trough pattern at the pseudomorphemic boundary: only 7 out of the 18 pseudoprefixed words had such a pattern (for the criteria applied for considering a trough pattern being present at a given boundary, see the Method section of Experiment 2). It would be also difficult to ascribe the slowing down of responses for pseudoprefixed words to the first syllabic boundary (which coincides with the pseudomorphemic boundary) being less often marked in pseudoprefixed than in control words: only 10 of the 18 control words had this pattern at the first syllabic boundary. Nonetheless, the pseudoprefixation effect proved reliable across stimuli (cf. the ANOVA by items). Furthermore, the material used in this experiment contained several pseudoprefixed words of which the recognition, according to an "orthographic/ semantic" interpretation, would not be slowed down: 8 of the 18 pseudoprefixed words selected had a prefix-like string that could be given a semantic interpretation consistent with the meaning generally attached to the corresponding true prefix form (e.g. *défalquer*, *dégoter*, and *déglingué*). Nonetheless, once again, the pseudoprefixation effect was reliable across stimuli.

Still, these observations are too indirect to count against a strictly orthographic view of apparent morphological processing. This view, at least as developed by Seidenberg (1987, 1989; Seidenberg & McClelland, 1989), was therefore subjected to an empirical test in Experiment 2.

EXPERIMENT 2

This experiment sought to replicate the basic finding of Experiment 1, that the processing of pseudoprefixed words is delayed in comparison to other monomorphemic words even when the experimental conditions do not favour a decomposed-access procedure. In this experiment, the critical stimuli were presented in a stimulus list that contained no prefixed words at all.

The other purpose of this experiment was to address the following question: Do pseudoprefixes act as processing sublexical units because of the orthographic pattern they generally display or, instead, because prefixes, of which they are homographs, are sublexical units coded and manipulated by the visual access system to the lexicon? The specific claim submitted to empirical test is the one made by Seidenberg (1989: 98): "'prefix stripping' should occur when the boundary between prefix and stem is marked in the orthography . . . but not if it is not. Thus, readers are not obliged to strip prefixes and search for stems, but these units may emerge under some circumstances." A clear prediction can be extracted from this claim: "This view would be shown to be incorrect if it were the case that . . . other units affect processing whether they are marked by orthographic redundancy or not" (Seidenberg, 1987: 260). Therefore, in this experiment the pseudoprefixation test was reapplied by also manipulating the bigram-trough pattern at the critical boundary—that is, at the pseudomorphemic boundary in the case of pseudoprefixed words and at the first syllabic boundary in the case of control words. If, as Seidenberg claimed, only the presence of a bigram trough at the pseudomorphemic boundary will cause sublexical units such as pseudoprefixes to emerge in the course of processing, then one would expect to find a pseudoprefixation effect whenever and only whenever pseudoprefixed words display this pattern.

Method

Subjects

Thirty-two subjects from the Université catholique de Louvain (Belgium) took part in this experiment. They were either volunteers or undergraduate students participating to fulfil a course requirement. All were native French speakers.

Stimuli and Design

Sixty experimental word stimuli were selected, half being pseudoprefixed words and the other half control words. The pseudoprefixed words had the prefix-like initial bigrams *dé* or *re* but were not truly prefixed words (the criteria used were identical to those in Experiment 1). Half of them (15) had a bigram-trough pattern at their first syllabic boundary, which coincides with the pseudomorphemic boundary; the other half did not. The control words did not have any prefix-like bigram but commenced with one of the bigrams *ca*, *fa*, *ma*, *mo*, *sa*, *to*, or *vo*, which are frequent initial bigrams in French. Half of these control words (15) also had a bigram-trough pattern at their first syllabic boundary, whereas the other half did not.

The following criteria were applied for considering a bigram trough to be present or absent at the first syllabic boundary (which was also a pseudomorphemic boundary in the case of pseudoprefixed words). In the Content–Radeau (1988) tables, the textual frequency listed for initial bigiams was used to index the first bigram frequency and the textual frequency listed for mid-position bigrams to index the next bigrams' frequency. I considered the first syllabic boundary to be marked by a bigram trough when the bigram straddling the syllabic boundary was of lower frequency than the previous bigram *and* of lower frequency than the following one. Thus, for example, in the pseudoprefixed word *délirer*, the three critical bigrams *dé*–/ –*él*–/ –*li*–, that is, the bigrams surrounding the first syllabic and pseudomorphemic boundary, have a frequency sequence of 815/ 70/ 595. The same pattern is found at the first syllabic boundary of the control word *modeler*, where the frequencies of *mo–/ –od–/ –de–* are 1426/ 76/ 353. In these two instances, the word was considered to have a "marked" first syllabic boundary. Conversely, when the bigram straddling the first syllabic boundary was higher in frequency than the previous one or than the next one or than both, the word was considered to be "unmarked" as to its first syllabic boundary. An unmarked first syllabic boundary is present, for example, in the pseudoprefixed words *renifler*, whose *re–/ –en–/ –ni–* frequency pattern is 1255/ 2700/ 641, and *dégoter*, whose *dé–/ –ég–/ –go–* frequency pattern is 815/ 99/ 38, and in the control words *maniéré*, whose *ma–/ –an–/ –ni–* frequency pattern is 1679/ 2448/ 641, and *macérer*, whose *ma–/ –ad –cé–* frequency pattern is 1679/ 335/ 24.

The two independent variables (i.e. initial bigram and pattern at the first syllabic boundary), each having two levels (pseudoprefixed/ control and marked/ unmarked), led to the selection of four sets of 15 experimental word stimuli. These stimuli were designed in quadruplets (each containing a word from each set), so that the words in a given quadruplet were as similar as possible in lemma frequency (*Trésor de la langue française*, 1971) and letter length. The mean lemma frequency of the marked pseudoprefixed and the marked control was 239 and 232, respectively ($t < 1$); for the unmarked pseudoprefixed and the unmarked control, it was 258 and 219 ($t < 1$). The mean letter length in the marked condition was 7.7 for the pseudoprefixed words and 7.6 for the control words ($t < 1$); in the unmarked condition it was 7.9 for the pseudoprefixed words and 7.8 for the control words ($t < 1$). The mean textual frequency of the initial bigram (cf. Content & Radeau, 1988) was 903 and 1089 for the marked pseudoprefixed and control words, respectively, $t(17.6) = 1.35$, two-tailed, $p > .1$; it was 1050 and 1265 for the unmarked pseudoprefixed and control words, $t(21.9) = 1.78$, two-tailed, $p < .1$.

