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Morphological decomposition in early visual word processing ☆

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Abstract

In this study, we looked at priming effects produced by a short presentation (47 ms) of morphologically complex pseudowords in French. In Experiment 1, we used as primes semantically interpretable pseudowords made of the grammatical combination of a root and a suffix, such as *rapidifier* "to quickify." In Experiment 2, we used non-morphological pseudowords such as *rapiduit*, where *-uit* is an existing ending in French, but is not a suffix. In Experiment 3, primes were pseudowords consisting of a non-interpretable combination of roots and suffixes, such as *sportation*, formed by the noun *sport* "sport" and the suffix *-ation* (*-ation* only attaches to verbs). Results of Experiment 1 show that morphologically complex pseudowords significantly facilitated the recognition of their roots. This priming effect was equivalent to the facilitation obtained when existing derived words were used as primes. In Experiment 2, no priming effect was obtained with non-morphological pseudowords, demonstrating that the mere occurrence of the target at the beginning of the pseudoword prime is not sufficient to produce any priming and that an orthographic account of the results is not viable. Finally, Experiment 3 shows that the semantic interpretability of the morphologically complex pseudowords does not affect priming, as facilitation effect is obtained with morphologically complex non-interpretable pseudowords. The results reveal an early morphological decomposition triggered by the morphological structure of the prime, but insensitive to its lexicality or interpretability.

Keywords: Morphology; Visual word processing; Masked priming; Morphologically complex pseudowords

About 75% of the words contained in the French lexicon are morphologically complex, that is, can be analyzed as two or more morphemic units (Rey-Debove, 1984). For example, words like *jardinier* "gardener" or *jardinage* "gardening" contain a root and a suffix (respectively [jardin + ier] and [jardin + age]), both relevant to the global meaning of the derived words. Whether this structure—in French, English or in any

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other language featuring morphologically complex words—is represented in the mental lexicon and/or exploited during word recognition has been the object of a long-term debate in the literature. A growing amount of experimental evidence shows that morphology has an important role to play, even though this role is not yet clear (see Assink & Sandra, 2003; Baayen & Schreuder, 2003; Frost & Grainger, 2000).

Several models have been proposed to explain how morphological information influences complex word processing; they contrast on their basic assumptions about how morphologically complex words are processed and stored in the brain. For example, Butterworth (1983) and Manelis and Tharp (1977) have proposed that all morphologically complex words are listed in the mental lexicon, while Taft and Forster (1975) suggested that only morphemic units and their combinatorial restrictions are stored, without any whole word representations. More recent models allow the coexistence of whole word representations and morphological information. Morphological information is then integrated within the lexicon by postulating links between words of a same morphological family (cf. Bradley, 1979; Bybee, 1985, 1995; Colé, Beauvillain, & Segui, 1989; Segui & Zubizarreta, 1985). Thus, the words *jardinier* and *jardinage* would have their own whole word representation, but would be linked to each other as well as to the representations of their root *jardin* "garden" and other members of *jardin*'s morphological family. Morphological structure can also be conveyed by adding a specific level of morphemic representation, distinct from the lexical level (featuring the whole word representations) but linked to it by bidirectional links. This morphemic level can be prelexical, implying that a word like *jardinier* is decomposed into *jardin* and *-ier* prior to the activation of its full lexical representation (Colé, Segui, & Taft, 1997; Taft, 1994, 2003, 2005); or supralexical, in which case it is only when the whole word representation of *jardinier* has been activated that the morphemic units *jardin* and *-ier* are accessed (Giraudo & Grainger, 2000, 2001, 2003). These two latter models postulate a successive activation of morphemes and whole word representations (or vice-versa), but it has also been proposed that these representations were accessed in parallel (Caramazza, Laudanna, & Romani, 1988; Frauenfelder & Schreuder, 1992; Schreuder & Baayen, 1995). In these models, morphologically complex words can be accessed via two routes: a direct route, leading to the activation of whole word representations, and a decompositional route, activating the morphemic units. Whether it is the direct or the decompositional route that first activates the relevant units depends on the linguistic and distributional properties of the word, such as frequency, formal and semantic transparency, morpheme productivity, lexicality, etc. (see Schreuder & Baayen, 1995).

These models were proposed in order to account for a wide range of empirical data showing that morphological information is used during word processing and/or represented in the mental lexicon. Priming experiments provide one source of evidence. The main effect obtained in a priming paradigm is that a morphologically complex word facilitates the recognition of its base or another morphologically related word in comparison to an unrelated baseline. For example, the recognition of the simple word *garden* is faster when it is preceded by *gardening* than by an unrelated control word like *structural*, showing that the representation of the base is activated during the recognition of the derived word. Morphological priming effects have been obtained in several languages, such as English (e.g., Feldman, 2000; Marslen-Wilson, Tyler, Waksler, & Older, 1994; Rastle, Davis, Marslen-Wilson, & Tyler, 2000), French (Grainger, Colé, & Segui, 1991; Giraudo & Grainger, 2000, 2001; Longtin, Segui, & Hallé, 2003; Meunier & Segui, 1999, 2002), Hebrew (e.g., Deutsch, Frost, & Forster, 1998; Frost, Forster, & Deutsch, 1997), German, Dutch (e.g., Drews & Zwitserlood, 1995), and Spanish (e.g., Badecker & Allen, 2002; Dominguez, Cuetos, & Segui, 2002; Sanchez-Casas, Igoa, & Garcia-Albea, 2003).

Results obtained with a masked priming technique suggest that the morphological effect emerge quite early in visual word processing (e.g., Diependaele, Sandra, & Grainger, 2005; Feldman, 2000; Forster & Azuma, 2000; Frost et al., 1997; Giraudo & Grainger, 2000, 2001; Grainger et al., 1991; Pastizzo & Feldman, 2002; Rastle et al., 2000; Rastle & Davis, 2003). This technique consists of presenting the prime for a very short duration (typically for less than 50 ms) and to mask it immediately by the subsequent presentation of the target. Masked priming was first used to avoid episodic effects associated with the unmasked priming paradigm, and to avoid strategies in the lexical decision process (see Forster & Davis, 1984; Forster, 1998). It is hypothesized that the observed masked priming effects reflect the early stages of word processing, and show what properties of words are extracted before they are consciously perceived. Studies on morphological processing conducted using this priming paradigm have shown that reliable morphological facilitation effects are obtained with derived and inflected words, in the absence of a pure orthographical priming effect (between pairs such as *cardiac*/*card*) (Diependaele et al., 2005; Feldman, 2000; Feldman & Soltano, 1999; Giraudo & Grainger, 2000, 2001; Grainger et al., 1991; Longtin et al., 2003; Pastizzo & Feldman, 2002; Rastle et al., 2000; Rastle & Davis, 2003; Rastle, Davis, & New, 2005) or a semantic priming effect (e.g., *idea*/*notion*) (Dominguez et al., 2002; Feldman, 2000; Rastle et al., 2000; Raveh, 2002).

All the theoretical models presented above can explain morphological priming effects. Full listing models explain it by the spreading of activation from the complex word to the root or to related complex words through links between their lexical representations. On the other hand, the decompositional models assume that morphological priming reflects direct activation of the root extracted during the decomposition process (e.g., Marslen-Wilson et al., 1994). Prelexical and supralexical models account for the facilitation effect by suggesting that the activation spreads from the morphemic level to the lexical level (or vice-versa).

One way to separate these explanations is to see whether facilitation can be obtained with morphologically complex pseudowords, like *quickify*, which do not exist in English but can be easily interpreted on the basis of the meaning of its parts *quick* and *-ify*. Morphologically complex pseudowords like *quickify* can thus be analyzed into a root and a suffix, but are not represented as full forms in the lexicon because they are not real words and have never been encountered before. If morphological priming effects are due to the spreading of activation from the complex word to its root, then the pseudoword *quickify* should not prime its root *quick* because the search for its whole word representation would be unsuccessful. Similarly, if morphological information is represented at a supralexical level and is retrieved only once the whole word representation has been activated, then the fact that the pseudoword has no such representation should prevent the activation of the root at the morphemic level. On the other hand, if morphological priming effects are due to the activation of the root through morphological decomposition—either because only morphemes are represented or because there is a prelexical morphemic level—then morphologically complex pseudowords should prime their root as efficiently as existing derived words do.

