Pseudo-Family Size Influences the Processing of French Inflections: Evidence in Favor of a Supra-Lexical Account

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1. Introduction

Since Rumelhart & McClelland (1986) first presented their connectionist model of the English past tense system, the nature of morphological representation has divided psycholinguists. This question is central in debates about the nature of cognition, since it concerns the understanding of how the lexicon is organized in terms of structural units, and how these units interact with each other during lexical access. One of this domain's important controversies concerns the description of the core units of the lexicon, namely the *morpheme versus lexeme* problem. The former posits that a unit smaller than the word, preserving basic semantic and orthographic/phonological characteristics and commonly called *morpheme* is the structural unit of the lexicon, whereas the later argues that morphology is primarily a set of systematic correspondences between the forms and meanings of the words, and that the source of morphology is the network of paradigmatic relations between the existing words of a language. This position implies that it is the word that forms the basis of morphological operations, and that morphology cannot be simply defined as the concatenation of morphemes into words. As pointed out by Aronoff (1994), it is better to speak of *lexeme-based morphology*, because the term *'word-based'* has led to the misunderstanding that it is the concrete form of a word that is the basis for morphological operations. However, it is often an abstract stem form of a lexeme, which never surfaces as a concrete word form, that constitutes the basis for morphological operations, and hence, the term 'lexeme-based' is more appropriate. This lexeme-based view of morphology is shared by many morphologists (Bybee 1988; 2001, Booij 2002): morphology is not the "syntax of morphemes", but the extension of patterns of existing systematic form-meaning correspondences between words. The Dutch tradition of morphological studies provided some pieces of convincing evidence for this view, see the work by Harald Baayen and his colleagues on family size effects (e.g. de Jong *et al.* 2000).

The morpheme based approach has lead to models claiming a general and mandatory decomposition of the surface form (Taft 1981; Taft & Forster 1975), and more recently to theorizations in which decomposition occurs for some words, but not for others (e.g. Caramazza *et al.* 1988; Marslen-Wilson *et al.* 1994; Schreuder & Baayen 1995; Pinker 1991). Complex words are recognized either by applying a general computational rule that parses the word into its morphemes or by retrieving directly from memory the whole word form. This 'dual-route' approach, which includes a variety of theoretical frames, has to be reconciled with findings that suggest that morphological processing is not an 'all or none' phenomenon and that different levels of semantic, orthographic or phonological similarity induce graded effects of morphological facilitation, at least as far as the priming technique is concerned (Frost *et al.* 2000; Plaut & Gonnerman 2000, Rueckl *et al.* 1997; Seidenberg & Gonnerman 2000; Velan *et al.* 2005).

One of the difficulties of the study of morphology for alphabetic languages – in which the vast majority of research is conducted – is not only that morphology is correlated with semantic, orthographic and phonological factors, but also that stems and inflected or derived words exist as free word-forms, entertaining with each other different relations. These relations have been shown to be relevant to morphological processing: with the masked priming technique, Grainger *et al.* (1991) have found that orthographic similarity of the prime affects (inhibits) lexical access of morphologically complex targets, despite (or because of) the absence of any morphological relation between them. For example, the prime *mûrir* ('ripen') inhibits the target MURAL ('of a wall') and this inhibition reaches 27ms for words that share their initial letters. This inhibition is accounted for in terms of "preactivation of lexical representations during the processing of the prime, that interfere with the processing of the target" (Grainger *et al.* 1991: 380). The inhibitory effect of a prime like *blue* on the target BLUR (Segui & Grainger 1990) is found, according to the same logic, because *blue* is a very powerful competitor in the recognition process of its neighbor BLUR. The presentation of *blue* as a prime only reinforces its competitor status, already quite important (because of its frequency), thus delaying target processing. This inhibition of O+M- (orthographically but not morphologically related primes) combined with the absence of such an effect for nonword primes, is also found by Drews & Zwitserlood (1995) on derivational morphology in German and Dutch. The fact that nonword primes do not behave in the same manner argues in favor of the hypothesis that this competition does indeed take place at the lexical level. Interference can even be exerted by items that acquired their lexical status during the experiment: recently, Bowers *et al.* (2005) have shown that having participants learn new words (e.g., BANARA) that were neighbors of familiar words that previously had no neighbors (e.g., BANANA), made it more difficult to semantically categorize the familiar words and this interference was larger the day following initial exposure.