All the experimental words began with a C–V–C spelling string. All the pseudoprefixed words and the majority (26/ 30) of the control words had a C–V initial syllabic pattern; four control words had their first syllable corresponding to a C–V–C pattern. In all instances but one (*mandater*), the initial spelling pattern was congruent with the initial syllabic pattern—that is, the first C–V syllable was spelled with a C–V string, and the first C–V–C syllable was spelled with a C–V–C string.[15] All the experimental words were verbs in the infinitive or the past participle form.

The mean *log* root frequency was checked a posteriori for the pseudoprefixed and control words and was not significantly different for the two word categories. The mean *log* root frequency for the marked pseudoprefixed and control words was 2.67 ($SD = 0.74$) and 2.87 ($SD = 0.41$), respectively, $t < 1$; the mean *log* root frequency for the unmarked pseudoprefixed and control words was 2.71 ($SD = 0.79$) and 2.91 ($SD = 0.48$), respectively, $t < 1$. The overall orthographic redundancy (indexed by the geometric mean frequency of all the bigrams composing the target word) was also checked a posteriori. The mean value of this index was 531 ($SD = 233$) for the marked pseudoprefixed words and 639 ($SD = 188$) for the marked control words, which difference was not significant, $t(28) = 1.41$, two-tailed, $p > .1$. As for the unmarked words, the mean orthographic redundancy was 531 ($SD = 240$) and 613 ($SD = 274$) for the pseudoprefixed and the control words, respectively, and this difference was also not significant, $t < 1$.

Ninety-nine filler-word stimuli were mixed with these 60 experimental-word stimuli. None of these filler-word stimuli had a potential prefix. They were of various frequencies, lengths, and syntactic categories. Some of them were selected in order to balance the number of first bigram repetitions between pseudoprefixed and control words (as was done in Experiment 1). By changing two or three letters in the middle of the 159 word stimuli, 159 nonword stimuli were made up, so the entire number of stimuli in the experimental list amounted to 318. Of these 318 stimuli, 258 (81%)

[15] For determining whether or not a bigram trough was present at the first syllabic boundary of the target word, it was always the first (spoken) syllable that was taken in consideration, whatever its spelling or syllabic pattern.

did not present an initial prefix-like string (the 60 remaining stimuli were the 30 pseudoprefixed experimental words and the 30 nonwords formed by changing letters in the middle of these pseudoprefixed words). The stimulus context thus reproduced the "non-prefixed" condition of Experiment 1. The list was divided into three blocks of 106 stimuli. These stimuli were presented in a pseudorandomized order in conformity with the following constraints: (1) practice effects were controlled by distributing the four types of experimental words equally across the various sub-parts of the blocks; (2) possible initial bigram-repetition effects were controlled by presenting, prior to the words of a given quadruplet, an equal number of stimuli bearing the initial bigram of those words (as in Experiment 1); (3) the first 20 items of each block were considered practice items (there were no experimental words among them). Finally, no more than 4 word or nonword stimuli were presented successively.

Procedure and Apparatus.

The subjects were run individually in approximately 45-min sessions. All were presented with the three blocks in the same order, with a 5-min rest period between the blocks. The apparatus, the instructions, and the experimental sequence were identical to those of Experiment 1.

Results and Discussion

The mean response times and percentages of errors for the pseudoprefixed and control words according to the first syllabic pattern (marked/ unmarked boundary) are given in Table 2. (Results for individual words are given in Appendix C.) ANOVAs by subjects and by items were carried out only for the correct response-time data. On average, the pseudoprefixed words were responded to 80 msec more slowly than were the control words. This main effect was significant, $F_1(1, 31) = 64.96$, $MS_e = 2432$, $p < .001$; $F_2(1, 56) = 7.41$, $MS_e = 12{,}764$, $p < .01$, but the 25-msec difference between marked and unmarked words was not, $F_1(1, 31) = 3.15$, $MS_e = 3746$, $p = .09$; $F_2(1, 56) < 1$, $MS_e = 12{,}764$. The control words were responded to 48 msec more slowly when their first syllabic boundary was unmarked, but no such trend was found for the pseudoprefixed

TABLE 2
Mean Response Times in Msec and Error Percentages for Pseudoprefixed and Control Words According to Initial Syllabic Pattern (Experiment 2)

	First Syllabic Boundary						Δ (*Markedness Effect*)
	Marked		*Unmarked*		*Mean*		
	M	%	*M*	%	*M*	%	
Pseudoprefixed words	876	6.5	877	7.3	877	6.9	−1
Control words	773	2.3	821	2.9	797	2.6	−48
Mean	824	4.4	849	5.1	837	4.8	−25
Δ (Pseudoprefixation effect)	+103		+56		+80		

words. Inspection of individual word–stimuli results suggested that the longer mean response time for the unmarked control words was probably due to the exceptionally slow responses (> 1 sec) obtained for two words (*mandater, magnifier*). The interaction between the initial bigram and the first syllabic boundary pattern effects did not reach significance in the item analysis, $F_1(1, 31) = 7.46$, $MS_e = 2946$, $p < .02$; $F_2(1, 56) < 1$, $MS_e = 12{,}764$. Decomposing the by-subject significant interaction by performing separate ANOVAs by condition revealed a significant effect of the type of words both for the unmarked condition, $F(1, 31) = 10.15$, $MS_e = 3058$, $p < .01$, and the marked condition, $F(1, 31) = 64.18$, $MS_e = 2319$, $p < .001$.