Very few priming experiments using pseudowords are reported in the literature. Bentin and Feldman (1990) reported no priming effect between Hebrew pseudowords primes and real words sharing a root, using a visual priming paradigm with long lags. Drews and Zwitserlood (1995), using Dutch inflected pseudowords as primes and their roots as targets, did not find any priming effect in a visual priming paradigm. Giraudo and Grainger (2001), using French pseudowords as targets with a masked priming paradigm, found no priming between a real derived word prime like *laitier* “milkman” and a derived pseudoword target with the same root like *laitiste.* Taken together, these results suggest that morphological priming only occurs with real words and that morphemes are not available if whole word representations are not. However, pseudoword processing might entail a meta-linguistic analysis not required for the processing of real words, especially if the pseudoword is perceived consciously as an unmasked prime or used as a target on which a lexical decision has to be made. As argued by Henderson (1985), the processing which leads to the answer “nonword” in this task may imply different mechanisms than the processing which leads to identifying real words. Indeed, reaction times observed in lexical decision are much longer for pseudowords than for real words, suggesting the presence of post checking stages not involved in the processing of real words. These additional stages could interfere with priming effects and lead to erroneous conclusions about word processing and representation.

To avoid this possible confound, a masked priming paradigm can be used. If pseudowords are used as primes and presented for a very short duration, no decision has to be made on the pseudoword and the linguistic processing of the prime will be stopped by the presentation of the target before it reaches any type of lexical status checking stage. The use of masked priming paradigm will prevent conscious identification of the prime and any meta-linguistic analysis of the pseudowords. Priming effects will thus be more likely to reflect the early stages of the automatic processing of complex pseudowords rather than their conscious analysis.

Results from experiments conducted in Hebrew show that when the prime is masked, a priming effect is obtained with morphologically complex pseudowords. Deutsch et al. (1998) report a facilitation effect between pseudowords and related existing words in a masked priming paradigm: a pseudoword containing a root and a verbal pattern facilitates the recognition of an existing word with the same verbal pattern (i.e., a verbal affix). These results suggest that complex words are decomposed into morphemic units and that this decomposition is prelexical (but see Frost et al., 1997). However, several typological differences separate Hebrew and French: in Semitic languages such as Hebrew or Arabic, a morphologically complex word is built from a root and a word pattern, and those two morphemes are intertwined rather than being linearly concatenated as in French or English. Moreover, almost every word in these languages is morphologically complex and consequently morphology is likely to be predominant in Hebrew, influencing both word processing and lexical organization. By contrast, a different pattern of results might emerge in a concatenative language such as French.

In this study, we used French morphologically complex pseudowords with a masked priming paradigm in order to tease apart the various hypotheses relating to the role of morphology during lexical access. We will present three experiments in which we compared the masked priming effect found using existing derived word primes such as *rapidement* “quickly” with morphologically complex pseudoword primes like *rapidifier* (*rapide* “quick” + *-ifier* “-ify”). Across experiments, we manipulated the morphemic status of the pseudowords’ ending: pseudowords used in Experiments 1 and 3 correspond to the combination of an existing root and a suffix, such as *rapidifier* “quickify” and *sportation* “sport + ation,” whereas pseudowords used in Experiment 2 are composed of an existing root and a non-morphemic ending, that is, an orthographic sequence that do not correspond to a suffix, like *-uit* in *rapiduit* “quick + uit.” We also contrasted the semantic interpretability of the pseudowords across Experiments 1 and 3: in Experiment 1 the pseudowords were well-formed pseudowords that were semantically interpretable, like *rapidifier* “to make more quick”; in Experiment 3 we used non-interpretable morphologically complex pseudowords, such as *sportation.*

Experiment 1

In this first experiment, we explored the priming effects of interpretable pseudowords on their roots. An interpretable pseudoword is formed according to the word formation rules of French. Speakers of a language often encounter such words in everyday spontaneous speech: the most frequent processes that create words in French are derivation and compounding (Sablayrolles, 2000). For example, *opérationnalité* “operationality,” from *opérationnel* and *-ité*, or *labelliser* “to label,” from *label* and *-iser*, are relatively new and widely used by French speakers, in the media, and on the Internet, even though they are not yet attested in official dictionaries. The question of what factors determine which words become neologisms among all the potential words of French is subject to discussion (see Bauer, 2001; Kjellmer, 2000), but some criteria are necessary: potential words need to be grammatically formed, respect the phonotactic rules of the language, and have morphological and semantic correlates which already exist. For example, the word *rapidifier* is derived from the adjective *rapide* “quick” and is well formed because the suffix *-ifier* “-ify” attaches to adjectives in order to form causative verbs. If *rapidifier* existed, it would mean “to make quicker.” It has several morphological and semantic correlates in French, such as the causative verb *solidifier* “to solidify,” made of the adjective *solide* “solid” and the same suffix *-ifier*. All these factors contribute to the semantic interpretability and plausibility of *rapidifier* as a French word.

We used three types of prime for each target in this experiment: an interpretable pseudoword (*rapidifier/RAPIDE*), an existing derived suffixed word (*rapidement/RAPIDE*), and an unrelated control (*autrement/RAPIDE*). Priming with pseudoword primes was thus compared with two types of control: a morphologically related control and an unrelated control.

Material

Creation of pseudowords

An initial list of 46 potential roots was used to coin the pseudowords. Each root was combined with all the compatible suffixes, using Brousseau and Nikemia (2001), and Dubois and Dubois-Charlier (1999) as references. One root could thus have more than one derived pseudoword, as in the examples given below.

frotter → *frottation*; *frotterie*
fragile → *fragilard*; *fragilâtre*; *fragilerie*; *fragilesse*; *fragilisme*
cellule → *cellulade*; *celluliser*; *cellulage*; *celluliste*

Three judges were asked to make an initial selection of the more plausible candidates in French from that first list. The resulting short list thus contained only words that were phonologically and orthographically plausible, and seemed easily semantically interpretable and possible in a sentential context.

Pretest

A pretest was carried out with naïve French speakers in order to obtain subjective evaluations of each of the resulting 97 pseudowords. For each pseudoword, participants had to indicate whether they had already seen that word (yes = 1; maybe = 2; no = 3) and whether the word seemed plausible in French or not on a 1–7 rating scale (1 = not plausible; 7 = very plausible). They were also asked to give a definition of the pseudoword when possible. Fifty fillers were added to the 97 pseudoword candidates: 25 non-interpretable or non-morphological pseudowords (e.g., *dispensou*, *plauseté)*, and 25 novel words consisting of neologisms reported in the written press (*criser*, *labelliser*). These fillers were added to encourage the participants to use all values of the plausibility and novelty scales. The 147 items were split into seven different lists, ensuring that no more than one pseudoword derived from the same root appeared in the same list. Ninety-eight native French speakers, studying psychology in Université Paris Nord (Paris 13), volunteered to participate in the pretest.

The definitions of the pseudowords given by the participants were coded in 7 different categories: (1) a transparent definition, coherent with the morphological structure of the word; (2) a transparent definition, based on the less frequent meaning of the root (mainly a metaphoric meaning, e.g., the main meaning of *chambre* is “room,” but it can mean, as a verb, to tease” or “to bring wine to room temperature”; *chambrage* could thus be defined in a transparent manner relative to any of these meanings); (3) a definition containing the root, but not coherent with the morphological structure of the word; (4) definition with a meaning related to the root (but not containing the root itself), not coherent with the morphological structure of the word; (5) the root itself as definition; (6) an unrelated or weird definition; and (7) no answer.

For the final selection of items, we kept pseudowords that had been defined in a transparent way (definitions of type 1 and 2) by more than 50% of the participants, judged as new (more than 2.1 out of 3) and plausible[1] (more than 2.6 out of 7). Thirty pseudowords formed from 30 different roots were retained. For these selected pseudowords, the mean percentage of transparent definitions was 67.68% (*SD* 12.9; all other answers were mainly blank definitions, 29.54%, *SD* 12.93). The mean novelty value was 2.6/3 (*SD* 0.27) and the mean plausibility value was 3.8/7 (*SD* 0.62).