Following this logic, Giraudo & Grainger (2000, 2001, 2003) proposed a supra-lexical approach of morphological processing, in which abstract morphemic representations (in the sense of Aronnoff 1994) receive activation from whole-word form representations, so that word recognition enables the activation of the morphological level, and not the other way round. The key notion here is lexical competition, central for interactive activation models (e.g., McClelland & Rumelhart 1981; Grainger & Jacobs 1996; Davis 1999; Bowers *et al.* 2005). The presentation of the stimulus at the entry of the cognitive system (prime) will produce multiple activations, namely the activation of all lexical entries that share formal characteristics with the prime. These multiple representations enter a phase of competition, and identification is achieved when a single word first exceeds a given threshold, thus ending the competition. The central assumption of this model is that if lexical competition processes strongly affect the identification system, they should also have an impact on morphological effects. Indeed, the manipulation of pure lexical factors like surface frequency can modify morphological effects, as Giraudo & Grainger (2000) demonstrated under masked conditions: high surface frequency derived primes showed significant facilitation relative to form control primes, whereas low frequency primes did not, suggesting that during prime word processing, it is the printed frequency of the prime word itself that will primarily determine morphological effects. The other component of lexical competition refers to the role of the number and the relative frequency of neighbors, i.e., words differing by a single letter (such as BANISH and VANISH, Coltheart *et al.* 1977). Evidence from this type of research has given mixed results: reviewing them is beyond the scope of this paper. However we stand by the remark of Bowers *et al.* (2005a) relative to the fact that in competitive network models like IA (Interactive Activation, McClelland & Rumelhart 1981) and SOLAR (self-organizing lexical acquisition and recognition, Davis 1999) the critical contrast is between words that have no neighbors ("hermits") and words that have one or more neighbors. As noticed by the same authors, (Bowers *et al.* 2005b) it is important to have a psychologically accurate definition of what is a neighbor, and considering as such only words of the same length that differ by one letter (Coltheart's N) is based rather on simplicity than on perceptual similarity.

The two experiments reported were designed to investigate the role of lexical variables in the morphological domain: given the importance of lexical competition effects for the supra-lexical model of morphology and for the domain of word identification in general, we consider that a variable such as the pseudo-family size should not be neglected. Let us first explain what we mean by pseudo-family size. When a prime like *portons* (meaning 'carry$_{\text{1PL PRES IND}}$', where *port-* is the stem and *-ons* is the conjugation mark) is presented to the lexical processing system, it can potentially activate (at least) all the words that share its initial letters, i.e. the letters of the stem. Following this criterion, a prime like *portons*, has numerous pseudo-relatives at the lexical level: *portail* ('portal'), *porte* ('door'), *port* (‘harbour’), *portier* (‘porter’), *portion* (‘portion’), *portique* (‘porch’), *portrait* (‘portrait’), *portière* (‘door of a car’), *portugais* (‘Portuguese’), but also a true (in the sense of BANISH-VANISH) neighbor *postons* (‘mail carry$_{1PL\ PRES\ IND}$’), and all these pseudo-relatives behave like competitors at the lexical level. A verb like *mourir* (‘die$_{INF}$’), on the other hand, is almost a hermit, since the only pseudo-relative it has is the rare *mouron* (‘scarlet pimpernel’), and therefore will receive a very small amount of competition in the lexical-orthographic level. A word can belong to the pseudo-family of another word even if they don’t share their stem: for example, *portugais*, under our definition, is a pseudo-relative of *portons* because the stem of the latter is a part of the superset *portugais*. The decision to include this type of pseudo-relative in the computation of pseudo-family size was based on previous studies emphasizing the role of the beginnings of words in lexical access (Humphreys *et al.* 1990; Grainger *et al.* 1992), as well as on recent studies on lexical co-activation (Bowers *et al.* 2005b). Consequently, this measure of pseudo-family should not be assimilated to stem homographs, such as those of Laudanna *et al.* (1989), ex. It. *colpo* – *colpa* (‘blow’ – ‘guilt’). In short, we can say that our definition of the pseudo-family size of a lexical entry is a mix of neighbors in the classic sense, of members of their morphological family, but also of all words sharing their stem with that entry, even if what remains of the word once the stem is removed is not really an affix (e.g., *porter* – *portugais*). Thus, we can consider *mourir* as a hermit, from a morphological point of view, and oppose priming effects obtained with this kind of word to effects obtained with words like *porter,* where the prime word can activate a legion of lexical competitors.