Additional Analyses. As noted in the Method section, there was a trend for the pseudoprefixed words to be associated, on average, with a lower *log* root frequency, a lower initial bigram frequency, and a lower mean bigram frequency than the control words. Although none of these trends turned out to be significant, they might have influenced the results towards a pseudoprefixation effect. In order to ascertain that the pseudoprefixation effect obtained was not due to a confound with these factors, an ANCOVA analysis was performed with the mean RT obtained for each experimental item as the dependent variable. The type of initial bigram (pseudoprefix/ control) and the first syllabic boundary pattern (marked/ unmarked) were entered as classification variables, with the factors *log* lemma frequency, *log* root frequency, textual frequency of the initial bigram, geometric mean of the bigram frequencies, and number of letters as covariates. The main effect of pseudoprefixation still turned out to be significant, $F(1, 51) = 6.91$, $MS_e = 9857$, $p < .02$, once all the other factors (including the interaction between type of initial bigram and first syllabic boundary pattern, which remained not significant, with $F < 1$) were controlled for.

A further aspect of the results requiring clarification is whether the pseudoprefixation effect obtained was driven by both the pseudoprefixed words bearing the *dé* initial bigram and those bearing the *re* initial bigram. Indeed, *dé* has a lower textual bigram frequency than does *re* (815 vs. 1255), and *dé* also has a lower than average initial bigram frequency (the average initial bigram frequencies for the marked and unmarked pseudoprefixed words and for the marked and unmarked control words were 903, 1050, 1089, and 1265, respectively). Another ANCOVA analysis was therefore performed with the mean RT obtained for each experimental item as the dependent variable, with the same factors as previously (i.e. the *log* lemma frequency, the *log* root frequency, the textual frequency of the initial bigram, the geometric mean of the bigram frequencies, and the number of letters) as covariates, but with the type of initial bigram (which has here three levels: *dé*/ *re*/ control bigrams) and the first syllabic boundary pattern (marked/ unmarked) as classification variables. The results indicated that the type of initial bigram had a significant effect on the response times, $F(2, 49) = 4.67$, $MS_e = 9690$, $p < .02$, when all the other factors (including the interaction between type of initial bigram and first syllabic boundary pattern, which remained non-significant, with $F(2, 49) = 1.52$, $MS_e = 9690$, $p > 1$) had been controlled for. Multiple t-tests (LSD; $\alpha = .05$) indicated, moreover, that both the pseudoprefixed words bearing the *dé* bigram (mean RT = 879 msec) and the pseudoprefixed words bearing the *re* bigram (mean RT = 873 msec) were responded to significantly more slowly than were the control words (mean RT = 797 msec), but there was no significant difference when the mean RT for the "*dé*" words were compared to the mean RT for the "*re*" words.

In summary, the results of the present experiment replicated those of Experiment 1: pseudoprefixation caused a processing delay even when the subjects were presented with no prefixed words at all—that is, in a context that prevented the strategic use of a decomposed-access procedure. They further show that the pseudoprefixation effect was not an artifact of a particular pattern of letters present in pseudoprefixed words. The pseudoprefixed words incurred a delay in processing in comparison with the control words whatever the pattern of initial bigram frequencies, that is whether or not the pseudomorphemic boundary was marked by a bigram trough.

The trend noted for the unmarked control words to be responded to more slowly than the marked control words could suggest that recognition is facilitated when the first syllable of a word is marked in orthography but not when the first syllable is a prefix-like string. However, I must stress that markedness was a between-item factor in this experiment and that some items were very low-frequency words. As frequency counts are particularly susceptible to sampling bias for this frequency range, it might be that *some* unmarked control words were indeed of lower frequency than were others. Thus, the non-significant trend observed might be due to incorrect matching between the marked and the unmarked control words because of this bias.

In spite of this uncertainty, the results suggest that prefix-like strings act as processing units at some stage of lexical access, and that, if this is so, it is because prefixes are *morphemic* units relevant for the access system, not because they accidentally present salient orthographic features from the point of view of the connection structure of the lexicon. However, an objection could be raised about the index of orthographic redundancy used in the experiment. One could argue that it might not be the proper one to capture orthographic redundancy. Indeed, this objection has already been made by Seidenberg (1987: 260): "Orthographic redundancy reflects a complex set of facts about the distribution of letter patterns in the lexicon: measures such as bigram frequency, the frequency of a series of bigrams, or positional letter frequency capture very little of this structure."[16] I must acknowledge that the criteria used to consider a bigram trough to be present or not have no theoretical or empirical basis. Whether or not these criteria are relevant is thus a matter of further empirical investigation. However, the choice of the trough-bigram pattern among other possible measures of orthographic redundancy was not totally arbitrary: it was proposed by Seidenberg himself, who claimed that it was responsible for apparent "syllabic" effects in an experiment using the illusory conjunction paradigm (Seidenberg, 1987; see, however, Rapp, 1992, for contrary evidence). Thus there is a danger that the notions of "orthographic redundancy" and "trough pattern" protect the author's lexical theory from discomfirmation, as any unwelcome facts could be attributed to an inappropriate measure of redundancy, whereas welcome facts—such as Seidenberg's (1987) findings—would support the theory.

[16] He then added: "This is perhaps a case in which computational modelling provides a useful alternative to traditional experimental approaches. Instead of deriving statistics that summarize aspects of orthographic redundancy, we can simulate the structure of the lexicon itself" (Seidenberg, 1987: 260). As far as I know, no such simulation has yet been published.

