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Morphological decomposition and semantic integration in word processing ☆

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Abstract

In the present study, we looked at cross-modal priming effects produced by auditory presentation of morphologically complex pseudowords in order to investigate semantic integration during the processing of French morphologically complex items. In Experiment 1, we used as primes pseudowords consisting of a non-interpretable combination of roots and suffixes, such as °*sportation*, formed by the noun *sport* "sport" and the suffix *-ation*. In Experiment 2, primes were semantically interpretable pseudowords made of the combination of a root and a suffix, such as °*rapidifier* "to quickify". In Experiment 3, we used as primes semantically interpretable pseudowords that were designed to be synonymous with existing derived words, for example °*cuisineur*, which, if it existed, would mean the same as *cuisinier* "a cook". Finally, in Experiment 4, we used as primes non-morphological pseudowords like °*rapiduit*, *-uit* being an existing ending of French but not a suffix. The results of the four experiments show that priming only occurs with those morphologically complex pseudowords which are interpretable (including those which are synonymous with a pre-existing derived form), providing evidence that semantic factors are taken into account when the prime is overtly presented. Our results further support the view that morphological effects come into play at at least two processing stages, a morphological decomposition based on formal properties and a semantic integration based on semantic compatibility between morphemes.

Keywords: Morphology; Visual word processing; Cross-modal priming; Pseudowords

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In natural languages, many words can be analysed into two or more morphemic units, like the French word *lunaire* "lunar" that contains the root *lune* "moon" and the adjectival suffix *-aire*. These morphologically complex words represent about 75% of the words listed in a French dictionary (Rey-Debove, 1984). In languages such as English and French, the formation of complex forms typically entails the addition of an affix to a base morpheme, and in most cases, the meaning of a complex word can be computed from the meanings of its parts. In this paper, we focus on the role played by semantic features of morphologically complex items during lexical processing.

A now long-standing debate on morphology concerns the role of morphemic information in lexical organisation and processing. Although the literature provides ample experimental evidence that morphology has a role to play in the processing and representation of morphologically complex words, the question of the representational architecture underlying morphological effects is still open.

Several models have been proposed to explain how morphological information influences complex word processing. They contrast on the type of units stored in the mental lexicon (morphemes vs. whole words) and on the point at which morphology comes into play during word recognition. For instance, Taft and Forster (1975) proposed that only morphemic units and their combinatorial constraints are stored in the lexicon, without any whole-word representations. In this model, only *lun-* and *-aire* would be represented in the lexicon. Other authors have proposed that morphological information is represented only through links between whole-word representations of morphologically related words (cf. Bradley, 1979; Bybee, 1985, 1995; Colé, Beauvillain, & Segui, 1989; Segui & Zubizarreta, 1985). Thus, the words *lunaire* and *lunatic* would have their own whole-word representations, but would be linked to each other as well as to the representation of their root *lune* "moon" and of other members of *lune*'s morphological family.

Later models allow the coexistence of whole-word and morphological representations for complex words, either by postulating a specific level of morphemic representations, distinct from the whole-word representation level, or by postulating two parallel access routes. The morphemic level has been viewed either as prelexical, implying that a word like *lunaire* is decomposed into *lun-* and *-aire* prior to the activation of its full lexical representation (Colé, Segui, & Taft, 1997; Taft, 1994, 2003, 2005); or as supralexical, in which case the morphemic units *lun-* and *-aire* are accessed only when the whole-word representation of *lunaire* has been activated (Giraudo & Grainger, 2001). In parallel, or dual, route models (Caramazza, Laudanna, & Romani, 1988; Frauenfelder & Schreuder, 1992; Schreuder & Baayen, 1995), morphologically complex words can be accessed via a direct route, leading to the activation of whole-word representations, and/or a decompositional route, activating the morphemic units prelexically. Linguistic and distributional properties of the word, such as frequency, formal and semantic transparency, morpheme productivity, lexicality, etc., determine which route will activate the relevant lexical units (see Schreuder & Baayen, 1995).

Recently, Longtin and colleagues (Longtin & Meunier, 2005; Longtin, Segui, & Hallé, 2003) have published results which pose challenges for a number of different models. They demonstrated that prelexical decomposition was achieved on every letter string that can be fully parsed into existing morphemes, including real derived words like *gardener*, pseudo-derived words like *corner*, or derived pseudowords like °*quickify*.[1] These conclusions were drawn from a series of visual masked priming experiments (with a 47 ms prime duration, see Forster & Davis, 1984) showing facilitation effects on the (pseudo-)root whenever the prime is morphologically decomposable at the surface level. Compare, for instance, the French words *clochette* "little bell" and *baguette* "French bread, chopstick". While both appear to be morphologically decomposable at the surface level, *clochette* into *cloche* "bell" + *ette* and *baguette* into *bague* "ring" + *ette*, in fact only *clochette* is truly derived from and semantically related to its (apparent) root. Nevertheless, *baguette* primes *bague* just as *clochette* primes *cloche*. By contrast, words containing an embedded pseudo-root but no suffix, such as *abricot* "apricot" (*-cot* is not a suffix in French), do not prime their embedded words, in this case *abri* "shelter" (Longtin et al., 2003; see also Diependaele, Sandra, & Grainger, 2005 for additional results on French; and Rastle, Davis, Tyler, & Marslen-Wilson, 2000; Rastle & Davis, 2003; Rastle, Davis, & New, 2004, for similar results in English). Longtin and Meunier (2005) further showed that this morphological priming effect can be obtained even with morphologically complex pseudowords, such as °*quickify*, which has never been encountered before but can easily be understood on the basis of its constituent morphemes *quick* and *-ify*. In this masked priming study, French morphologically structured pseudowords produced a facilitation effect for their roots equivalent to that shown by existing derived words: for instance, the pseudoword °*rapidifier* "quick + ify" primed *rapide* "quick" with the same magnitude as the existing derived word *rapidement* "quickly". However, no priming effect was found with non-morphological pseudowords (such as °*rapiduit*, made of the root *rapid-* and the non-morphological French ending *-uit*), demonstrating that the mere

[1] Pseudowords will be marked by °.

occurrence of the target at the beginning of the pseudoword prime is not sufficient to produce priming. An additional experiment further showed that this morphological decomposition effect was insensitive to the semantic interpretability of the pseudoword, as equivalent facilitation was obtained with morphologically complex but semantically non-interpretable pseudowords, such as °*sportation* (with the target *sport* "sport"). The pseudoword °*sportation* is made of the ungrammatical combination of the nominal root *sport* and the suffix -*ation* (-*ation* only attaches to verbs, and *sport* is not a verb in French), and is very difficult to define.