For each root target, we selected an existing derived word and an unrelated control matched for frequency and length. A target like *INFIRME* was therefore preceded by (1) the pseudoword *infirmiser*, (2) the existing derived word *infirmité*, or (3) the unrelated control *outillage*. Average frequencies per million for targets, existing derived word and unrelated primes are, respectively, 76.5, 10.6, and 10.2 (from the Lexique database; New, Pallier, Ferrand, & Matos, 2001). Mean length in number of letters for targets, pseudoword, derived word and unrelated primes are, respectively, 7, 9.4, 9.5, and 9.4. The orthographic overlap between related prime and target pairs averages 5.8 letters for pseudoword and derived pairs.

List composition

The 90 test pairs (3 priming conditions × 30 targets) were split into three experimental lists. In each list, one third of the targets was preceded by a pseudoword prime, one third by a derived prime and one third by an unrelated control prime. The three lists were counterbalanced so that each target was preceded by the three primes across lists but appeared only once in each list.

We added 30 filler pairs with word targets to each list. Among these, 20 were unrelated word pairs (réformiste/LOQUE) and 10 were unrelated pseudoword/word pairs (noiriste/ANGE). Sixty pairs with nonword targets were also added: 10 related pseudoword/nonword pairs (solutionnette/SODUTION); 10 related derived word/nonword pairs (férocité/FELOCE); 10 unrelated pseudoword/nonword pairs (anodinat/REFRET) and 30 unrelated word/nonword pairs (acheminer/VOGET). All nonword targets were created by changing one or two letters of an existing word, making sure that the result conformed to the phonotactic constraints of French. Therefore, each subject had to perform a lexical decision task on 120 targets, 60 words and 60 nonwords. The experiment was preceded by a practice session consisting of 16 trials.

Procedure

We used a masked priming procedure as in Forster and Davis (1984). For each trial, a pre-mask of hash marks (#########) appeared in the middle of the screen for 500 ms; the pre-mask was immediately followed by the prime, in lower case, displayed for 47 ms and then immediately masked by the target, in upper case; the target remained on the screen for 3000 ms or until a response was given. Reaction times were measured from the onset of the target display. Primes and targets were displayed with a 14 point Courier font in white on a black background. The experiment was run on a PC-compatible microcomputer using DMDX software (Forster & Forster, 2002), with on-line randomization of trial order. Responses were entered via a Logitech Wingman gamepad. Participants used their dominant hand for the “yes” (i.e., “word”) response.

Participants first received written instructions as to the task to perform. They were seated in front of a computer screen (about 50 cm from their eyes) in a quiet room. The presence of a visual prime was not mentioned. Participants were told that in each trial, a string of letters would appear on the screen and they would have to decide as quickly and accurately as possible whether the letter string was a French word or not. The total duration of the experiment was 10 min.

Participants

Forty-one students at Ecole des psychologues praticiens and at the Institut d’études politiques de Lyon (France) were paid for their participation. All the participants were native speakers of French and had normal or corrected-to-normal vision. None of them participated to the pretest or to the other experiments.

Results and discussion

Three participants were rejected because their error rate for test target words exceeded 10%, which was considered too high (the error rate averaged to 3.9% for the other participants). Only reaction times for correct “yes” responses shorter than 1500 ms were retained for RT analyses (outliers corresponded to 0.88% of the data). The results are summarized in Table 1. The RT and error rate data were submitted to by-subject and by-item analyses of variance with priming condition (unrelated, inter-

[1] The average score of plausibility for all 97 candidates was low (3.8 out of 7). A deeper analysis of all answers revealed that participants of this pretest (different from the participants of the pretest conducted for Experiment 3) never used the higher values of the plausibility scale, even for the neologisms included as fillers (average of 3.8 out of 7). We also noticed incoherence between the precision and the transparency of the definitions given and the plausibility score. For example, the pseudoword *adaptiste* was defined in a transparent way by 85% of the participants, but its plausibility score was of 2.6 out of 7. As a consequence, we kept in priority pseudowords that were defined in a transparent way, and among these, retained the 30 candidates that had the highest plausibility and novelty scores.

Table 1
Experiment 1: average RT (ms) and error rates by priming condition (standard errors in brackets)

Priming condition	Results	
	RT	Errors (%)
Unrelated	700 (17)	5.27
Interpretable pseudoword	659 (17)	2.51
Existing derived word	657 (13)	3.15

pretable pseudoword, existing derived word) as a within subjects independent variable.

Reaction times

Priming relation had a significant main effect by subjects and by items $F_1(2,74) = 5.45$, $p = .006$; $F_2(2,58) = 5.09$, $p = .009$. Planned comparisons showed that the 41 ms facilitation effect between the pseudoword condition and the unrelated condition was significant, $F_1(1,37) = 6.83$, $p = .01$; $F_2(1,29) = 8.65$, $p = .006$, and facilitation effect between the existing derived word and the unrelated conditions (43 ms) was also significant, $F_1(1,37) = 7.92$, $p = .008$; $F_2(1,29) = 7.12$, $p = .012$. There was no significant difference between the pseudoword and the existing derived word conditions, *F*s < 1.

Error rates

The main effect of priming relation was not significant by subjects and marginally significant by items, $F_1 < 1$; $F_2(2,58) = 2.9$, $p = .06$. There were less errors in the pseudoword condition than in the unrelated condition but this 2.76% difference was only significant by items, $F_1 < 1$; $F_2(1,29) = 4.68$, $p = .04$. The error rate in the existing derived word condition was not significantly different from the unrelated condition, $F_1 < 1$; $F_2(1,29) = 2.50$, $p = .12$, nor from the pseudoword condition, *F*s < 1.

The results of this first experiment show a significant facilitation effect with primes consisting of a new combination of a root and a suffix. This effect is of the same magnitude as the classical morphological priming effect obtained with existing derived word primes. It indicates that French pseudowords like *rapidifier* activate the representation of their roots even if they have never been encountered before and therefore do not have any lexical entry in the participants' mental lexicon. These results suggest that words are decomposed into morphemes very early on during visual word processing and that morphological decomposition occurs before any lexical-status checking stage. However, it remains possible that the priming effect observed between morphologically complex pseudowords and their roots is due to the orthographical overlap between the target and the prime, and not to morphological decomposition. We will address this issue in the next experiment, which uses non-morphological pseudoword primes.

Experiment 2

The goal of the second experiment was to see whether the facilitation effect obtained with morphological pseudoword primes of Experiment 1 is due to orthographic overlap between the prime and the target, rather than to morphological decomposition. In this experiment, we used as primes non-morphological pseudowords, made of the combination of a root and a non-morphemic ending of French. For example, we compared the effect of a non-morphological pseudoword like *rapiduit* and of an existing derived word like *rapidement* "quickly" on the recognition of the base word *rapide* "quick." The ending -*uit* is not a suffix in French, but appears at the end of existing words like *fortuit* "fortuitous," *biscuit* "cookie," etc. If the processing of pseudowords is not morphological but orthographic in a left-to-right manner, then we should obtain a facilitation effect for these pseudowords as well. If the effects obtained in Experiment 1 are morphological in nature and are due to decomposition in the early stages of processing, then we should not obtain any effect with those non-morphological pseudoword primes. In other words, the non-morphological pseudowords used in this experiment are an orthographic control for the priming with morphological pseudowords.

Material

Creation of pseudowords

We used the 30 targets from Experiment 1, to which we added a non-morphemic ending. We used endings that already exist in French but that do not correspond to suffixes. We chose endings appearing in at least 5 words of French, and appearing in at least one word with a pseudo-root, like the ending -*cot* from the word *abricot* "apricot," in which we can isolate the pseudo-root *abri* "shelter." Each ending was used in one to three words of the experiment in order to standardize the material with Experiment 1, in which the same suffix was sometimes used to coin more than one pseudoword. The pseudowords respected the graphemic and phonological rules of French and could be easily pronounced. Average frequencies (per million, New et al., 2001) for targets, derived and unrelated primes are, respectively, 76.5, 10.6, and 10.2. Mean length in number of letters for targets, pseudoword, derived and unrelated primes were, respectively, 7, 9.2, 9.5, and 9.4. The orthographic overlap between related primes (pseudoword and derived word) and targets was 5.8 letters.