The measure of pseudo-family size that we used in this study is divergent from that of the morphological family size of a stem, defined as the number of different complex words containing the same stem (excluding inflectional variants). This morphological family size has been found to affect response latencies in tasks such as visual lexical decision (Schreuder & Baayen 1997) in a variety of languages, (ex. Dutch, Schreuder & Baayen 1997; Bertram *et al.* 2000) and reflects the number of words that will work as ‘synagonists’ during the recognition process. Our measure of pseudo-family size reflects the amount of words that will work as ‘antagonists’ for words coming from large pseudo-families. In the opposite case, we can speak of a ‘lack of antagonism’ or, in terms of lexical activation, of ‘morphological hermits’.

The experiments we report on here were designed to test the role of the lexical environment of the prime (in terms of competitors) and the way this lexical environment influences derivational and inflectional effects, under masked conditions. If the rationale exposed above, central to the supralexical approach, corresponds to the way things happen in the lexicon, then morphological priming for verbs having low pseudo-family sizes (morphological hermits) should be more efficient than for verbs coming from a rich pseudo-family which share formal features with many other words. The members of the pseudo-family (if any) will function as competitors at the lexical level, retarding the rise of activation of the lexical entry above threshold, and consequently the activation of the morphological level.

2. Experiment 1a

2.1. Method

Participants. 62 undergraduate students from the University of Aix-en-Provence, native speakers of French, who reported normal or corrected-to-normal vision participated in the experiment.

Stimuli and design. 56 French words and 56 nonwords were used as targets. All targets were the infinitive form of French verbs, from 4 to 9 letters long (mean: 5.6 letters) with an average frequency of 66.17 occurrences per million (New *et al.* 2001) and consisted of i) 28 verbs, 4 to 9 letters long (mean: 5.6 letters), that had large pseudo-families, and ii) 28 verbs, 4 to 7 letters long (mean: 5.75 letters) that were ‘morphological hermits’, i.e. without any or any significant pseudo-family (a pseudo-family consisting of marginal frequency items). These two categories of target word represent the two levels of the pseudo-family size factor that was estimated with the help of a French dictionary (Petit Robert) by exhaustive inspection.

Each target was given four types of prime: a repetition prime, two morphologically related primes, and an unrelated prime. The two conditions of morphologically related primes were a frequent inflection and a much less frequent one (see Table 1 for examples and lexical frequencies). Frequent primes for large pseudo-family verbs included 12 present forms and 16 past participles (passé composé), whereas less frequent primes for the large PsFam verbs included 10 past continuous forms, 10 future forms as well as 8 present forms. Frequent primes for small PsFam verbs included 10 present forms and 18 past participles, whereas less frequent primes for the small PsFam targets included 16 past continuous forms, 11 future forms as well as 1 present form.

The justification for this heterogeneity of the inflections used as primes is that we tried to keep constant the form overlap between prime and target, i.e. between frequent and less frequent inflectional primes as well as across the two types of targets (large and small PsFam sizes).

56 French nonverbs were created respecting the orthotactic constraints of the language and were matched for length with the real verbs. The primes for nonword targets matched the word primes in terms of orthographic overlap, and were constructed so as to mimic the two types of morphologically related primes for word targets. Four experimental lists were created by rotating targets across the four priming conditions using a Latin-square design, so that each target appeared only once for a given participant, but was tested in all priming conditions across participants. Participants were randomly assigned to one of the four lists.

Procedure and apparatus. The experiment was conducted on a PC computer using the DMDX software (Forster & Forster 2003). Each trial consisted of three visual events. The first was a forward mask consisting of a row of nine hash marks that appeared for 500ms. The mask was immediately followed by the prime. The prime was in turn immediately followed by the target word which remained on the screen until participants responded. The intertrial interval was 1 second. The prime duration used in this experiment was 50ms. All stimuli appeared in the middle of the screen presented in lowercase characters in order to preserve stress markers over the appropriate vowels. In order to prevent orthographic overlap being confounded with visual overlap, the size of the font was manipulated (Arial 18 point for targets and 12 point for primes; Participants were seated 50 cm from the computer screen. They were requested to make lexical decisions on the targets as quickly and as accurately as possible, by pressing the appropriate button on a gamepad. After 20 practice trials, participants received the 112 experimental trials in one block.