Overall, these masked priming results suggest that there is a blind morphological decomposition process very early on during visual word recognition, applied to every item that looks morphologically complex, irrespective of its lexicality and whether its morphological structure is relevant to the word's meaning or not. The idea of a very early decomposition process into root and suffix of all parsable items—complex words, pseudo-complex words and complex pseudowords—is consistent with theoretical models in which morphological decomposition is done prelexically, such as the original model proposed by (Taft & Forster (1975), see also Colé et al., 1997; Taft, 1994, 2003, 2005 for more recent version) and parallel route models (Caramazza et al., 1988; Frauenfelder & Schreuder, 1992; Schreuder & Baayen, 1995).

As mentioned above, one main outcome of the masked priming results obtained by Longtin and Meunier (2005) with morphologically complex pseudowords is the blindness of the decompositional process to semantic interpretability: there was no difference in priming effects between semantically interpretable pseudowords like °*quickify* and non-interpretable pseudowords like °*sportation*. We argued that these results revealed a morphological decomposition at the early stages of word processing, before integration of the semantic properties of the morphemes has begun. In this paper, we will focus on these later semantic stages of word processing, which have mainly been studied with existing morphologically complex words in priming paradigms and with morphologically complex pseudowords in simple lexical decision tasks.

When working with real words, the degree to which a derived word's meaning is related to the meaning of its root is referred to as *semantic transparency*. For instance in French, the word *clochette* "little bell" has a transparent semantic relationship with its base *cloche* "bell", while an opaque word like *lunettes* "glasses" has a much less transparent relationship with its etymological root *lune* "moon". Whereas semantic transparency does not affect morphological priming in a masked priming paradigm, as we have seen earlier, it does affect morphological priming in unmasked priming paradigms. Rastle et al. (2000) reported facilitation with opaque and transparent word primes with a prime duration of 43 ms (e.g., both transparent pairs such as *departure*/*depart* and opaque pairs like *apartment*/*apart* yielded facilitation), but when the prime duration was increased to 230 ms, only transparent words primed their root (e.g., facilitation was found with *departure*/*depart* but not *apartment*/*apart*). Marslen-Wilson, Tyler, Waksler, and Older (1994) reported similar results with an auditory-visual cross-modal priming paradigm: the recognition of a root was facilitated only when the semantic relationship between the prime and the target was transparent (see also Longtin et al., 2003).

Simple lexical decision experiments with pseudowords offer another source of data on the role of semantics in the processing of morphologically complex words. In this case, the semantic transparency, or interpretability, of morphologically complex pseudowords corresponds to the degree to which one can define and understand those words. For instance, a pseudoword like °*quickify* is more easily interpretable than a pseudoword like °*quickion*. The awkwardness of the latter comes from the fact that it is formed by the adjunction of the nominal suffix -*ion* which attaches only to verbs and not to adjectives such as *quick*. When used with a lexical decision task, pseudowords take longer to reject and yield more errors when they are semantically interpretable than when they are not (Burani, Dovetto, Spuntarelli, & Thornton, 1999; Burani, Marcolini, & Stella, 2002; Wurm, 2000; see Coolen, van Jaarsveld, & Schreuder, 1991; Jaarsveld, Coolen, & Schreuder, 1994, for similar results with novel nominal compounds). These studies show that participants are sensitive to the morphemic and semantic properties of pseudowords when they process them consciously in the context of a lexical decision task.

In summary, these contrasting patterns of results in masked and unmasked priming suggest two types of morphological effects: an early morphological decomposition effect based only on the surface properties of words (i.e., whether they can be parsed exhaustively into morphemic units), and a later effect based on the activation of semantic properties, which is morpheme-based in the case of semantically transparent words and whole-word-based in the case of semantically opaque words. The results provided by simple lexicon decision studies also support this view by showing that participants integrate semantic properties of the constituents of pseudowords during the process of interpretation.

The aim of this paper is to further test this hypothesis about the semantic activation stage in the time-course of complex word processing and to understand how the integration of the semantic properties of morphemic units is achieved. In order to do this, we ran four unmasked, auditory-visual cross-modal priming experiments using morphologically complex pseudoword primes with different semantic properties (the same pseudowords used previously in masked priming

experiments—Experiments 1, 2, and 3 reported in Longtin & Meunier, 2005, plus an additional set of stimuli). Within each experiment, we compared priming with pseudowords and priming with existing, semantically transparent derived words. Across experiments, we compared the priming effects with pseudowords which contain a root and suffix but which differ with respect to semantic interpretability and conceptual redundancy. In Experiment 1, we tested the priming effect observed with semantically non-interpretable pseudowords made of an illegal combination of a root and a suffix, such as °*sportation*, formed by the noun *sport* "sport" and the suffix *-ation*. If semantic relationships govern morphological decomposition, as previous experiments using word primes suggest, then non-interpretable pseudowords should not prime their roots to the same extent as real derived words. The second experiment's goal was to test if semantically interpretable pseudowords would produce a priming effect comparable to that observed with real derived words on their root. This second type of pseudoword corresponded to non-existent but well-formed derived words of French, such as °*rapidifier* "to quickify". In Experiment 3, we again tested priming patterns for morphologically complex pseudowords. In this experiment, however, our test words were synonyms of existing complex words: the non-existent °*jardineur*, for instance, would be synonymous with the existing *jardinier* "gardener" (an English equivalent would be the synonym pseudoword °*gardenist*). In the last experiment, we looked at the effect of the occurrence of the target at the beginning of a non-morphological pseudoword prime in order to rule out a potential formal overlap effect with morphologically complex pseudowords. Pseudowords were made of roots (the same as those used in Experiment 2) combined with French non-suffixal endings, as in °*rapiduit*/*RAPIDE*. In each experiment, we compared priming effects from pseudoword primes to unrelated baseline control primes and to existing semantically transparent derived primes.

We chose to use the cross-modal priming paradigm (as in Marslen-Wilson et al., 1994) because of the insights it offers into the nature of central lexical representations. In this paradigm, participants hear a prime word and, at its acoustic offset, see a target item (word or nonword). They have to make a lexical decision only on the target that is visually presented. Since the stimuli are presented in different modalities, this task is assumed to tap selectively into activation effects at the level of the central representation, and is not sensitive to pure phonological or orthographic overlap between the prime and the target (Boudelaa & Marslen-Wilson, 2001; Marslen-Wilson et al., 1994; Meunier & Segui, 2002). Priming effects are interpreted as reflecting repeated access to a lexical representation shared by the prime and the target. Another advantage is that participants do not have to make a lexical decision on the pseudowords but only on the targets. Their task was to process the pseudowords passively and to concentrate on the target. Our priming effects are thus more likely to reflect automatic processing of the pseudowords rather than the active analysis required by a lexical decision task.