List composition

The lists were composed as for Experiment 1. The 90 prime target pairs (3 prime relations × 30 targets) were separated into three lists and counterbalanced across lists. The fillers were the same, except that pseudoword primes were non-morphological pseudowords (pendulive/PENDUTE; inventide/LOISIR).

Procedure

The procedure was the same as for Experiment 1.

Participants

Thirty-eight students took part in the experiment: 26 students from Université René Descartes, on a voluntarily basis, and 12 students of Ecole des psychologues praticiens and of the Institut d'études politiques de Lyon, paid for their participation, were evenly distributed among lists. All participants were native speakers of French and had normal or corrected-to-normal vision. None of them participated to the other experiments.

Results and discussion

Three participants were rejected because their error rates for test target words exceeded 10%, which was considered too high (error rate averaged to 3.24% for the other participants). Only reaction times for correct "yes" responses shorter than 1500 ms were retained for RT analysis (outliers corresponded to 0.57% of the data). The results are summarized in Table 2. The RT and error rates data were submitted to by-subject and by-item analyses of variance with priming condition (unrelated, non-morphological pseudoword, existing derived word) as the independent variable.

Reaction times

The main priming effect was significant by subject and by items, $F_1(2,68) = 6.11$; $p < .004$; $F_2(2,58) = 6.08$, $p = .004$. The priming effect for the non-morphological pseudoword condition in comparison to the unrelated condition was not significant, Fs < 1. Reaction times obtained in derived word condition were different both from those obtained in unrelated condition (37 ms: $F_1(1,34) = 15.41$; $p < .001$; $F_2(1,29) = 11.397$; $p = .002$) and in pseudoword condition (29 ms: $F_1(1,34) = 5.69$; $p < .023$; $F_2(1,29) = 7.47$; $p = .011$).

Error rates

The analysis of the error rates did not yield any significant difference, all Fs < 1.

The results of this experiment show that the mere occurrence of the target at the beginning of the pseudoword prime is not sufficient to produce significant priming: the non-morphological pseudoword *rapiduit* does not facilitate the embedded word *rapide*, whereas an existing derived word like *rapidement* does, as in Experiment 1. This absence of orthographic priming effect obtained with these pseudowords is comparable to results obtained in masked priming experiments with real words. In French, pairs like *abricot/ABRI* "apricot/shelter," which are only orthographically related, do not yield any significant facilitation effect (Longtin et al., 2003). These results strongly suggest that the facilitation effect obtained in Experiment 1 with the interpretable morphological pseudowords is morphological in nature and not orthographical. Yet, the pseudowords used in Experiments 1 and 2 not only differed on the morphemic status of their ending, but also on their semantic interpretability. While it is possible to find a meaning to the pseudoword *rapidifier*, it is far less obvious what a word like *rapiduit* could mean. As a consequence, we do not know if *rapiduit* fails to prime *rapide* because of its non-suffixal ending or because it cannot be semantically interpreted. We will address this issue in Experiment 3.

Table 2
Experiment 2: average RT (ms) and error rates by priming condition (standard errors in brackets)

Priming relation	Results	
	RT	Errors (%)
Unrelated	659 (15)	3.14
Non-morphological pseudoword	651 (15)	3.43
Existing derived word	622 (15)	3.14

Experiment 3

When used with a simple lexical decision task, morphologically complex pseudowords take longer to reject when they are semantically interpretable than when they are not (Burani, Dovetto, Spuntarelli, & Thornton, 1999; Burani, Marcolini, & Stella, 2002; Wurm, 2000). In turn, pseudowords containing morphemes take longer to reject than simple pseudowords, or pseudowords built out of a root and an orthographic ending (Caramazza et al., 1988; Laudanna, Burani, & Cermele, 1994; Taft & Forster, 1975, 1976; Taft, 1979a; Taft, Hambly, & Kinoshita, 1986). Those studies show that participants are sensitive to pseudowords' morphological structure and semantic properties when they process them consciously within a simple lexical decision task, but whether these factors come into play at an early or late stage of processing is an open question.

The goal of this experiment is thus to determine whether the absence of priming observed with non-morphological pseudowords in Experiment 2 is due to their non-morphological structure or to their non-interpretability. In this third experiment, we used non-interpretable morphological pseudowords as primes, in this case instantiated by nonwords containing a grammatical violation, i.e., made of the combination of a root and a suffix whose grammatical categories are incompatible. New words cannot be coined by the simple concatenation of any suffix to any root: French morphology has combinatorial rules, based on phonological, syntactic, and semantic factors. For example, the French suffix *-ion* has several allomorphs (*-ation*; *-ition*) and the choice of the allomorph depends on the phonological and morphological properties of the base. This suffix also has strong grammatical constraints: it only attaches to verbs, and any pseudowords formed with *-ion* and a non-verbal base would be ungrammatical. As a result, a pseudoword like *sportation* is not a potential word of French because s*port* "sport" is a noun. This type of violation leads to semantic oddness, and it is difficult to find any meaning to such a word. As in Experiments 1 and 2, the priming effect to these pseudowords was compared with priming from an existing derived word and an unrelated control word.

Materials

Creation of pseudowords

To create non-interpretable pseudowords, we first made a list of the productive suffixes of French and their combinatorial constraints (based on Brousseau & Nikemia, 2001). For example, the suffix *-eur* in French can only be attached to verbs and adjectives, and every formation with that suffix and a nominal base would be ungrammatical. We matched these suffixes with base words (nouns, verbs, and adjectives), making sure that the combination of the two morphemes was illegal and that the result was not semantically interpretable, but still orthographically and phonologically plausible, as in the following examples: N + *eur* → *denteur*; V + *elle* → *utiliselle*. Forty-eight non-interpretable pseudowords were formed this way.

Pretest

A pretest ensured that the pseudowords were not semantically interpretable. For each pseudoword, participants were asked to indicate whether the pseudoword was plausible or not on a 1–7 scale and to give a definition if possible. We added 50 fillers consisting of interpretable pseudowords with various degrees of plausibility. Eighty native French-speaking students (54 from Université René Descartes, France, for course credit in psychology, and 26 from Université Louis Lumière, on a voluntary basis) completed the pretest. The results were coded using the same categorization as in Experiment 1.

Final selection of items

We selected 30 pseudowords for which participants failed to give a definition and that were judged not plausible by participants. The mean percentage of blank answers was 74.22% (*SD* 13.89). All the other answers were the root itself (12.44%, *SD* 10.81), a transparent definition[2] (4.82%, *SD* 7.33), a definition containing the root but not coherent with the morphological structure (2.86%, *SD* 3.91) or a definition related to the meaning of the root (1.79%, *SD* 4.15). The mean plausibility value was 2.2/7 (*SD* 0.56).

For each root target, we selected an existing derived word and an unrelated control matched for frequency and length. For example, the target *GARAGE* "garage" was preceded by (1) the pseudoword prime *garagité*, (2) the existing derived word *garagiste* "garage owner, mechanics," and (3) the unrelated control word *diversion* "diversion." Average frequencies (per million, New et al., 2001) for targets, derived and unrelated primes are 94.2, 13, and 11.9, respectively. Mean length in number of letters for targets, pseudoword, derived and unrelated primes are 6.1, 9.1, 9.2, and 9.2 respectively. The average orthographic overlap between related prime (pseudoword and derived word) and target pairs is 5.3 letters.

List composition

Experimental lists were created in the same way as for the previous experiment. The 90 prime-target pairs were distributed among three experimental lists and the prime and target relations were counterbalanced among these lists. The fillers were the same as in Experiments 1 and 2, except for the pseudoword primes, which were replaced by non-interpretable morphological pseudowords (e.g., inventiser/MASSUE; pendulement/PENDUTE).

Participants

Forty-five students at Ecole des psychologues praticiens and at the Institut d'études politiques de Lyon (France) were paid for their participation. All participants were native speakers of French and had normal or corrected-to-normal vision. None of them participated to the pretest or to the other experiments.

Procedure

We used the same procedure as in Experiments 1 and 2.

Results and discussion

Four participants were rejected because their error rate for test target words exceeded 10% (error rate averaged 2.68% for the other participants). Reaction times for "yes" responses above 1500 ms were eliminated (0.41% of data was removed according to this criterion). The results are summarized in Table 3. Reactions times and error rates were submitted to by-subject and by-item analysis of variance with the priming relation as the main factor (unrelated, non-interpretable pseudoword, derived word).