In any case, it must be stressed that the pseudoprefixed and the control words used in this experiment were closely matched with respect to a number of orthographic properties in addition to frequency, length, and syntactic category: all the experimental words presented a C–V–C initial spelling string; the first C–V bigram was always a high-frequency initial bigram in the written language; and the bigram pattern of the first syllabic boundary was similar for both sets of words (half of the pseudoprefixed and control words were marked by a bigram trough at this first syllabic boundary, the other half were not). However, the pseudoprefixed and control words were not perfectly matched with respect to their first C–V syllabic pattern (4 out of 30 control words began with a C–V–C syllable, whereas all the pseudoprefixed words had a C–V first syllable) and to the congruency of the initial spelling pattern with the initial syllabic pattern (one control word had its first C–V syllable spelled out with a C–V–C string). That the pseudoprefixation effect was produced by a *systematic* confusion between the independent variable and extraneous syllabic or/ and orthographic factors seems, however, very unlikely.

EXPERIMENT 3

The need for highly selected material led to the use of some very-low-frequency critical words in Experiments 1 and 2. This might have introduced some noise into the data, resulting in non-significant trends for interaction between the magnitude of the pseudoprefixation effect and list-composition (Experiment 1) or markedness (Experiment 2) effects, which were attributed tentatively to a sampling bias in the frequency counts for very-low-frequency words. In order to reduce these potential sources of noise, critical words were selected in the present experiment within a larger frequency range, although this meant loosening the selection criteria. Moreover, only unmarked control and unmarked pseudoprefixed words were used in this experiment, and no prefixed items were presented in the stimulus list. This means that the pseudoprefixation cost was measured within experimental conditions where it was least likely to appear.

Method

Subjects

Forty subjects, undergraduate students of the Université catholique de Louvain (Belgium), participated in this experiment to fulfil a course requirement or as volunteers. All were native French speakers.

Stimuli and Design

Sixteen pseudoprefixed words and 16 monomorphemic control words comprised the experimental stimuli. The criteria used to select pseudoprefixed and control words were identical to those of Experiments 1 and 2. The pseudoprefixed words had one of the prefix-like initial bigrams *dé*, *re*, or *in*. The initial bigrams present in the control words were among the most frequent non-prefix-like initial bigrams in French. All the pseudoprefixed and control words were "unmarked" as to their first syllabic boundary (i.e. as to their pseudomorphemic boundary in the case of pseudoprefixed words). The criteria applied for considering a word to be "unmarked" were the same as those of Experiment 2. All the experimental word stimuli were verbs in the infinitive or the past participle form.

The pseudoprefixed and control words were set up in pairs so that the two words in a given pair were as similar as possible in lemma frequency, letter length, frequency of the initial bigram, and initial-consonant/vowel string. The words were selected within three frequency ranges. For each word type, 4, 8, and 4 words were included in the lower, medium, and higher frequency range, respectively. The mean lemma frequency (*Trésor de la langue française*, 1971) of the pseudoprefixed and control words were, respectively, 173 and 175 for the lower frequency range, 587 and 578 for the medium frequency range, and 5340 and 5273 for the higher frequency range (see individual word frequency in Appendix D).[17] Both within each frequency range and on the whole, the pseudoprefixed and control words did not significantly differ in lemma frequency, all $t < 1$. The mean letter length was 8.3 (range = 7–11) for the pseudoprefixed words and 7.6 (range = 6–9) for the control words, a difference that was marginally significant, $t(30) = 1.98$, two-tailed, $p < .1$. The mean textual frequency (Content & Radeau, 1988) of the first bigram was 963 for the pseudoprefixed and 1084 for the control words, $t < 1$. All the pseudoprefixed words whose initial-consonant/vowel string was C–V–C (i.e. words starting with *dé* or *re*) were paired with control words presenting the same pattern. However, of the 7 pseudoprefixed words presenting a V–C–C initial string (words with the *in* pseudoprefix bigram), only 3 could be paired with a control word presenting an identical initial pattern (the 4 others were paired with a control word starting with a C–V–C string).

As in the previous experiments, the *log* root frequency and the overall orthographic redundancy (indexed by the geometric mean frequency of all the bigrams composing the target word) of the pseudoprefixed and control words were checked a posteriori. Both variables were not significantly different for the two word categories. The mean *log* root frequency for the pseudoprefixed words and the control words was 3.04 ($SD = 0.64$) and 3.20 ($SD = 0.76$), respectively, $t < 1$. The mean value of the index of overall orthographic redundancy was 637 ($SD = 157$) for the pseudoprefixed words and 663 ($SD = 257$) for the control words, $t < 1$.

Eighty-four filler-word stimuli, with various frequencies, lengths, and syntactic categories were mixed with the 32 experimental word stimuli. None of these filler-word stimuli had a potential prefix (i.e. none was prefixed or pseudoprefixed). As in the two previous experiments, some of the filler words were selected in order to balance the number of first bigram repetitions between the pseudoprefixed and the control words. Two or three letters were changed in the middle of the 116 word stimuli in order to form 116 nonword stimuli. Thus, the experimental list contained 232 stimuli, of which 200 (86%) did not present an initial prefix-like bigram. The 32 remaining stimuli were constituted by the 16 experimental pseudoprefixed words and the 16 “pseudoprefixed” nonwords formed by changing letters in the middle of these pseudoprefixed words.

The experimental list was divided into two blocks of 116 stimuli. These stimuli were presented in a pseudorandomized order in accordance with the same principles as those applied in Experiment 2.

[17] The *Trésor de la langue française* (1971) does not report the frequency rank corresponding to the word frequencies in the corpus of the second half of the twentieth century. In order to estimate the frequency rank of the experimental words selected in this experiment, the French lexical database BRULEX (Content, Mousty, & Radeau, 1990) was consulted. This database provides information on approximately 36,000 French words, including their frequency for the second half of the twentieth century, as reported by the *Trésor de la langue française*. The experimental words included in the “lower-frequency-range” set belonged in the frequency rank of the 9253 to 13,413 most frequent words of this list of 36,000 words; the words in the “medium frequency range” belonged within the frequency rank of the 4678 to 7835 most frequent words, and those in the “higher frequency range” belonged in the frequency rank of the 771 to 3704 most frequent words.