Experiment 1—non-interpretable pseudowords

In this first experiment, we explored the unmasked priming effects of non-interpretable pseudowords on their roots. We used as primes non-interpretable morphological pseudowords, made of the illegal combination of a root and a suffix. *Illegal* means here that the grammatical categories of the root and the suffix are incompatible. As a consequence, the pseudoword created is not semantically interpretable. For example, the pseudoword °*sportation* is not grammatical and therefore non-interpretable in French because the nominal root *sport* and the suffix *-ation* are incompatible. The suffix *-ion* forms action nouns or resulting action nouns from verbs, *sport* is not a verb and there is no such verb as °*sporter* in French. An experiment previously conducted with a masked priming paradigm revealed that this type of pseudoword can facilitate the recognition of its root as much as an existing derived word (Longtin & Meunier, 2005). Our experiment with non-interpretable morphological pseudowords will allow us to see whether the grammaticality of the prime as well as its semantic interpretability modulates the morphological priming effects observed in cross-modal paradigm.

Materials

Thirty non-interpretable pseudowords were formed using combinatorial constraints of productive suffixes (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. The illegal combinations of suffixes with base words (nouns, verbs and adjectives) were not semantically interpretable. Semantic interpretability was assessed in a pretest in which participants were asked to write down a definition of each pseudoword (if they could) and rate their plausibility on a scale from 1 to 7 (1 = not plausible; 7 = very plausible). We selected pseudowords for which participants failed to give a definition (average of blank responses is 74.22%, $SD = 13.89$) and were judged as not plausible (average of 2.2/7, $SD = 0.56$, for the selected pseudowords). Despite their non-interpretability, these pseudowords were orthographically and phonologically plausible. For more details see the material section of Experiment 3 in Longtin and Meunier (2005).

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, mechanic", and (3) the unrelated control word *diversion* "diversion". Average frequencies (per million, New, Pallier, Ferrand, & Matos, 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 and phonological overlap between pseudoword primes and targets are 5.3 letters ($SD = 1.17$) and 4.4 phonemes ($SD = 1.14$); and the orthographic and phonological overlap between derived word primes and targets are 5.3 letters ($SD = 1.06$) and 4.4 phonemes ($SD = 1.16$).

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 were 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. Each participant was assigned to one of the three lists and therefore saw each target only once. Thirty filler pairs with word targets were added to each list. Among these, 20 were unrelated word pairs (*réformiste*/*LOQUE*) and 10 were unrelated pseudoword/word pairs (°*inventiser*/*MASSUE*). Sixty pairs with nonword targets were also added: 10 related pseudoword/nonword pairs (°*pendulement*/°*PENDUTE*); 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. Overall, 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.

Participants

Thirty-nine students at the 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 in the pretest or in the other experiments. Each participant was assigned to one of the three lists.

Procedure

We used a cross-modal priming procedure similar to that used by Marslen-Wilson et al. (1994). Each trial began with a blank for 500 ms, followed by the auditory prime. The visual target was displayed in the middle of the screen at the acoustic offset of the prime. The target disappeared after 3000 ms, or as soon as a response button was pressed. Response times were measured from the onset of target display. The next trial was then initiated after a 750 ms delay. Targets appeared in black on a light-grey background in lower-case 14 point Arial font. The experiment was run on a PC-compatible microcomputer using DMDX software (Forster & Forster, 2002), and the participants heard the auditory primes through Sennheiser headphones at a comfortable listening level. The participants' task was to make a lexical decision on the visual target, using a Logitech Wingman gamepad.

Participants were told that they would hear an item in the headphones and then see a string of letters in the middle of the screen; they would have to decide as quickly and accurately as possible whether the letter string was a word in French or not. The total duration of the experiment was 15 min.

Results and discussion

Error rate averaged 0.6% for participants. Reaction times for "yes" responses above 1500 ms were eliminated (2% of data were removed according to this criterion). The results are summarized in Table 1. Reaction 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

Overall, there was a significant main effect of priming condition, $F_1(2,76) = 11.25$, $MSE = 3551$, $p < .0001$; $F_2(2,58) = 8.35$, $MSE = 3782$, $p < .001$, $minF'(2,124) = 4.79$, $p < .01$. The 4 ms effect ($95\%CI = \pm 21.93$)[2] obtained with non-interpretable pseudoword primes compared to the unrelated condition was not significant, Fs < 1. The 57 ms ($95\%CI = \pm 17.90$) facilitation effect for existing derived primes was significant, $F_1(1,38) = 21.31$, $MSE = 3051$, $p < .0001$; $F_2(1,29) = 13.52$, $MSE = 3831$, $p = .001$, $minF'(1,59) = 8.27$, $p < .006$, as was the 53 ms ($95\%CI = \pm 17.82$) difference between the pseudoword and derived conditions, $F_1(1,38) = 17.97$, $MSE = 3024$, $p < .001$; $F_2(1,29) = 12.08$, $MSE = 3518$, $p < .01$, $minF'(1,60) = 7.22$, $p < .01$.

[2] All confidence intervals reported in this paper are 95% confidence intervals for pairwise comparisons based on the mean square errors of the relevant effects from the analyses by participants (Masson & Loftus, 2003).

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

Priming relation	Results	
	RT	Errors (%)
Unrelated	711 (20)	0.3
Non-interpretable pseudoword	707 (17)	0.1
Existing derived word	654 (15)	0.2

Error rates

The analysis of the error rates did not yield any significant difference.

The results of this first experiment show that, in a cross-modal priming paradigm, existing derived words facilitate significantly the recognition of their root but non-interpretable pseudowords do not. This contrasts with what is observed in masked priming, where non-interpretable pseudowords and existing derived words yielded comparable and reliable facilitation (Longtin & Meunier, 2005). The absence of cross-modal priming for non-interpretable pseudowords can be explained either by their non-lexicality—pseudowords *per se* do not prime their roots in cross-modal priming; or by their ungrammaticality and semantic non-interpretability—pseudowords that cannot be interpreted fail to activate their root long enough for priming effects to emerge in a cross-modal paradigm. A second experiment was designed to test these hypotheses.