Reaction times

There was a significant main effect of priming condition, $F_1(2,80) = 10.36$, $p = .001$; $F_2(2,58) = 14.33$,

[2] Some participants gave a definition that contained both the root and the semantic properties of the suffix, even if this definition was describing an implausible object, action, agent, etc.

Table 3
Experiment 3: average RT (ms) and error rates by priming condition (standard errors in brackets)

Priming relation	Results	
	RT	Errors (%)
Unrelated	629 (11)	3.87
Non-interpretable pseudoword	593 (10)	3.1
Existing derived word	588 (10)	0.97

$p = .0001$. A facilitation effect of 36 ms obtained with non-interpretable pseudoword primes compared to the unrelated condition was significant, $F_1(1,40) = 11.29$, $p = .002$; $F_2(1,29) = 16.68$, $p < .001$, as was a 41 ms facilitation effect for existing derived primes, $F_1(1,40) = 20.76$, $p < .001$; $F_2(1,29) = 22.64$; $p < .001$. The difference between the pseudoword and derived conditions was not significant, Fs < 1.

Error rates

The main effect of priming relation was significant by subjects and by items, $F_1(2,80) = 3.92$, $p = .024$; $F_2(2,58) = 4.53$, $p = .015$. There was no difference between the non-interpretable pseudoword and the unrelated conditions, Fs < 1. The error rate obtained in the derived word condition was significantly lower than that obtained in the non-interpretable pseudoword condition, $F_1(1,40) = 8.52$, $p = .006$; $F_2(1,29) = 6.27$, $p = .018$, and than the error rate in the unrelated condition, $F_1(1,40) = 6.07$, $p = .018$; $F_2(1,29) = 6.15$, $p = .019$. This difference seems to be due to a particularly low error rate in the existing derived word condition (0.97% compared to 3.15% in Experiment 1 and 3.14% in Experiment 2). Considering that the pseudoword and the unrelated condition elicited comparable error rates to those obtained in the previous experiments, we will not discuss this difference further.

The reaction time results show that the priming effect observed with non-interpretable morphologically complex pseudowords is comparable to the effect obtained with existing derived words. These results rule out the possibility that the difference in pseudoword priming effects between Experiment 1 and Experiment 2 are due to the difference in semantic interpretability. They rather show that it is the morphological structure of pseudowords which is critical to obtain facilitation effects: if pseudowords can be parsed into root and suffix, then there is a facilitation effect of the same magnitude as the effect obtained with existing derived words. Furthermore, a combined analysis of Experiment 1 and Experiment 3 showed no interaction between priming effects and type of pseudowords used (neither compared to the unrelated condition nor to the derived word condition, all Fs < 1), showing that the semantic interpretability had no effect in masked priming.

General discussion

In this study, we investigated the role of the morphological structure and semantic properties of pseudowords in three masked priming experiments. In each experiment, we directly compared priming from existing derived words with priming from pseudowords. Across experiments, we controlled the interpretability of the morphological pseudowords as well as the morphemic status of their endings. In Experiment 1, we used interpretable morphologically complex pseudowords consisting the grammatical combination of roots and compatible suffixes. The main finding from this experiment is that the masked presentation of a pseudoword containing a root and a suffix such as *rapidifier* facilitates the recognition of its root *RAPIDE.* The facilitation effect obtained with these pseudoword primes did not differ in magnitude from the effect observed with existing derived primes: There was no difference between the facilitation yielded by *rapidifier* and *rapidement* on the target *RAPIDE.* Experiment 2 was conducted in order to verify that the priming effect obtained with interpretable morphologically complex pseudowords was morphological in nature and not due to orthographic overlap between prime and target. For this purpose, we used non-morphological pseudowords, consisting of a root and a non-suffixal ending of French. This experiment demonstrated that the mere occurrence of the root target at the beginning of the pseudoword prime was not sufficient to produce priming: *Rapiduit*, with non-suffixal ending *-uit*, does not prime *RAPIDE*, although the length of the orthographic overlap between the prime and the target is the same as that in Experiment 1 (*rapiduit* vs. *rapidifier*). The goal of Experiment 3 was to see if the lack of priming observed in Experiment 2 was due to the non-suffixal ending of pseudowords or to their semantic opacity. In this last experiment, we used non-interpretable morphologically complex pseudowords involving the ungrammatical combination of roots and suffixes, like *sportation.* The facilitation obtained with these pseudowords showed that the interpretability of the root-suffix combination does not interfere with morphological priming; the priming effect is insensitive to the fact that the root and the suffix are not compatible and violate word formation rules of French. Overall, these results show that words' morphological structure plays an important role in word recognition. We will argue that morphologically complex pseudowords are decomposed during access, that decomposition occurs in the early stages of visual word processing and is blind to the semantic properties of the prime and its lexical status.

When compared to experiments using pseudowords in combination with lexical decision task and no priming, the results of our masked priming experiments show that different properties are taken into account at early and late(r) stages of word processing. As we mentioned earlier, semantically interpretable pseudowords yield longer lexical decision times than non-interpretable pseudowords (Burani et al., 1999, 2002; Wurm, 2000). In contrast, our results show the same priming effects for interpretable and non-interpretable pseudowords in masked priming. Taken together, these results suggest that the semantic properties of pseudowords are only taken into account at later stages of word processing. The early stages are only sensitive to the morphological structure of the pseudoword (whether it is parsable into morphemes or not), not to its well-formedness or interpretability.

These different patterns of results with pseudowords are consistent with results from priming experiments conducted with real words. In particular, the absence of a semantic interpretability effect observed in our experiments is consistent with the absence of semantic transparency effect observed with real words in masked priming (Feldman & Soltano, 1999; Longtin et al., 2003; Rastle et al., 2000; Rastle & Davis, 2003; Rastle et al., 2005). Semantic transparency refers to the degree to which a derived word's meaning is related to the meaning of its root. For example, the French word *clochette* "small bell" is strongly semantically related to its root *cloche* "bell," while the word *vignette* "label, road tax sticker" is not related to the meaning of its etymological root *vigne* "vine" and is for this reason semantically opaque. Equivalent to opaque words are pseudo-derived words like *baguette* "French bread, chopsticks/ring," which can be parsed into the base morpheme *bague* and the suffix *-ette*, but is neither etymologically nor semantically related to *bague. Clochette*, *vignette*, and *baguette* all have the same morphological surface structure (a noun and the suffix *-ette*) but only the first one is truly morphologically complex. Yet they all show the same facilitation effect in masked priming, which is different from priming obtained with orthographically related pairs (Longtin et al., 2003). Studies conducted in English also show that facilitation is obtained between opaque words (Feldman & Soltano, 1999; Longtin et al., 2003; Rastle et al., 2000; Rastle & Davis, 2003; Rastle et al., 2005). These masked priming data using real word primes support the hypothesis that the early stages of visual word recognition are sensitive to the morphological structure of the prime but not to their semantic properties. Results provided by unmasked priming experiments with transparent and opaque words further show that it is only later that semantic properties are taken into account. Indeed, when an auditory or unmasked visual prime is used, a priming effect is observed only for morphologically related words that are also semantically related: A semantically transparent word like *clochette* primes *cloche*, but an opaque word like *vignette* does not prime *vigne* (Feldman & Soltano, 1999; Longtin et al., 2003; Marslen-Wilson et al., 1994; Rastle et al., 2000).