Procedure and Apparatus

The subjects were run individually in approximately 30-min sessions. All were presented with the two blocks in the same order, with a 5-min rest period between them. The apparatus, the instructions, and the experimental sequence were identical to Experiments 1 and 2.

Results and Discussion

The mean response times and percentages of errors for the pseudoprefixed and control words in the three frequency ranges are given in Table 3. (The individual word stimuli results are given in Appendix D.) ANOVAs, by subjects and by items, were carried out only on the correct response-time data (General Linear Model procedures with Type III MS were used). On average, the pseudoprefixed words were responded to 60 msec more slowly than were the control words, and this main effect was significant, $F_1(1, 39) = 33.35$, $MS_e = 6539$, $p < .001$; $F_2(1, 26) = 6.8$, $MS_e = 4110$, $p < .02$. Frequency also had a significant main effect on the response times, with the words of the lower frequency range being responded to 83 msec more slowly than were the words of the medium range, which were themselves responded to 64 msec more slowly than the words belonging to the higher frequency range, $F_1(2, 78) = 61.05$, $MS_e = 6340$, $p < .001$; $F_2(2, 26) = 10.63$, $MS_e = 4110$, $p < .001$. Multiple T tests (LSD) indicated that each frequency range was significantly different from the others ($\alpha = .05$), both in the subject and in the item analyses. Moreover, the results showed a trend for the pseudoprefixation effect to be greater for words in the lower frequency range (87 msec) than for words in the medium (56 msec) and the higher (43 msec) frequency ranges. This interaction effect between pseudoprefixation and frequency was far from reaching significance, $F_1(2, 78) = 1$, $MS_e = 7568$; $F_2(2, 26) < 1$, $MS_e = 4110$, a result that might be due, however, to the small number of items in each frequency range.

Additional Analysis. As the pseudoprefixed words used in this experiment tended to be associated, on average, with a longer letter length, a lower *log* root frequency, a lower initial bigram frequency, and a lower mean bigram frequency than the control words, an

TABLE 3
Mean Response Times in Msec and Error Percentages for Pseudoprefixed and Control Words According to Frequency Range (Experiment 3)

	Frequency Range							
	Lower		*Medium*		*Higher*		*Mean*	
	M	%	*M*	%	*M*	%	*M*	%
Pseudoprefixed words	856	5.6	757	0.6	686	1.3	764	2
Control words	769	2.5	701	0	643	0	704	0.6
Mean	812	4.1	729	0.3	665	0.6	734	1.3
Δ (Pseudoprefixation effect)	+87		+56		+43		+60	

ANCOVA was performed in order to ascertain whether the pseudoprefixation effect obtained was due to a confound with these factors. The mean RT obtained for each experimental item was entered as the dependent variable, the type of words (pseudoprefixed/ control) and the range of frequency (lower/ medium/ higher) as classification variables, and the factors *log* root frequency, textual frequency of the initial bigram, geometric mean of bigram frequencies, and number of letters as covariates. The results of this analysis indicated that the main effect of pseudoprefixation was still significant, $F(1, 23) = 7.73$, $MS_e = 2431$, $p < .02$, once all the other factors (including the interaction between the type of words and range of frequency, which remained non-significant, with $F < 1$) were controlled for.

The results of this experiment replicate the main finding of Experiments 1 and 2—the pseudoprefixed words incurred a processing delay in lexical access—and allow one to generalize it to words belonging to a greater frequency range. More importantly, a reliable pseudoprefixation effect was found here with the same experimental conditions that led in Experiments 1 and 2 to the smallest pseudoprefixation effect: critical words were presented in a list that contained no prefixed items at all, and only *unmarked* pseudoprefixed and control words were selected. These results clearly demonstrate, therefore, that the pseudoprefixation effect cannot be reduced to strategic or strictly orthographic effects.

Nevertheless, it might be objected that this effect was found in an experiment using a lexical decision task and that, accordingly, it might not reflect a general property of word-recognition processes. In particular, it could be argued, first, that given that "pseudoprefixed" nonwords had to be included in the stimulus list, strategic decomposition effects cannot be positively ruled out, and second, again because of the presence of "pseudoprefixed" nonwords, that the word/ nonword discrimination was made more difficult for pseudoprefixed than for control words. As regards the first point, it is very unlikely that the presence of only 15 "pseudoprefixed" nonwords out of 232 stimuli would be sufficient to encourage subjects to decompose the stimulus strings. More importantly, it is reasonable to assume the strategic use of a special procedure in a lexical-decision task only when it appears that this procedure facilitates or speeds up the decision. This is not the case here. Decomposing the pseudoprefixed items would not at all speed up the decision for pseudoprefixed words and nonwords: for both kinds of items, decomposition entails a search based on the pseudostem and then a search based on the whole form, whereas the latter search would be sufficient if no decomposition were made; nor does decomposition facilitate word/ nonword discrimination, as the decision for both words and nonwords can only be taken on the basis of the processing of the whole form. Thus, it is unlikely that decomposition has been used as an optional strategy in the present conditions, because it would be an absolutely useless one. The only plausible interpretation, therefore, is that stimulus strings were decomposed because decomposition is indeed triggered as an *automatic* procedure.