Experiment 2—interpretable pseudowords

In this second experiment, we explored the priming effects of interpretable pseudowords on their roots in order to see if the lack of priming effect observed in Experiment 1 is due to the general lack of priming power of pseudowords in the cross-modal paradigm or to their non-grammaticality/interpretability. In this second experiment, we used as primes morphological pseudowords made of the grammatically legal combination of a root and a suffix. For example, we compared the effect of a morphological pseudoword like °*rapidifier* and of an existing derived word like *rapidement* "quickly" on the recognition of the base word *rapide* "quick". Using masked priming, we found that these items primed their stems to the same extent as existing derived words (Longtin & Meunier, 2005). In this cross-modal priming experiment, we wanted to see if a priming effect could be obtained and if it was comparable to the priming effect observed for existing derived words (e.g. Longtin et al., 2003).

Materials

Thirty pseudowords formed from 30 different roots were used. Each root was combined with a compatible suffix, using Brousseau and Nikemia (2001) and Dubois and Dubois-Charlier (1999) as references. All pseudowords were phonologically and orthographically plausible. They were selected on the base of a pretest assessing that transparent definitions could be given to these pseudowords by more than 50% of the participants (the mean percentage of transparent definitions was 67.68%, $SD = 12.9$). We also selected pseudowords that were judged as plausible on a scale from 1 to 7 in a pretest (the mean plausibility value was 3.8/7, $SD = 0.62$; see Materials of Experiment 1) and that were considered to be non-existing words by participants (to the question "Have you seen or heard this word before?", participants had to say either 1 "yes"; 2 "maybe"; or 3 "no"; the selected pseudowords had an average of 2.6/3, $SD = 0.27$). For more details see the Materials of Experiment 1 in Longtin and Meunier (2005).

For each root target, an existing derived word and an unrelated control matched for frequency and length were selected. A target like *INFIRME* was therefore preceded by (1) the pseudoword °*infirmiser*, (2) the 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 et al., 2001). Mean length in number of letters for targets, pseudowords, derived words and unrelated primes are, respectively, 7, 9.4, 9.5, and 9.4. The average orthographic and phonological overlap between pseudoword primes and targets is 5.8 letters ($SD = 1.33$) and 4.6 phonemes ($SD = 1.17$); the orthographic and phonological overlap between derived word primes and targets is 5.8 letters ($SD = 1.21$) and 4.5 phonemes ($SD = 1.14$).

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, except for the pseudoword primes, which were replaced by interpretable morphological pseudowords (e.g., °*noiriste*/*ANGE*; °*solutionnette*/°*SODUTION*). Each participant saw only one of the three lists.

Procedure

We used the same procedure as in Experiment 1.

Participants

Forty students at the 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 in the pretest or in the other experiments.

Results and discussion

Only reaction times for correct "yes" responses shorter than 1500 ms were retained for RT analyses (outliers corresponded to 2.1% of the data). The error rate averaged 0.9%. The results are summarized in Table 2. RTs and error rate data were submitted to by-subject and by-item analyses of variance with priming condition as the main factor (unrelated, interpretable pseudoword, existing derived word).

Reaction times

Priming relation had a significant main effect by subjects and by items $F_1(2,78) = 8.16$, $MSE = 4027$, $p < .001$; $F_2(2,58) = 11.25$, $MSE = 1852$, $p < .0001$; $minF'(2,136) = 4.73$, $p = .01$. Planned comparisons showed that the 43 ms ($95\%CI = \pm 22.05$) facilitation effect between the pseudoword condition and the unrelated condition was significant, $F_1(1,39) = 7.69$, $MSE = 4756$, $p < .01$; $F_2(1,29) = 14.8$, $MSE = 1589$, $p < .001$; $minF'(1,66) = 5.06$, $p < .05$, and the 54 ms ($95\%CI = \pm 20.97$) facilitation effect between the derived word and the unrelated conditions was also significant, $F_1(1,39) = 13.78$, $MSE = 4302$, $p < .001$; $F_2(1,29) = 13.54$, $MSE = 2762$, $p = .001$; $minF'(1,66) = 6.83$, $p = .01$. The 11 ms ($95\%CI = \pm 17.58$) difference between the pseudoword and the existing derived word conditions was not significant $F_1 < 1$; $F_2(1,29) = 1.33$, $MSE = 1206$, n.s.; $minF' < 1$.

Error rates

The analysis of the error rates did not yield any significant difference.

The results of this experiment show that a significant facilitation effect is observed with primes consisting of a novel and interpretable 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 (as found, for example, in Longtin et al., 2003; Marslen-Wilson et al., 1994). This shows that pseudowords can indeed prime their root in a cross-modal paradigm provided that they are semantically interpretable. The results demonstrate that interpretable pseudowords can activate their component morphemes even if they have never been encountered before and therefore do not have a lexical entry or semantic representation in the participants' mental lexicon. The lexical status of the prime does not seem to play any role in this case.

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

Priming condition	Results	
	RT	Errors (%)
Unrelated	722 (20)	0.5
Interpretable pseudoword	679 (17)	0.3
Existing derived word	668 (19)	0.1

The results of Experiments 1 and 2 are consistent with the priming effects obtained with real words, in which cross-modal priming effects are obtained with semantically transparent derived words but not with semantically opaque words (Longtin et al., 2003). It thus seems that the semantic properties of words and pseudowords are processed and that any item that cannot be interpreted on the basis of its morphemic constituents will fail to prime these constituents.

Experiment 3—synonym pseudowords

The aim of this third experiment is to investigate whether cross-modal priming effects are modulated by the potential synonymy of pseudowords. In descriptive linguistics, 'blocking' is used to refer to the non-existence of a derivative because of the prior existence of some other synonymous lexeme. The idea is that a previously existing derived word would block the production of a new word derived from the same root and genuinely synonymous with it (Aronoff, 1976). In Experiment 2, we used pseudowords that were interpretable but denoted a new concept within the morphological family of the root. For instance, in the morphological family of *rapide* "rapid", there are no existing derived words denoting the concept of "making more rapid", and °*rapidifier* therefore denotes a new concept within this family. In Experiment 3, we took existing derived words as a starting point and coined pseudowords by replacing their suffixes with semantically equivalent ones in order to create synonymous derived words. This was made possible by the fact that some suffixes in French have equivalent meaning as well as syntactic functions and restrictions. For instance, the suffixes *-ation* and *-age* both create deverbal nouns denoting an action or a result. The noun *installation* "installation, setting up" and the pseudoword °*installage* are interpreted by French speakers as meaning the same thing, even though °*installage* is not listed in any dictionary.