We argue that morphological structure plays a role at a very early stage of word processing, before the activation of whole word lexical representations and before the integration of the semantic properties has begun. Very early on in lexical processing, a blind decomposition process appears to start as soon as the item presented *looks* morphologically complex, irrespective of whether its morphological structure is relevant to the word's meaning or not. Results with orthographically related words suggest that this decomposition is not a left-to-right process but rather a parallel mapping of the input to the available morphemic units (both roots and affixes). If it were a left-to-right process, we would have expected pseudowords like *rapiduit* to activate their pseudo-root: instead it fails to produce any significant priming because *-uit* is not a morpheme and no other possible morphological segmentation is available.[3]

In this respect, results obtained in a masked priming paradigm with real French words support this interpretation, as no facilitation effect is found with orthographically related pairs like *abricot/abri* "apricot"/"shelter," in which *-cot* is not a morpheme of French (Longtin et al., 2003). However, it is worth noting that there are many discrepancies in the literature regarding orthographic priming. Studies in which morphological and orthographical priming were compared have yielded quite diverging results: many authors reported weak and non-significant orthographic facilitation (Boudelaa & Marslen-Wilson, 2001; Chateau, Knudsen, & Jared, 2002; Diependaele et al., 2005; Feldman, 2000; Feldman & Soltano, 1999; Forster & Azuma, 2000, Exp. 3; Giraudo & Grainger, 2000; Rastle et al., 2000, Exp. 1; Rastle & Davis, 2003; Rastle et al., 2005); Forster and Azuma (2000, Exp. 2) reported significant orthographic facilitation; others reported non-significant inhibition (Badecker & Allen, 2002; Longtin et al., 2003; Pastizzo & Feldman, 2002; Rastle et al., 2000, Exp. 2), or significant inhibition (Drews & Zwitserlood, 1995; Grainger et al., 1991). In summary, the majority of the studies report non-significant effects with orthographically related pairs and in most cases (except Forster & Azuma, 2000), morphological facilitation was significantly stronger than orthographic priming. These studies contribute to the idea that the observed decomposition is not entirely orthographic, even if it is driven by the surface morphological structure of the prime. Early decomposition would occur only on words which are parsable into mor-

[3] Studies in simple lexical decision have shown that pseudowords containing a root but no suffix such as *rapiduit* take longer to reject than simple pseudowords like *dapiduit* (e.g., Taft, 1979b), suggesting that the pseudo-root in the pseudoword is identified. As these results contrast with what we observed in Experiment 2 in masked priming, it suggests that conscious processing of nonwords differ significantly from unconscious processing.

phemes at the surface level, even when it seems unhelpful because the prime is semantically opaque, and even if the prime has no whole word lexical entry in the lexicon.

One concern in our experiments is that the distributional properties of the pseudowords' endings differ between morphological and non-morphological pseudowords. In Experiment 2, we chose orthographical endings that already existed in the lexicon in order to assure a certain ecological validity, but they were not matched in frequency to the real suffixes used in Experiments 1 and 3. As a consequence, it could be argued that the difference between the priming effects with morphological and non-morphological pseudowords is due to the frequency of the endings used in each experiment and not to their morphemic status per se. We believe however that suffixes and orthographic endings are fundamentally different and that frequency alone does not explain our results. Suffixes tend to be more frequent than orthographical endings. Even more importantly, suffixes appear in words that are parsable into morphemes, that is, in which a root—either bound or unbound—and other affixes can be isolated. In contrast, even though some orthographic endings are relatively frequent in the French lexicon, they almost never appear simultaneously with a root. By definition, affixes appear in words next to existing roots, which in turn appear in other words with other morphemes. This is not the case of orthographic endings. As Rastle and colleagues pointed out (Rastle & Davis, 2003; Rastle et al., 2005), morphemes develop salient representations because they constitute orthographic units that occur and recur in the language. It seems useful for the system to capitalize on the orthographic regularity provided by morphology in addition to the regularity in form-meaning association. It is likely that these representations are exploited during the early stages of visual word recognition and guide the system into later stages of morphological processing and semantic integration (see Rastle et al., 2005). One possible approach to check whether it is the frequency of the ending and not its morphemic status that is critical in obtaining a priming effect would have been to use rare suffixes that matched in frequency with orthographic endings. However, these suffixes would likely have been unproductive, and productivity might also affect morphological priming (see Bertram, Baayen, & Schreuder, 2000 for a study on the role of affix productivity with a simple lexical decision task). It thus seems difficult to really disentangle these factors, given the intrinsic nature of morphemes: sequences that correspond to morphemes are frequent and recurrent in complex words, which is probably the reason why they play a role in both the architecture of the mental lexicon and word processing.

The fact that morphologically complex pseudowords facilitate the recognition of their root constrains theoretical models of the mental lexicon. It implies that morphemes (roots and affixes) are represented in the lexicon and are directly available. Any model in which access to complex words can be made only in a direct manner would fail to explain our results, even if the morphological structure of words is conveyed by links among morphologically related words (Bradley, 1979; Colé et al., 1989; Segui & Zubizarreta, 1985) or by a morphemic supralexical level (Giraudo & Grainger, 2000, 2001). In Giraudo and Grainger (2000, 2001) multi-level model of morphology, morphemes are represented in the lexicon but the morphological level is between the lexical (whole word) level and the semantic representations. Morphologically complex words are thus accessed directly, and it is only when their whole word representations are activated that their morphemes are activated as well. Accordingly, a pseudoword, which does not have a representation at the lexical level, will not be able to directly activate its morphological components, and will not be able to cause priming.

Our proposal of a very early decomposition of words which are composed of a root and a suffix is consistent with prelexical models of morphological processing such as that of Taft (2003; see also Taft, 1994, 2005) in which three different levels of representations are distinguished: form (morpheme-based), lemma, and semantic features. The recognition of complex words is achieved by the successive activation of these three levels: the decomposition into morphemic units, the activation of the corresponding lemmas and of their semantic features. Allen and Badecker (1999, 2002; Badecker & Allen, 2002) propose a similar model for the processing of inflected words and argue that morphologically complex word processing is initially achieved by the activation of morphemic units at the lexical level, then by the activation of syntactic and semantic units at the lemma level.

The priming effect obtained with pseudowords can also be explained by models allowing two parallel access routes—one direct route and one analytic, decompositional route—or two access codes—full and morphemic representations (Caramazza et al., 1988; Caramazza, Miceli, Silvieri, & Laudanna, 1985; Frauenfelder & Schreuder, 1992; Schreuder & Baayen, 1995; Schreuder, Burani, & Baayen, 2003). In these models, a derived word can be accessed directly, via its full form representation, or via its morphemic components. Full-form or morphemic representations can be activated in parallel for real words (depending on the word's properties; see, for example, Frauenfelder & Schreuder, 1992); pseudowords will be accessed via their morphemic components, and the decomposition route will be used for their processing.

Irrespective of the specific architecture of the models which explain the results presented in this paper, our data show that morphemic units are extracted automatically very early on in visual word processing, suggesting that the morpheme is a central access unit. The system's blindness to semantic properties shows the strength of this morphological mapping, as it is applicable even when it is not useful to the semantic interpretation of the word and even when it is processing words that it has never seen before. Moreover, the use of pseudoword primes in masked priming provides a useful way of studying various aspects of morphology. It makes it possible to control the frequency and productivity of root and affixes, a control that is difficult to achieve when working within the limits of the lexicon. Recent studies have shown that distributional and linguistic factors such as productivity, homonymy, morphological family size, stem and affixes frequency have an important role to play in word processing (e.g., Bertram et al., 2000; Bertram, Laine, Baayen, Schreuder, & Hyönä, 2000; Bertram, Schreuder, & Baayen, 2000; Burani & Thornton, 2003; de Jong, Schreuder, & Baayen, 2000; Schreuder & Baayen, 1997). Using pseudowords as primes in a masked priming paradigm to study these factors would allow us to see if—and how—they affect early visual word processing and morphological decomposition.

Appendix A

Stimuli of Experiment 1

Primes			Targets
Interpretable pseudowords	Existing derived word	Unrelated	
adaptiste	adaptation	modalité	ADAPTER
brusqueur	brusquerie	guitariste	BRUSQUE
canaleur	canaliser	glorifier	CANAL
catastrophier	catastrophique	astrologique	CATASTROPHE
celluliser	cellulaire	périodique	CELLULE
chambrage	chambrette	gouvernail	CHAMBRE
chanceté	chanceux	adhésif	CHANCE
claquiste	claquement	trouvaille	CLAQUER
digestatoire	digestion	procureur	DIGERER
douaniser	douanier	émetteur	DOUANE
éclateur	éclatement	résignation	ECLATER
embrasseur	embrassade	récréation	EMBRASSER
esclaver	esclavage	barricade	ESCLAVE
frottoir	frottement	arrestation	FROTTER
groupoir	groupement	souffrance	GROUPER
hilarisme	hilarité	attirance	*HILARE
hurlard	hurlement	migration	HURLER
infirmiser	infirmité	outillage	INFIRME
inquiéteur	inquiétude	protection	INQUIET
lointaineté	lointainement	affectivement	LOINTAIN
misérifier	misérable	forestier	MISERE
navigade	navigation	rhumatisme	NAVIGUER
noisettine	noisetier	colonnade	NOISETTE
onctuosifier	onctuosité	réservation	ONCTUEUX
placette	placement	tolérance	PLACER
propreur	propreté	abattoir	PROPRE
prunasse	prunier	lainage	PRUNE
rapidifier	rapidement	autrement	RAPIDE
restrictionner	restrictif	maniable	RESTREINDRE
timidifier	timidité	punition	TIMIDE

*This target was removed from the analysis.