As regards the second point, the word/ nonword discrimination might indeed have been more difficult for the pseudoprefixed than for the control words if the "pseudoprefixed" nonwords happened to be more similar to the pseudoprefixed words than the control nonwords were to the control words. However, it must be recalled that, given the procedure employed to form the nonword items, "pseudoprefixed" and non-pseudoprefixed ("control") nonwords differed to the same extent from the pseudoprefixed and control words present in the experimental list. Moreover, both nonword types resulted in strings beginning with a high-frequency first bigram. Therefore, one can consider that word/ nonword discrimination would not be more difficult for the pseudoprefixed than for the control words, if discrimination is made only on the basis of a whole-form processing. It remains, however, that word response times might be influenced not only by the degree of resemblance between the word and the nonword items presented in the experimental list, but also by the size of the orthographic neighbourhood of these words and nonwords. Thus, for example, word/ nonword discrimination could be more difficult for the pseudoprefixed words than for control words if the ‘‘pseudoprefixed’’ nonwords happened to have more word neighbours (i.e. happened to be more wordlike) than the ‘‘control’’ nonwords. Although it was not strictly controlled in this experiment, the orthographic neighbourhood size for both the pseudoprefixed and the control items was checked a posteriori by means of the N metric (number of same-length words differing from an item by a single letter). As regards the nonword items, it turned out that ‘‘pseudoprefixed’’ nonwords did not have more word neighbours than did the ‘‘control’’ nonwords: of the 100 ‘‘control’’ nonwords, 69 (69%) had no word neighbours, and the 31 remaining ‘‘control’’ nonwords had 1–5 word neighbours; of the 16 ‘‘pseudoprefixed’’ nonwords, 12 (75%) had no word neighbours, and the 4 remaining ‘‘pseudoprefixed’’ nonwords had 1 to 3 neighbours. As for the word items, the control and pseudoprefixed words appeared to be comparable as to their orthographic neighbourhood size: only 3 of the 16 pseudoprefixed words had 1 neighbour and 1 had 2 neighbours, whereas 4 of the 16 control words had 1 neighbour and 1 had 2 neighbours. It is, therefore, highly improbable that the present results were biased by factors likely to influence the word/ nonword discrimination speed. On the whole, there is thus no apparent reason to suspect that the results were biased by the use of a lexical decision task.

GENERAL DISCUSSION

The findings reported here show that monomorphemic words whose initial bigram is homographic with a prefix incur a temporal delay in visual processing compared to other monomorphemic words. They further demonstrate that this pseudoprefixation effect cannot be ascribed to the strategic use of a decomposed access device, which is usually unnecessary, or to the common co-occurrence of a morphemic or pseudo-morphemic structure with certain aspects of orthographic redundancy. Therefore, this effect cannot be accounted for by models in which access to morphological information is viewed as a strategic/ supplementary device (Andrews, 1986; Butterworth, 1983) or as an artefact of orthographic redundancy (Seidenberg, 1987, 1989). In all likelihood, the pseudoprefixation effect originates from an automatic identification of a prefix-like string present in the stimulus, which interferes with the recognition of the word form.

Among the various models of morphological processing discussed throughout this paper, only the prelexical decomposition hypothesis put forward by Taft and his colleagues assumes a mechanism with which such an interference effect could occur. It may be recalled that, according to this hypothesis, the pseudoprefixation effect arises because the stimulus string is processed through three discrete stages applied successively: (1) an affix-stripping process operating ‘‘blindly’’ with a left-to-right parsing procedure; (2) a search process in the peripheral file for matching the letter string remaining after affix-stripping with a stem access code; (3) a second search proceeding on the basis of the entire stimulus representation. As whole-word access models such as SRE do not assume any level where morphemic units are processed, they are unable to account for such an interference effect: within such models, no prefix unit could be identified at all. Moreover, the processing mechanisms assumed by the AAM or MR dual-route models for accessing morphemic representation units are such that no interference effect should occur during the recognition of pseudoprefixed words. Although the AAM and MR models made different assumptions about the factors determining which route wins the race, both models view the decomposed access and the whole-word access procedures as two parallel, non-interacting access mechanisms, with the one reaching completion first giving its output. It is clear that, upon presentation of a pseudoprefixed word, the whole-word access procedure is the only one likely to reach completion and then allow word recognition. That, in the meanwhile, an inappropriate prefix unit happens to be identified through the morphemic access route should not have any effect on the activation of the proper whole-word form through the whole-word access route.

Although the pseudoprefixation effect imposes at least a sublexical account of morphological involvement in word recognition, it does not require the lexical access theory used as the framework for the PMD hypothesis—that is, the serial-search model of lexical access (Forster, 1976). It would probably be possible to model this effect within another theory of lexical access such as an interactive-activation, spreading-activation, or connectionist theory—provided it includes a mechanism allowing the activation of an inappropriate prefix unit to slow down the recognition of a monomorphemic word form.

As a matter of fact, Taft recently proposed a reformulation of the PMD hypothesis within an interactive-activation framework (Taft, 1994): he now assumes that activation enters the system via the grapheme units and spreads up to the concept level via morpheme- and then word-node levels. During this process, increased activation at higher levels can feed back down to enhance the activation of lower-level units. This new framework still includes both morpheme (affixes and stems) and whole-word level representation units intervening between the grapheme (and body) level and the concept level. It also retains the notion that polymorphemic words are represented both in a decomposed way (at the morpheme level) and as whole-word forms (at the word level) and that activation passes through the former to get to the latter. Morpheme-level units are thus still conceived as pre-access units. (Note, however, that morpheme nodes, including affixes, are here directly linked to their concept node.) However, in this new framework, the equivalent of the "prefix-stripping" procedure is an integral part of the access process itself, rather than a discrete stage of processing that takes place prior to access. Likewise, access to morpheme representation and then to whole-form representations is no longer viewed as discrete successive stages. The pseudoprefixation effect, in this context, can be explained as follows: the letter string composing a pseudoprefixed word (e.g. *religion*) will activate, at the morpheme level, both a prefix node (RE) and a morpheme node corresponding to the whole string (RELIGION) (monomorphemic words are probably represented at both the morpheme and word levels). The prefix node will then activate its corresponding concept node ("AGAIN"), which in turn will lead to competition with the whole-word node (RELIGION) at the morpheme, word, and concept levels.