This manipulation was designed to allow us to see whether there was competition between the pseudoword and the derived word at the semantic and syntactic levels, which would potentially lead to a reduced priming effect due to interference between the two instances of the same semantic representation. In visual masked priming, these pseudowords have been shown to facilitate the recognition of their root as much as their

synonym source words (Longtin & Meunier, unpublished data).

Materials

In order to create synonym pseudowords, we first made a list of suffixes that had the same meaning as well as the same syntactic functions and combinatorial constraints (based on Brousseau & Nikemia, 2001). For example, the suffix *-eur* in French can be attached to verbs in order to create nouns corresponding to "the man who", as can the suffix *-ier*. For example we have *nageur* "a swimmer" but *cuisinier* "a cook". We then selected 53 derived words containing these suffixes and created corresponding pseudowords (ex. *cuisinier*/°*cuisineur*; *aptitude* "ability"/°*apteté*; *fatalité* "fatality"/°*fatalitude*). All pseudowords were phonologically and orthographically plausible. Out of an initial list of 53 synonym pseudowords submitted to a pretest, we selected pseudowords that had been judged plausible and for which participants were able to give the intended definition. The average plausibility was 4.85/7 ($SD = 0.76$) and participants in the pretest provided the intended definition of the synonym source word in 44.24% of the cases ($SD = 12.72$; all other answers were either blank, 39.31%; containing the root, 6.87%; or containing the synonym source word, 3.18%).

For each root target, we selected an unrelated control matched for frequency and length to the existing derived word. For example, the target *CUISINE* "kitchen" was preceded by (1) the pseudoword prime °*cuisineur*, (2) the synonymous existing derived word *cuisinier* "a cook", and (3) the unrelated control word *feuillage* "foliage". Average frequencies (per million, New et al., 2001) for targets, derived and unrelated primes are 61.9, 12.7, and 12.8, respectively. Mean length in number of letters for targets, pseudoword, derived and unrelated primes are 6.7, 9.3, 9.5, and 9.4, respectively. The average orthographic and phonological overlap between pseudoword primes and targets are 5.79 letters ($SD = 1.15$) and 5.07 phonemes ($SD = 1.07$), whereas the orthographic and phonological overlap between derived word primes and targets are 5.69 letters ($SD = 1.07$) and 5.07 phonemes ($SD = 1.07$).

List composition

Experimental lists were created in the same way as for the previous experiments. 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 synonym morphological pseudowords (e.g., °*cellulable*/*MASSUE*; °*personniser*/°*PERDONNE*). Each participant was assigned randomly to only one of the three lists.

Participants

Thirty-one students at the 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 in the pretest or in the other experiments.

Procedure

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

Results

Error rate averaged 1% for participants. Reaction times for "yes" responses above 1500 ms were eliminated (0.6% of data was removed according to this criterion). The results are summarized in Table 3. Reaction times and error rates were submitted to by-subject and by-item analysis of variance with the priming relation as the main factor (unrelated, synonym pseudoword, derived word).

Reaction times

Priming relation had a significant main effect by subjects and by items $F_1(2,60) = 13.24$, $MSE = 2070$, $p < .0001$; $F_2(2,58) = 4.43$, $MSE = 5810$, $p < .05$; $minF'(2,93) = 3.32$, $p < .05$. Planned comparisons showed that the 48 ms facilitation effect ($95\%CI = \pm 17.82$) between the pseudoword condition and the unrelated condition was significant, $F_1(1,30) = 14.84$, $MSE = 2365$, $p < .001$; $F_2(1,29) = 5.09$, $MSE = 6356$, $p < .05$; $minF'(1,47) = 3.87$, $p = .05$, and the 55 ms facilitation effect ($95\%CI = \pm 15.13$) between the existing derived word and the unrelated conditions was also significant, $F_1(1,30) = 27.19$, $MSE = 1704$, $p < .0001$; $F_2(1,29) = 7.29$, $MSE = 6039$, $p = .01$; $minF'(1,44) = 5.75$, $p < .05$. The 7 ms difference ($95\%CI = \pm 16.95$) between the pseudoword and the existing derived word conditions was not significant, $Fs < 1$ (Table 3).

Error rates

The analysis of the error rates did not yield any significant difference.

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

Priming relation	Results	
	RT	Errors (%)
Unrelated	671 (24)	0.5
Synonym pseudoword	623 (19)	0.1
Existing derived word	616 (21)	0.4

The results show a strong facilitation effect of the synonym pseudowords on their roots, which is as strong as facilitation obtained with existing derived words. The fact that the pseudoword's meaning corresponds to a concept already denoted by an existing derived word from the same morphological family does not affect priming in a cross-modal paradigm, suggesting that there is no competition between the representation of the existing word and its novel synonym.

Experiment 4—non-morphological pseudowords

This fourth experiment was conducted in order to see whether the facilitation effect obtained with morphological pseudoword primes in Experiments 2 and 3 is due to phonological and orthographic overlap between the prime and the target, rather than to morphological decomposition. Experiment 1's results already suggest that this is not the case—non-interpretable pseudoword primes and targets had comparable overlap to pseudowords from Experiments 2 and 3 but failed to produce priming—but an additional control in which pseudowords are not morphologically complex would allow this possibility to be strongly ruled out. 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 phonological/orthographic, then we should obtain a facilitation effect for these pseudowords. If the effects obtained in Experiments 2 and 3 are genuinely morphological in nature, then we should not observe any facilitation with these non-morphological pseudoword primes.

Materials

Creation of pseudowords

A non-morphemic ending was added to the 30 targets of Experiment 1. Endings chosen already exist in French but do not correspond to suffixes. 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 average orthographic and phonological overlap between pseudoword primes and targets are respectively 5.8 letters ($SD = 1.30$) and 4.53 phonemes ($SD = 1.14$); and the orthographic and phonological overlap between derived word primes and targets are 5.8 letters ($SD = 1.21$) and 4.53 phonemes ($SD = 1.14$).

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

Forty students of the Ecole des psychologues praticiens and of the Institut d'études politiques de Lyon took part in the experiment and were paid for their participation. All participants were native speakers of French and had normal or corrected-to-normal vision. None of them participated in the other experiments.