Stimuli of Experiment 2

Primes			Targets
Non-morphological pseudoword	Existing derived word	Unrelated	
adapteille	adaptation	modalité	ADAPTER
brusquèche	brusquerie	guitariste	BRUSQUE
canalare	canaliser	glorifier	CANAL

(*continued on next page*)

Appendix A (*continued*)

Primes			Targets
Non-morphological pseudoword	Existing derived word	Unrelated	
catastropherge	catastrophique	astrologique	CATASTROPHE
cellulogne	cellulaire	périodique	CELLULE
chambrour	chambrette	gouvernail	CHAMBRE
chancerge	chanceux	adhésif	CHANCE
claquogne	claquement	trouvaille	CLAQUER
digestuit	digestion	procureur	DIGERER
douanoupe	douanier	émetteur	DOUANE
éclatuche	éclatement	résignation	ECLATER
embrastime	embrassade	récréation	EMBRASSER
esclavecte	esclavage	barricade	ESCLAVE
frottume	frottement	arrestation	FROTTER
groupume	groupement	souffrance	GROUPER
hilarigne	hilarité	attirance	HILARE
hurlerne	hurlement	migration	HURLER
infirmare	infirmité	outillage	INFIRME
inquiéteille	inquiétude	protection	INQUIET
lointainape	lointainement	affectivement	LOINTAIN
misérigne	misérable	forestier	MISERE
navigape	navigation	rhumatisme	NAVIGUER
noisetoupe	noisetier	colonnade	NOISETTE
onctugon	onctuosité	réservation	ONCTUEUX
placeps	placement	tolérance	PLACER
proprèche	propreté	abattoir	PROPRE
pruneps	prunier	lainage	PRUNE
rapiduit	rapidement	autrement	RAPIDE
restrictape	restrictif	maniable	RESTREINDRE
timiderne	timidité	punition	TIMIDE

Stimuli of Experiment 3

Primes			Targets
Non-interpretable pseudoword	Existing derived word	Unrelated	
aptade	aptitude	vocation	APTE
canalitude	canaliser	glorifier	CANAL
cellulitude	cellulaire	périodique	CELLULE
chambritude	chambrette	gouvernail	CHAMBRE
claquitude	claquement	trouvaille	CLAQUER
cuisinitude	cuisinier	feuillage	CUISINE
denteur	dentiste	nageoire	DENT
drôlage	drôlerie	studieux	DROLE
équipâtre	équipier	déraison	EQUIPE
exactage	exactitude	plantation	EXACT
fatalage	fataliste	évocation	FATAL
favoreté	favorable	minuscule	FAVEUR
fragilade	fragilité	altération	FRAGILE
frottelle	frottement	arrestation	FROTTER
garagité	garagiste	diversion	GARAGE
groupeté	groupement	souffrance	GROUPER
hurlitude	hurlement	migration	HURLER
inquietelle	inquiétude	protection	INQUIET
miséreur	misérable	forestier	MISERE
naviguitude	navigation	rhumatisme	NAVIGUER
niaisaire	niaiserie	graduation	NIAIS
personneur	personnifier	interrupteur	PERSONNE
placeté	placement	tolérance	PLACER

(*continued on next page*)

Appendix A (*continued*)

Primes			Targets
Non-interpretable pseudoword	Existing derived word	Unrelated	
prioritation	prioritaire	inestimable	PRIORITE
propriste	proprement	abattoir	PROPRE
prunation	prunier	lainage	PRUNE
saluteté	salutaire	judicieux	SALUT
sportation	sportif	fiscal	SPORT
stylation	styliser	triturer	STYLE
utiliselle	utilisation	communauté	UTILISER

References

Allen, M., & Badecker, W. (1999). Stem homograph inhibition and stem allomorphy: Representing and processing inflected forms in a multi-level lexical system. *Journal of Memory and Language, 41*, 105–123.

Allen, M., & Badecker, W. (2002). Stem homographs and lemma level representations. *Brain and Language, 81*, 79–88.

Assink, E. M. H., & Sandra, D. (Eds.). (2003). *Reading Complex Word: Cross-language Studies*. New York: Kluwer Academic.

Baayen, H. R., & Schreuder, R. (Eds.). (2003). *Morphological structure in language processing*. Berlin: Mouton de Gruyter.

Badecker, W., & Allen, M. (2002). Morphological parsing and the perception of lexical identity: A masked priming study of stem homographs. *Journal of Memory and Language, 47*, 125–144.

Bauer, L. (2001). *Morphological productivity*. Cambridge, UK: Cambridge University Press.

Bentin, S., & Feldman, L. B. (1990). The contribution of morphological and semantic relatedness to repetition priming at short and long lags: Evidence from Hebrew. *The Quarterly Journal of Experimental Psychology, 42A*, 693–711.

Bertram, R., Baayen, R. H., & Schreuder, R. (2000). Effects of family size for complex words. *Journal of Memory and Language, 42*, 390–405.

Bertram, R., Laine, M., Baayen, R. H., Schreuder, R., & Hyönä, J. (2000). Affixal homonymy triggers full-form storage, even with inflected words, even in a morphologically rich language. *Cognition, 74*, B13–B25.

Bertram, R., Schreuder, R., & Baayen, R. H. (2000). The balance storage and computation in morphological processing: The role of word formation type, affixal homonymy, and productivity. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 26*, 489–511.

Boudelaa, S., & Marslen-Wilson, W. D. (2001). Morphological units in the Arabic mental lexicon. *Cognition, 81*, 65–92.

Bradley, D. (1979). Lexical representation of derivational relation. In M. Aronoff & M. L. Kean (Eds.), *Juncture* (pp. 37–55). Saratosa, CA: Anma Libri.

Brousseau, A.-M., & Nikemia, E. (2001). *Phonologie et morphologie du français [Phonology and morphology of French]*. Saint-Laurent, Québec: Fidès.

Burani, C., Dovetto, F. M., Spuntarelli, A., & Thornton, A. M. (1999). Morpho-lexical access and naming: The semantic interpretability of new-root suffix combinations. *Brain and Language, 68*, 333–339.

Burani, C., Marcolini, S., & Stella, G. (2002). How early does morpholexical reading develop in readers of a shallow orthography?. *Brain and Language, 81*, 568–586.

Burani, C., & Thornton, A. M. (2003). The interplay of root, suffix and whole word frequency in processing derived words. In H. R. Baayen & R. Schreuder (Eds.), *Morphological Structure in Language Processing* (pp. 157–208). Berlin: Mouton de Gruyter.

Buttherworth, B. (1983). Lexical representation. In B. Butterworth (Ed.), *Language production* (pp. 257–294). London: Academic Press.

Bybee, J. L. (1985). *Morphology: A study of the relation between meaning and form*. Amsterdam: Benjamins.

Bybee, J. L. (1995). Regular morphology and the lexicon. *Language and Cognitive Processes, 10*, 425–455.

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

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

Chateau, D., Knudsen, E. V., & Jared, D. (2002). Masked priming of prefixes and influence of spelling-meaning consistency. *Brain and Language, 81*, 587–600.

Colé, P., Beauvillain, C., & Segui, J. (1989). On the representation and processing of prefixed and suffixed derived words: A differential frequency effect. *Journal of Memory and Language, 28*, 1–13.

Colé, P., Segui, J., & Taft, M. (1997). Words and morphemes as units for lexical access. *Journal of Memory and Language, 37*, 312–330.