It is worth pointing out that the shift from the discrete stages to interactive-activation processing assumptions introduces a different prediction about the way morphemic and whole-word units are expected to enter into play during lexical recognition. Contrary to the previous one, this formulation of the PMD hypothesis predicts an interaction effect between word frequency and pseudoprefixation: the lower the frequency of the pseudo-prefixed word, the more time it will take for its morpheme and word nodes to be activated, and, therefore, the more competitive will be the activation of an inappropriate prefix node. No such effect has yet been reported in the literature, but a trend towards such an effect was noted in the third experiment reported here. This could favour the interactive-activation account over the serial-search account for the pseudoprefixation effect. Unfortunately, it was not possible, given the limitations on the available stimuli in French, to investigate further the precise relationship between pseudoprefixation and word frequency. This issue thus remains a matter for further research in a language that would allow the selection of enough appropriate items. In my view, this could be a fruitful way of achieving a deeper understanding of the respective involvement of morphemic and whole-word form units in lexical recognition.

The meta-model for morphological processing recently proposed by Schreuder and Baayen (1995), which is a spreading-activation model, could probably also accommodate the findings of a pseudoprefixation effect. This model assumes access representations for full complex forms, bound and free stems, and affixes, each being connected to a lexical representation, a "concept node". This "concept node" is, in turn, connected to syntactic and semantic representations. Both concept nodes and access representations may receive activation feedback from a higher level. In this context, the pseudoprefixation effect could be explained along the same lines as in the Taft's (1994) model. On presentation of a pseudoprefixed word, both a prefix representation and a word representation would be activated at the access level, and the prefix access representation would activate its corresponding concept node and semantic representation. The activation feeding back from these levels to access nodes would then compete with the activation of the appropriate word access node.

Furthermore, for the pseudoprefixation effect to be modelled, explicit representations for morphemic units might not be required. SRE models (e.g. Lukatela et al., 1987; Stanners et al., 1979) and connectionist architectures that do not represent any morphological information (e.g. Rumelhart & McClelland, 1986; Seidenberg & McClelland, 1989) might, therefore, be adapted to allow morpheme-level units to emerge automatically during stimulus processing. There are no difficulties with this in principle. Word morphology consists of nothing other than generalizations carried out on the basis of systematic co-variations between word forms and word meanings. Therefore, within parallel and/ or distributed processing systems, morpheme-level units could automatically emerge without being explicitly coded if specific interconnections between word-form units and word-meaning units were assumed to be acquired and thus implemented in some manner. But the important point is that implementation should be done in such a way as to allow morpheme units to emerge as intermediate output *before* a word-level unit output. It must be stressed that this would be an important theoretical change in Seidenberg and McClelland's model, as only orthography/ phonology generalizations are there taken to be relevant for the recognition system: "what is relevant to processing is not syllables or morphemes, but properties of words that are *correlated* with these structures. . . . In sum, the hypothesis is that effects of units such as syllables and morphemes in visual word recognition are secondary to facts about how these units are realized in the writing system. Thus, effects of these structures would be an emergent property of a model, like ours, that only encodes facts about orthographic redundancy and orthographic-phonological regularity" (Seidenberg & McClelland, 1989: 562).

Other critical points for our understanding of how sublexical structures such as morphemes are recovered during recognition processes that were not addressed in this paper deserve further research. One point is related to the means by which sublexical, morphemically defined units are isolated in the stimulus string. As far as I know, there is no clear evidence available at present that would favour, say, a decomposition of the stimulus string by left-to-right parsing (as proposed in the PMD model) over passive and parallel activation of potential morphemic units (as in the AAM model). It seems that the pseudomorphemic effect paradigm could help to choose between them. The critical test would be to compare control words with words containing a pseudostem but having neither a pseudoprefix nor a prefix. The French word *bafouiller* meets this criterion. In this word, the initial string *ba* is not homographic of any prefix, but *fouiller* is a homograph of a real stem. Only a parallel activation of the letter strings composing the stimulus would lead to isolation of a potential morphemic unit (*fouiller*) in such a word and then produce interference effects on the recognition of *bafouiller*.

Another question deserving further investigation concerns the properties that a linguistically defined affix must display in order to be treated as an independent morpheme unit by the lexical recognition system. In the experiments reported in this paper, only three prefix-like strings (*dé*, *re*, and *in*) were used. Each corresponds to a productive prefix in French that appears, moreover, more often in prefixed than in pseudoprefixed French words. Although the findings suggest that these three prefix-like strings are represented as morphemic units in the lexical recognition system of French speakers, they cannot answer the question of which properties are relevant for an affix to be represented in the mind as such. Is it productivity per se and *only* productivity? Or are some other features correlated with productivity, such as the type and/or token frequency of the prefix in language, and the probability for an initial letter sequence to be a prefix, as opposed to a pseudoprefix, in a given language? Laudanna and his colleagues (Laudanna et al., 1994; Laudanna & Burani, 1995) reported a series of experiments conducted in Italian to investigate this issue. Their findings highlighted the major role played by the ratio of truly prefixed and pseudoprefixed words sharing the same initial orthographic sequence: the higher the proportion of truly prefixed words for a given prefix string, the slower the reaction times for nonwords containing that prefix when compared to control nonwords. This was noted regardless of the absolute number of word types in the language containing the prefix (Laudanna et al., 1994; Laudanna & Burani, 1995). This suggests that the recognizability of a prefix is subject to a distributional restriction, which could reflect a functional principle of processing such as minimizing the number of incorrect decompositions (see Laudanna & Burani, 1995, and Schreuder & Baayen, 1994, for a detailed discussion of this point). Thus, it appears that the findings reported in the present paper are quite compatible with those reported by Laudanna and his colleagues, both empirically and theoretically. First, the pseudoprefixation effect was indeed observed with prefix-like strings that presented a ratio of truly prefixed/ pseudoprefixed words in favour of truly prefixed ones. Second, the mere observation of the role played by this variable can be interpreted as suggesting that pseudoprefixation might, indeed, constitute a processing cost for the lexical processing system. However, further investigations are required to disentangle the respective role of variables such as prefix productivity, prefix frequency, and prefix confusability (prefix/ pseudoprefix ratio), given that they are all probably correlated with each other.