Results and discussion

One participant was rejected because his/her error rates for test target words exceeded 10%, which was considered too high (error rate averaged at 1% for the other participants). Only reaction times for correct "yes" responses shorter than 1500 ms were retained for RT analysis (outliers corresponded to 1.6 % of the data). The results are summarized in Table 4. 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, $F_1(2,78) = 4.37$, $MSE = 4178$, $p<.05$; $F_2(2,58) = 4.48$, $MSE = 2810$, $p < .05$; $minF'(2,134) = 2.21$, $p = .11$. The 4 ms priming effect ($95\%CI = \pm 21.88$) 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 (39 ms with a $95\%CI = \pm 20.53$: $F_1(1,39) = 7.29$, $MSE = 4132$, $p = .01$; $F_2(1,29) = 5.99$, $MSE = 3483$, $p < .05$; $minF'(1,64) = 3.29$, $p = .07$) and in pseudoword condition (35 ms with a $95\%CI = \pm 19.46$: $F_1(1,39) = 6.55$, $MSE = 3711$, $p < .05$; $F_2(1,29) = 9.15$, $MSE = 1818$, $p < .01$; $minF'(1,68) = 3.82$, $p = .05$).

Table 4
Experiment 4: Average RT (ms) and error rates by priming condition (standard errors in brackets)

Priming relation	Results	
	RT	Errors (%)
Unrelated	723 (18)	0.6
Non-morphological pseudoword	719 (17)	0.3
Existing derived word	684 (18)	0.1

Error rates

In the analysis of the error rates, the only effect that reached marginal significance is between the pseudoword condition and the unrelated condition, $F_1(1,35) = 3.89$, $MSE = 0.117$, $p = .056$; $F_2(1,29) = 3.52$, $MSE = 8.6$, $p = .07$; $minF'(1,63) = 1.85$, $p = .18$, all other $Fs < 1$.

This experiment demonstrates that the mere occurrence of the root target at the beginning of the pseudoword prime is not sufficient to produce priming. These results are consistent with those obtained with the same stimuli in visual masked priming (Longtin & Meunier, 2005).

Additional analysis

The results of the four experiments were clear-cut: we obtained facilitation with pseudowords that were semantically interpretable, but not with pseudowords that were not. Given that the effects of morphological complexity, semantic interpretability and conceptual synonymy were tested separately, we ran additional statistical analyses on the priming effects with the four experiments grouped together. We first ran a by-subject and by-item variance analysis with, as main factors, Experiment (1, 2, 3, and 4) and Priming Condition (pseudoword vs. unrelated, derived word vs. unrelated). The dependant variable was the priming effect values. Overall we observed no effect of the factor Experiment, $F_1(3,146) = 1.23$, $MSE = 12193$, n.s.; $F_2(3,116) < 1$, $MSE = 12680$; $minF' < 1$, an effect of Priming Condition, $F_1(1,146) = 17.39$, $MSE = 3018$, $p < .0001$; $F_2(1,116) = 14.18$, $MSE = 2896$, $p < .001$; $minF'(1,250) = 7.81$, $p < .01$, and an interaction between these two factors that was significant by subjects but only marginally significant by items, $F_1(3,146) = 2.77$, $MSE = 3018$, $p < .05$; $F_2(3,116) = 2.37$, $MSE = 2896$, $p = .07$; $minF'(3,253) = 1.28$, $p = .28$. We then ran specific comparisons between experiments that differed on one dimension (in the following order: morphological complexity, semantic interpretability, and conceptual synonymy). The specific comparison between non-morphological pseudowords and non-interpretable pseudoword effects showed no effect of Experiment $Fs < 1$, an effect of Priming Condition $F_1(1,77) = 22.58$, $MSE = 3361$, $p < .0001$; $F_2(1,58) = 21.01$, $MSE = 2672$, $p < .0001$; $minF'(1,131) = 10.88$, $p = .001$, and no interaction between the two factors $F_1 < 1$; $F_2(1,58) = 1.11$, $MSE = 2672$, n.s; $minF' < 1$. The comparison between non-interpretable and interpretable pseudoword effects revealed no effect of Experiment $Fs < 1$, an effect of Priming Condition $F_1(1,77) = 13.60$, $MSE = 3020$, $p < .001$; $F_2(1,58) = 12.85$, $MSE = 2368$, $p < .001$; $minF'(1,131) = 6.61$, $p = .01$, and a significant interaction between the two factors $F_1(1,77) = 5.55$, $MSE = 3017$, $p < .05$; $F_2(1,58) = 5.77$, $MSE = 2368$, $p < .05$; $minF'(1,133) = 2.83$, $p = .09$. Finally, the comparison between interpretable and synonym pseudowords showed no effect of Experiment, $Fs < 1$, no effect of Condition $F_1(1,69) = 1.16$, $MSE = 2636$, n.s.; F_2 and $minF' < 1$, and no interaction between the two factors $Fs < 1$.

We then ran another by-subject and by-item variance analysis on priming effects with, as main factors, Priming Condition (pseudoword vs. unrelated, derived word vs. unrelated) and Semantic Interpretability (interpretable and synonym pseudowords vs. non-interpretable and orthographic pseudowords). We observed a trend of the factor Semantic Interpretability $F_1(1,148) = 3.39$, $MSE = 12056$, $p = .067$; $F_2(1,118) = 2.161$, $MSE = 12506$, $p = .14$; $minF'(1,239) = 1.361$, n.s., an effect of Priming Condition $F_1(1,148) = 17.76$, $MSE = 3000$, $p < .0001$; $F_2(1,118) = 14.294$, $MSE = 2872$, $p < .001$; $minF'(1,253) = 7.919$, $p < .01$, and an interaction between the two factors $F_1(1,148) = 7.23$, $MSE = 3000$, $p < .01$; $F_2(1,118) = 6.1$, $MSE = 2872$, $p = .01$; $minF'(1,256) = 3.308$, $p = .07$. Specific comparison for semantically interpretable items (interpretable and synonyms pseudowords) showed no effect of Priming Condition $F_1(1,70) = 1.27$, $MSE = 2601$, n.s.; F_2 and $minF' < 1$. In average, existing derived words produced 55 ms of facilitation whereas semantically interpretable pseudowords produced 45 ms, the 10 ms difference between being non significant ($95\%CI = \pm 12.04$). Specific comparison for semantically non-interpretable items (non-interpretable and orthographic pseudowords) showed a reliable effect of Priming Condition $F_1(1,75) = 22.43$, $MSE = 3416$, $p < .0001$; $F_2(1,59) = 20.97$, $MSE = 2677$, $p < .0001$; $minF'(1,131) = 10.83$, $p = .001$. In those two experiments, existing derived words produced an average facilitation of 47 ms while semantically non-interpretable pseudowords produced only 2 ms, the 45 ms difference being significant ($95\%CI = \pm 13.34$).