	Primes						
Word	Targets	Repe-tition	Frequent Inflection	Ortho. overlap	Not frequent inflection	Ortho. overlap	Unrelated
PsFam + verbs	monter (climb)	monter	monté (climbed)	3.75 lt. (64 %)	montais (I was climbing)	3.75 lt. (66 %)	perdre
PsFam- verbs	sentir (feel)	sentir	senti (felt)	4.07 lt. (69 %)	sentiront (they'll feel)	4.21 lt. (69 %)	appeler

	Primes						
Nonword	Targets	Repe-tition	Pseudo-inflection	Ortho. overlap	Pseudo-inflection	Orth. overlap	Unrelated
Pseudo verbs	dainier	dainier	dainions	3.71 (65%)	dainiais	3.79 lt (67 %)	taunnie
Pseudo verbs	vlâmir	vlâmir	vlâmé	3.68 (67%)	vlâmmais	3.7 lt (69 %)	sténon

Table 1. Sample stimuli and degree of prime-target orthographic overlap (letters, percentage) for the repetition, the two morphologically related primes (frequent and not frequent inflection) and the unrelated conditions for the two types of target (large pseudo-family verbs, low- pseudo-family verbs) tested in Experiment 1a.

3. Experiment 1b

Experiment 1b was identical to experiment 1a, except that targets were not the infinitive forms of French verbs and pseudoverbs, but their 1st person plural present indicative form. The aim of this manipulation was to modify the relative frequency between prime and target. For a language like French, where infinitive forms tend to have a surface frequency higher than conjugated forms, this means that (conjugated) targets will have a surface form frequency lower or equivalent to that of their inflections (see Table 2 for comparative frequencies of the materials used in Experiments 1a and 1b). 32 subjects from the same subject pool participated in this experiment.

	Targets Exp. 1a	Inflections F+	Inflections F-	**Targets Exp. 1b**	Inflections F+	Inflections F-
PsFam+ verbs	**monter** 115.4	monté 144.08	montais 4.16	**montons** 6.27	monté 144.08	montais 4.16
PsFam- verbs	**sentir** 78.4	senti 95	sentiront 2.39	**sentons** 4.64	senti 95	sentiront 2.39

Table 2. Examples of stimuli and frequencies (in occurrences per million) for materials used in experiments 1a and 1b: targets and morphologically related primes, frequent inflections (F+) and not frequent inflections(F-) for the two types of verbs, large pseudo-family size verbs (PsFam+) and small pseudo-family size verbs (PsFam-).

4. Results

Correct response times (RTs) were averaged across participants after excluding outliers (300 > RTs > 1300ms). The results for word stimuli for experiments 1a and 1b are presented in Table 3. An ANOVA was performed on the remaining data with prime type (repetition, frequent inflection, less frequent inflection, unrelated) and verb category (large pseudo-family size, small pseudo-family size) as within-participant factors. We report only Fs by subjects, since our Latin Square design permits us to remove all F2 analyses (Raaijmakers *et al.* 1999) which would be very conservative for this type of design.

Words

	Repetition (R)	Frequent inflection (F+)	Not frequent inflection (F-)	Unrelated (U)	Net Priming Effects		
Exp. 1a	**RT**	**RT**	**RT**	**RT**	**U– R**	**U – F+**	**U – F-**
PsFam+ verbs	602	617	633	634	32	16	1
PsFam- verbs	593	597	624	633	40	36	9
Exp. 1b	**RT**	**RT**	**RT**	**RT**	**U-R**	**U-F+**	**U-F-**
PsFam+ verbs	638	663	629	652	14	-11	23
PsFam- verbs	594	618	622	644	50	26	22

Table 3. Reaction times (RT in milliseconds) for lexical decisions to targets in the repetition (R), frequent inflection (F+), not frequent inflection (F-) and unrelated (U) prime conditions for the two categories of verbs, large pseudo-family (PsFam+) and small pseudo-family verbs (PsFam-) tested in Experiments 1a and 1b. Net priming effects are given relative to the unrelated prime condition.

Experiment 1a. There was a significant main effect of prime type, F1(3, 366) = 19.86, p<.0001. The main effect of pseudo-family size was not significant (F1<1), neither was the interaction between the two main factors, F1(3, 366) = 1.01.