Although this study leaves unresolved many processing issues regarding the way morpheme units are involved in visual word recognition, its main finding—namely, a pseudoprefixation effect that could not be reduced to a strategic or a strictly orthographic effect—imposes a strong constraint on lexical theory, which may be neutrally set out as follows: when a stimulus bears a potential prefix, the processing mechanisms are such that this prefix string addresses morphemically defined internal codes before any word-unit code is identified. This mechanism gives rise to interference effects in recognition when the stimulus is not a truly prefixed word precisely because its products become available before the product of the mechanism for contacting whole-word unit representations. It is in this sense that morphemic units may be termed "access units", as they are retrieved as a preliminary to whole-word form recognition.

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APPENDIX A

Extract of the "Non-prefixed" List (Experiment 1)

List shows the order of presentation for experimental and filler words and nonwords bearing critical bigrams (i.e. prefix-like bigrams present in pseudoprefixed words or non-prefix-like bigrams present in control words). The stimuli that are not reported here are other filler words and nonwords that do not start with one of the critical bigrams.

No. Item in List	*Item*	*Category of Item*	*No. of Experimental Pairs*	*Bigram*	*Number of Presentations*
25	déferler	pseudoprefixed word	18	DÉ	1
29	papoter	filler word		PA	1
30	modeler	control word	18	MO	1
31	basané	control word	7	BA	1
32	déginer	nonword filler		DÉ	2
43	cajoler	filler word		CA	1
44	relaté	pseudoprefixed word	7	RE	1
46	défidrer	nonword filler		DÉ	3
49	padaumer	nonword filler		PA	2
51	pacomer	nonword filler		PA	3
54	moturer	nonword filler		MO	2
56	bamagé	nonword filler		BA	2
58	marmonné	word filler		MA	1
60	délirer	pseudoprefixed word	14	DÉ	4
62	madélé	nonword filler		MA	2
64	capituler	word filler		CA	2
65	patauger	control word	14	PA	4
66	macéré	control word	6	MA	3
67	redufflé	nonword filler		RE	2
70	cavoupler	nonword filler		CA	3
80	reniflé	pseudoprefixed word	6	RE	3
81	détrober	nonword filler		DÉ	5
82	margouné	nonword filler		MA	4
87	castiner	nonword filler		CA	4
91	capiluder	nonword filler		CA	5
93	dénigrer	pseudoprefixed word	10	DÉ	6
95	renavé	nonword filler		RE	4
99	camoufler	control word	10	CA	6

APPENDIX B

Mean Response Times in Msec for Individual Word Stimuli of Experiment 1

Words	*Items*	*Mean RT in* "Non-prefixed" List	*Mean RT in* "Prefixed" List	*Mean RT*
1. Pseudoprefixed	détecter	752	810	781
	défalquer	832	962	897
	dégoter	925	906	916
	remorquer	718	728	723
	délingué	954	1054	1004
	reniflé	722	874	798
	relaté	813	829	821
	rechigner	975	969	972
	reluquer	854	1112	983
	dénigrer	786	783	785
	renâcler	939	908	924
	dépravé	745	776	761
	dépité	845	752	799
	délirer	725	769	747
	délabré	868	734	801
	recruter	773	765	769
	déserter	745	757	751
	déferler	838	1007	923
2. Control	mandater	908	762	835
	calciner	855	900	878
	capoter	901	755	828
	pavoiser	772	753	763
	matraqué	922	860	891
	macéré	773	847	810
	basané	887	898	893
	mastiquer	754	853	804
	maquiller	862	765	814
	camoufler	693	766	730
	captiver	708	692	700
	maniéré	815	914	865
	capturé	671	716	694
	patauger	740	793	767
	motivé	665	676	671
	modérer	709	673	691
	basculer	713	755	734
	modeler	712	712	712

APPENDIX C

Mean Response Times in Msec for Individual Word Stimuli in Experiment 2

Words	*Marked boundary* *Item*	*Mean RT*	*Unmarked boundary* *Item*	*Mean RT*
1. Pseudoprefixed	dédicacer	922	délingué	1032
	détecter	698	dégoter	878
	défalquer	1092	déglutir	988
	déluré	955	remorquer	764
	rechigner	1178	reniflé	875
	reluquer	871	décanter	875
	dénigrer	789	renâcler	1122
	dépravé	874	recruté	882
	reflété	860	relater	846
	délecter	867	dépité	924
	délirer	711	remédier	732
	délabré	839	décréter	869
	décorer	718	repérer	793
	déserter	837	dégringoler	900
	déferler	926	regretté	682
2. Control	matraqué	852	mandater	1014
	capoter	835	fagoter	886
	saliver	655	macérer	938
	caqueter	979	saboter	692
	cahoter	857	saturer	765
	cajoler	757	mastiquer	794
	maquiller	645	camoufler	732
	captiver	727	magnifier	1022
	capturer	794	saccager	898
	moduler	805	maniéré	897
	motiver	678	capituler	727
	modérer	706	manipuler	703
	voltiger	790	toléré	725
	massacrer	821	fasciner	751
	modeler	693	saccadé	773

APPENDIX D

Lemma Frequency per 100 Million Words and Mean Response Times in Msec of Individual Word Stimuli of Experiment 3

	Pseudoprefixed Words			*Control Words*		
Frequency Range	*Item*	*Frequency*	*RT*	*Item*	*Frequency*	*RT*
Lower	décanter	102	983	mastiquer	102	872
	incruster	153	810	camoufler	140	738
	inculquer	191	887	estomper	216	826
	recruté	246	742	parfumer	242	638
Medium	remédier	399	726	manipuler	344	674
	décréter	480	759	saturé	480	661
	repérer	531	806	labourer	446	702
	intégrer	578	725	onduler	536	706
	dégringoler	582	847	saccadé	595	814
	insérer	667	682	fasciner	625	703
	intriguer	684	723	figuré	748	667
	renifler	778	783	torturer	846	683
Higher	insulter	1259	722	tolérer	1233	676
	indiquer	5126	677	estimer	4900	649
	regretter	6572	697	dominer	6628	646
	déclarer	8402	648	habiter	8329	602