The results of this meta-analysis confirmed that both synonym and interpretable pseudowords produced priming effects on their roots that were comparable to the effects obtained with existing derived words, whereas priming effects obtained with non-interpretable and orthographic differed signifi-

cantly from that obtained with existing derived words.

General discussion

In this study, we investigated the role of morphological grammaticality and semantic properties of pseudowords in four cross-modal priming experiments. In each experiment, priming effects between pseudowords and their roots were compared to the priming effects produced by existing derived words. Across experiments, the morphological complexity, semantic interpretability and conceptual redundancy of the morphological pseudowords were manipulated. In Experiment 1, pseudowords were constructed via the ungrammatical combination of roots and incompatible suffixes; they were morphologically complex but semantically non-interpretable. Results showed that these pseudowords do not prime their roots: a non-interpretable pseudoword containing a root and a suffix such as °*sportation* did not facilitate the recognition of its root *sport*. The goal of Experiment 2 was to see if the absence of priming observed in Experiment 1 was due to the non-interpretability of pseudowords or whether pseudoword primes generally fail to produce priming in a cross-modal paradigm. In this experiment, morphologically complex pseudowords were made of the grammatical combination of roots and suffixes and were semantically interpretable, like °*rapidifier*. Results were clear-cut: the auditory 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 (°*rapidifier* and *rapidement* primed *rapide* with the same strength). The third experiment used pseudowords that were synonyms of real derived words such as °*jardineur*, which would have the same meaning as the existing word *jardinier* ''gardener''. Results showed that synonym pseudowords also primed their stem to the same extent as real derived words. These results were comparable to the ones observed in Experiment 2 where pseudowords were interpretable but not synonymous to existing words. The fact that these pseudowords had the same meaning as existing words from the same morphological family did not modulate priming effect. Experiment 4 ruled out an orthographic and phonological account of the priming effects observed in Experiments 2 and 3. Non-morphological pseudowords consisting of a root and a non-suffixal ending of French did not prime their embedded root.

Overall, these results first demonstrate that pseudowords can prime their root in a cross-modal priming paradigm, and second that semantic interpretability plays a major role during pseudoword recognition. On the basis of these results and previous ones obtained with the same stimuli in a masked priming paradigm, we will argue that morphology needs to be represented prelexically and that there are different stages during the processing of morphologically complex pseudowords.

As with our previous data obtained in masked priming, the fact that morphologically complex pseudowords can prime their root in cross-modal priming constrains theoretical models of the mental lexicon and the role they give to morphology. It implies that morphemes (roots and affixes) are represented in the lexicon. Any model in which access to the root of complex words is only made through the whole-word representation would fail to explain these results. This is the case for models in which morphological information is represented only through links between whole-word representations of morphologically related words (cf. Bradley, 1979; Bybee, 1985, 1995; Colé et al., 1989; Segui & Zubizarreta, 1985), or in which morphemes are represented at a supralexical level (Giraudo & Grainger, 2001). In models of this latter type, it is only when the whole-word representation has been activated that the morphemic units are accessed. A pseudoword, which does not have a representation at the lexical level, will not be able directly to activate its morphological components and thus cause priming. A possible solution to this problem has been proposed by Giraudo (2005), who argues that pseudowords and opaque words activate their roots via parallel interactive activation of all the whole-words to which they are formally related. For instance, °*rapidifier* ''rapidify'' would activate all the words starting by *rapide* and ending by *-ifier*. However, it remains unclear how the model would distinguish between pseudowords like °*rapidifier* and non-morphological pseudowords like °*rapiduit*: both start by a root morpheme and both have an ending that is found in French words.

Another main outcome of our results is the difference of priming patterns between non-interpretable and interpretable pseudowords, which demonstrates that the interpretability of the root-suffix combination is taken into account at the stage of processing investigated in the cross-modal priming paradigm. The importance of semantic interpretability demonstrated by these experiments is consistent with other experimental findings using a simple lexical decision task on pseudowords, without priming. As we mentioned in the introduction, Burani et al. (1999) showed that the process of licensing a new root-suffix combination is affected by semantic interpretability: in a lexical decision task, highly interpretable combinations are more likely to be accepted as words than less interpretable combinations. Wurm (2000) reached the same conclusions using prefixed pseudowords, as did Coolen et al. (1991) with novel nominal compounds.

This semantic interpretability effect observed with pseudowords is also in line with those observed using real words. As already pointed out in the introduction, a morphologically derived word has to be semantically transparent in order to facilitate the recognition of its root in an unmasked priming paradigm (Marslen-Wilson et al., 1994). Thus, in a cross-modal priming paradigm with a lexical decision task, a semantically transparent word like *punishment* will prime *punish*, but a semantically opaque word like *casualty* would not prime *casual*. This effect has been replicated many times (Feldman & Soltano, 1999; Longtin et al., 2003; Rastle et al., 2000; but see Boudelaa & Marslen-Wilson, 2001; Frost, Deutsch, Gilboa, Tannenbaum, & Marslen-Wilson, 2000, for different results on Semitic languages).

Taken together, these results demonstrate the importance of semantic interpretability during the processing of complex words. Previous results add another element to the picture: experiments using visual masked priming demonstrated that the early stages of visual word recognition are only sensitive to the superficial morphological structure of the word or pseudoword (whether it is parsable into morphemes or not), not to its semantic interpretability or well-formedness. Remember that the same stimuli used in a masked priming paradigm showed that both non-interpretable and interpretable pseudowords primed their roots as efficiently as existing derived words, whereas non-morphological pseudowords did not (Longtin & Meunier, 2005; additional unpublished data also show a strong masked priming effect with synonym pseudowords).

Overall these data suggest that while masked priming results reveal an early parsing procedure, triggered by the morphological structure of the prime, but insensitive to its semantic interpretability, the cross-modal results show that the lexical representations that are (or remain) activated during the processing of complex words must be semantically exploitable for whole-word comprehension. We argue that the difference between the masked priming data and the cross-modal ones are not due to modalities *per se*, i.e., visual in one case and auditory in the other, but to the time-course of the processes at issue (see Forster & Veres, 1998 for a similar line of argument). Indeed, Rastle et al. (2000) showed that different effects of semantic transparency on real word processing can be observed with visual primes and visual targets by changing the prime duration (60 and 230 ms). In agreement with Rastle and colleagues (Rastle & Davis, 2003; Rastle et al., 2004), we suggest that morphological effects are characterized by at least two stages: a very early first stage that is blind to semantic properties and that parses all items that are morphologically complex at the surface level, and a later stage that takes into account the semantic interpretability of the combination, irrespective of its lexicality. By ''processing stages'', we do not mean discrete, delimited processing steps, but rather a continuous process of decomposition and semantic integration.