Deutsch, A., Frost, R., & Forster, K. I. (1998). Verbs and nouns are organized differently in the mental lexicon: Evidence from Hebrew. *Journal of Experimental Psychology: Learning, Memory and Cognition, 24*, 1238–1255.

Diependaele, K., Sandra, D., & Grainger, J. (2005). Masked cross-modal priming: Unravelling morpho-orthographic and morpho-semantic influences in early word recognition. *Language and Cognitive Processes, 20*, 75–114.

Dominguez, A., Cuetos, F., & Segui, J. (2002). Representation and processing of inflected words in Spanish: masked and unmasked evidence. *Linguistics, 40*, 235–259.

Drews, E., & Zwitserlood, P. (1995). Morphological and orthographic similarity in visual word recognition. *Journal of Experimental Psychology: Human Perception and Performance, 21*, 1098–1116.

Dubois, J., & Dubois-Charlier, F. (1999). *La dérivation suffixale en français* [*Suffixal derivation in French*]. Paris: Nathan Université.

Feldman, L. B. (2000). Are morphological effects distinguishable from the effects of shared meaning and shared form? *Journal of Experimental Psychology: Learning, Memory, and Cognition, 26*, 1431–1444.

Feldman, L. B., & Soltano, E. G. (1999). Morphological priming: The role of prime duration, semantic transparency, and affix position. *Brain and Language, 68*, 33–39.

Forster, K. I. (1998). The pros and cons of masked priming. *Journal of Psycholinguistic Research, 27*, 203–233.

Forster, K. I., & Azuma, T. (2000). Masked priming for prefixed words with bound stems: Does submit prime permit?. *Language and Cognitive Processes, 14*(4/5), 539–561.

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

Forster, K. I., & Forster, J. C. (2002). DMDX version 2.9.01. Retrieved from the internet from: http://www.u.arizona.edu/~jforster/dmdx.htm.

Frauenfelder, U. H., & Schreuder, R. (1992). Constraining psycholinguistics models of morphological processing and representation: the role of productivity. In G. Booij & J. van Marle (Eds.), *Yearbook of morphology 1991* (pp. 165–183). Netherlands: Kluwer Academic Publishers.

Frost, R., Forster, K. I., & Deutsch, A. (1997). What can we learn from the morphology of Hebrew? A masked-priming investigation of morphological representation. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 23*, 829–856.

Frost, R., & Grainger, J. (2000). Cross-linguistic perspectives on morphological processing: An introduction. *Language and Cognitive Processes, 15*, 321–328.

Giraudo, H., & Grainger, J. (2000). Effects of prime word frequency and cumulative root frequency in masked morphological priming. *Language and Cognitive Processes, 15*, 421–444.

Giraudo, H., & Grainger, J. (2001). Priming complex words: Evidence for supralexical representation of morphology. *Psychonomic Bulletin & Review, 8*, 127–131.

Giraudo, H., & Grainger, J. (2003). A supralexical lexical model for French derivational morphology. In E. M. H. Assink & D. Sandra (Eds.), *Reading complex words: Cross-language studies* (pp. 139–157). New York: Kluwer Academic.

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

Henderson, L. (1985). Toward a psychology of morphemes. In A. W. Wallis (Ed.), *Progress in the psychology of language* (Vol. 1, pp. 15–72). London: Lawrence Erlbaum Associates.

de Jong, N. H., Schreuder, R., & Baayen, H. (2000). The morphological family size effect and morphology. *Language and Cognitive Processes, 15*(4/5), 329–365.

Kjellmer, G. (2000). Potential words. *Word, 51*, 205–228.

Laudanna, A., Burani, C., & Cermele, A. (1994). Prefixes as processing units. *Language and Cognitive Processes, 9*, 295–316.

Longtin, C.-M., Segui, J., & Hallé, P. A. (2003). Morphological priming without morphological relationship. *Language and Cognitive Processes, 18*, 313–334.

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

Marslen-Wilson, W. D., Tyler, L. K., Waksler, R., & Older, L. (1994). Morphology and meaning in the English mental lexicon. *Psychological Review, 101*, 3–33.

Meunier, F., & Segui, J. (1999). Morphological priming effect: The role of surface frequency. *Brain and Language, 68*, 54–60.

Meunier, F., & Segui, J. (2002). Cross-modal morphological priming in French. *Brain and Language, 81*, 89–102.

New, B., Pallier, C., Ferrand, L., & Matos, R. (2001). Une base de données lexicales du français contemporain sur Internet: LEXIQUE [A lexical database for contemporary French: LEXIQUE]. *L'Année Psychologique, 101*, 447–462.

Pastizzo, M., & Feldman, L. B. (2002). Discrepancies between orthographic and unrelated baselines in masked priming undermine a decompositional account of morphological facilitation. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 28*, 244–249.

Rastle, K., Davis, M. H., Marslen-Wilson, W. D., & Tyler, L. K. (2000). Morphological and semantic effects in visual word recognition: A time-course study. *Language and Cognitive Processes, 15*, 507–537.

Rastle, K., & Davis, M. H. (2003). Priming morphologically-complex words: Some thoughts from masked priming. In S. Kinoshita & S. Lupker (Eds.), *Masked priming: The state of the art*. New York: Psychology Press.

Rastle, K., Davis, M. H., & New, B. (2005) The broth in my brother's brothel: Morpho-orthographic segmentation in visual word recognition. *Psychonomic Bulletin & Review,* in press.

Raveh, M. (2002). The contribution of frequency and semantic similarity to morphological processing. *Brain and Language, 81*, 312–325.

Rey-Debove, J. (1984). Le domaine de la morphologie lexicale [The domain of lexical morphology]. *Cahiers de Lexicologie, 45*, 3–19.

Sablayrolles, J.-F. (2000). *La néologie en français contemporain* [*Neology in contemporary French*]. Paris: Honoré Champion Editeur.

Sanchez-Casas, R., Igoa, J. M., & Garcia-Albea, J. E. (2003). On the representation of inflections and derivations: Data from Spanish. *Journal of Psycholinguistic Research, 32*, 621–668.

Schreuder, R., & Baayen, R. H. (1995). Modeling morphological processing. In L. B. Feldman (Ed.), *Morphological aspects of language processing* (pp. 131–154). Hillsdale, NJ: Lawrence Erlbaum.

Schreuder, R., & Baayen, R. H. (1997). How complex simplex words can be. *Journal of Memory and Language, 37*, 118–139.

Schreuder, R., Burani, C., & Baayen, R. H. (2003). Parsing and semantic opacity. In E. M. H. Assink & D. Sandra (Eds.), *Reading Complex Word: Cross-language Studies* (pp. 159–189). New York: Kluwer Academic.

Segui, J., & Zubizarreta, M.-L. (1985). Mental representation of morphologically complex words and lexical access. *Linguistics, 23*, 759–774.

Taft, M. (1979a). Recognition of affixed words and the word frequency effect. *Memory & Cognition, 7*, 263–272.

Taft, M. (1979b). Lexical access via an orthographic code: The Basic Orthographic Syllabic Structure (BOSS). *Journal of Verbal Learning and Verbal Behavior, 18*, 21–39.

Taft, M. (1994). Interactive-activation as a framework for understanding morphological processing. *Language and Cognitive Processes, 9*, 271–294.

Taft, M. (2003). Morphological representation as a correlation between form and meaning. In E. M. H. Assink & D. Sandra

(Eds.), *Reading complex word: Cross-language studies* (pp. 113–137). New York: Kluwer Academic.

Taft, M. (2005). Morphological decomposition and the reverse base frequency effect. *Quarterly Journal of Experimental Psychology, 57A*, 745–765.

Taft, M., Hambly, G., & Kinoshita, S. (1986). Visual and auditory recognition of prefixed words. *Quarterly Journal of Experimental Psychology, 38A*, 351–366.

Taft, M., & Forster, K. I. (1975). Lexical storage and retrieval of prefixed words. *Journal of Verbal Learning and Verbal Behavior, 15*, 638–647.

Taft, M., & Forster, K. I. (1976). Lexical storage of polysyllabic words. *Journal of Verbal Learning and Verbal Behavior, 15*, 607–620.

Wurm, L. (2000). Auditory processing of polymorphemic pseudowords. *Journal of Memory and Language, 42*, 255–271.