A similar proposal has also been made by Taft (2003, based on Taft, 1994), who detailed an interactive activation model that includes three different levels of localist representations, i.e., form, lemmas and semantic features. Each form representation constitutes a unit that is activated by the presence of relevant orthographic features in the stimulus: syllables, free standing morphemes, and bound morphemes are represented at this level. The lemma level contains units that capture the correlation between form and meaning and provide the link between semantic features and the representation of form. This level includes representations for full forms of monomorphemic and derived words but also for free standing and bound stems. Formal morphemic units are connected to the full representation of derived words but also to stem and affix lemmas. A single form unit can also be associated with more than one lemma unit, in case of homonymy for instance. In this model, polymorphemic words that are entirely transparent with respect to their constituents (e.g., inflected words like *seeming* or *dogs*) do not possess their own lemmas as all functional and semantic information about these words can be generated entirely from their constituents.

Within this framework, semantically transparent complex words and opaque ones are differentiated by the links between the semantic features and the lemmas associated with morphemes and whole-words. In the case of a transparent word like *gardener*, there will be significant overlap between the semantic features associated to the lemmas of *garden-* and *-er* and those associated with the lemma of *gardener*. This would not be true for opaque words like *corner*, for which there would be no overlap between the semantic features associated with the lemmas of *corn-*, *-er*, and *corner*. Semantic transparency effects on lexical processing would therefore be explained by the presence or absence of overlap at the semantic level. Similarly to transparent words, morphologically complex pseudowords would be processed through the activation of the corresponding constituents at all three levels: form, lemma, and concept.

The remaining question is why, and how, semantic integration fails for non-interpretable pseudowords but succeeds for interpretable ones. Given the nature of our stimuli, there are two potential sources of failure: the first one is the non-grammaticality of the non-interpretable pseudowords, the second one their semantic non-interpretability. These two aspects are highly correlated as introducing a grammatical violation is very likely to have the consequence of making a pseudoword non-interpretable.

In a model such as that proposed by Taft (2004), interpreting a novel complex word would involve retrieving the semantic features related to each of its morphemic constituents and attempting to make sense

of their combination. A pseudoword like °*quickify* would be first decomposed into its morphemic constituents, which would in turn activate their lemma and the semantic features which would then be integrated into the complex conceptual notion "make something or someone quicker". Such a semantic integration would fail for pseudowords like °*sportation*, as the meaning of the constituents are conceptually incompatible: *-ation* denotes the "act of (verb)" or the "result of (verb)" and *sport* refers to a particular category of physical activity. The model's failure to integrate these two notions together into one meaningful concept could lead to the rejection of the word altogether and the loss of any morphemic activation.

Another possibility is that pseudoword processing is interrupted by the non-grammaticality of the formation and not by semantic incompatibility. This would imply that affixes' grammatical category restrictions are stored in the mental lexicon and that a compatibility check is achieved before or parallel to semantic integration. Schreuder and Baayen (1995) proposed a licensing mechanism along those lines. Their model is a spreading activation model associated with a mechanism that carries out symbolic computations on activated representations. This model consists of three levels: access representations, concept nodes, and syntactic and semantic representations. Each access representation is linked with at least one lexical representation seen as a concept node that in turn is linked with syntactic and semantic representations. Concept nodes and access representations may receive activation feedback from higher levels. Within this framework, the parsing process requires three different stages. The first stage, segmentation, divides the input into affixes and stems, so as to generate form-based access representations of free and bound morphemes (affixes, bound stems). The second stage, licensing, checks the appropriateness of morpheme combinations, for instance by assessing whether representations can be integrated on the basis of their subcategorization properties. It is only when the integration has been licensed that the third stage, combination, is reached. This last stage computes the lexical representation of the complex word from the syntactic and semantic representations of its morphemes. This model allows two parallel access routes, i.e. one direct route and one analytic, decompositional route. A derived word can be accessed either directly via its full-form representation or via its morphemic components with full-form and morphemic representations possibly activated in parallel. Novel complex words will be accessed via their morphemic components, and only the decomposition route will be used for their processing.

If we consider pseudoword processing within this framework, we can see how our results are handled: even though pseudowords do not have access representations or concept nodes, their constituent morphemes do have access representations, and these representations will become active during the segmentation of the morphologically complex pseudoword. These access representations will activate the concept nodes associated to the morphemes, and these in turn will activate their associated syntactic and semantic representations. The combination of the root with the suffix is then licensed or not on the basis of the subcategorization information available from the root and the suffix's concept nodes.

As we mentioned earlier, it remains unclear whether it is their non-grammaticality or their semantic non-interpretability or both that is responsible for the failure of non-interpretable pseudowords to prime their stems. Our results offer no evidence on this issue as our non-interpretable pseudowords were made with morphemes that were both syntactically and semantically incompatible. To our knowledge, the only experiment conducted on the subject is that of Burani et al. (1999). These authors compared lexical decisions for two types of non-interpretable pseudowords: pseudowords containing a grammatical violation between the root and the suffix vs. pseudowords containing a semantic violation between the root and the suffix (e.g., the Italian suffix *-aio* only attaches to concrete nouns, so they attached it to abstract nouns in order to create pseudowords). The two types of non-interpretable pseudowords were matched on semantic interpretability. The lexical decision experiment results showed no significant difference between these two types of non-interpretable pseudowords, both in lexical decision times and error rates. Moreover, they showed that semantically interpretable pseudowords took significantly more time to be rejected and yielded significantly more errors than non-interpretable ones. Further experimental work is needed to characterise this process in details.

Conclusion

In the light of our results, we propose that morphological processing is characterized by at least two stages: a first stage, blind to semantic properties, that parses items that are morphologically complex at the surface level, and a second stage during which the semantic properties of constituent morphemes are integrated, irrespective of their lexicality. Morphological parsing is done as soon as possible, and grammatical and semantic integration is completed only later during pseudoword processing. This later stage does not seem to take into account the existence of a word that expresses a similar concept. Further investigations are conducted in order to test how the system handles synonym pseudowords, for which a novel complex form maps onto an existing conceptual representation.

Appendix A. Supplementary data

Supplementary data associated with this article can be found, in the online version, at doi:10.1016/j.jml.2006.11.005.

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