Planned pair-wise comparisons show significant repetition priming for both types of verbs, F1(1, 61) = 12.79, p<.0003 for PsFam+ verbs and for PSFam- verbs, F1(1, 61) = 33.22, p<.0001. Facilitation induced by frequent inflections was significant for large, F1(1, 61) = 5.75, p<.00, as well as for low PSF-size size verbs, F1(1, 61) = 33.25, p<.001. Priming induced by infrequent inflections was not significant, either for PsFam+ verbs, F<1, or for PsFam- verbs, F1(1, 61) = 1.61. The two morphological prime conditions did not differ between them for PsFam+ verbs, F1(1, 61) = 3.27, but did for PsFam- verbs, where the difference of 27ms between frequent and infrequent inflections was significant F1(1, 61) = 11.81, p<.001.

Experiment 1b. The same type of analysis was conducted separately for the results from experiment 1b. Again, the main effect of prime type was significant, F1(3, 186) = 6.50, p<.05, and the main effect of pseudo-family size was not significant, F1(1, 62) = 1.99, p<.xx. Contrary to experiment 1a, the interaction between these two factors was significant, F1(3, 186) = 3.58, p<.05.

Planned pair-wise comparisons show significant repetition priming for small PsFam size verbs, F1(1, 31) = 28.62, p<.0003 but not for large PsFam size verbs, F1(1, 31) = 1.43. Morphological priming due to frequent inflections is significant for small PsFam size verbs, F1(1, 31) = 11.24, p<.0003 but not for large ones, F1<1, and priming due to infrequent inflections follows the same pattern, F1(1, 31) = 4.92, p<.05, and F1(1, 31) = 3.49 respectively. Morphological priming between frequent and infrequent inflections did not differ for PsFam- verbs, F1<1 whereas it differed for PsFam+ verbs, F1(1, 31) = 6.13, p<.005, that is the opposite situation than that observed in experiment 1a.

The robust repetition priming (50ms) obtained for PsFam- verbs differs significantly from morphological priming, F1(1, 31) = 6.42, p<.0003 for frequent and F1(1, 31) = 9.02, p<.0003 for not frequent inflections, whereas morphological and repetition conditions do not differ for PsFam+ verbs, neither for frequent inflections, F1(1, 31) = 3.45, nor for not frequent ones, F1<1.

5. Discussion

The main outcome of our study concerns the role of pseudo-family size under two different circumstances: in the first one, (exp. 1a) only primes that are frequent inflections of the infinitive targets facilitate processing, whereas not frequent inflections fail to induce any facilitation and pseudo-family size does not seem to influence morphological effects. In experiment 1b we replace the infinitive target by a much less frequent one, which is the 1^{st} person plural present indicative form. By this manipulation, the relative frequencies between primes and targets are modified comparatively to experiment 1a (for relative frequencies, see Table 2). The results are very clear: under the conditions of experiment 1b, only small PsFam size verbs induce repetition and morphological priming, for frequent as well as for not frequent inflections, whereas large PsFam verbs fail to induce repetition or morphological priming. Moreover, inflectional priming for small PsFam verbs does not differ for the two types of primes, i.e., frequent or not frequent inflections. In the remaining of the discussion we are going to see how the role of the pseudo-family size variable and the pattern of results it leads to can be incorporated in models of morphological processing.

In the vast majority of priming studies, and *a fortiori* of masked priming studies, targets are the base forms of their morphological primes – inflections or derivations. Base or infinitive forms are at the same time the most frequent members of the paradigm, and, because of their high frequency, have a quite low threshold of activation. Consequently, a base/infinitive form is the easiest member of the paradigm to activate. This is the situation of experiment 1a, in which no difference is observed between large and small pseudo-family size verbs. When lexical decision is no longer based on the member of the inflectional paradigm that is already the most activated by virtue of its frequency, we can examine a larger window of processing and observe that lexical interference effects manifest themselves in a more visible way than under the conditions of experiment 1a (and conditions of the majority of studies using the base form of the verb as the target). We thus obtain evidence for reduced lexical competition via the enhanced repetition and morphological priming for frequent and infrequent inflections that have no – or have a very small – pseudofamily. Under exactly the same circumstances, large PsFam verbs that have lots of competitors at the lexical-orthographic level, fail to induce inflectional priming. This pattern of results is a strong piece of evidence in favor of the idea that competition taking place at the lexical-orthographic level influences what is happening at the morphological level: inflections that have no 'antagonist' at the lexical level can facilitate the processing the target, whereas inflections with many 'pseudorelatives' fail to contact the morphological representation of the target.

Thus, the first contribution of the present study, in terms of understanding inflectional processing, is that by manipulating lexical factors (pseudo-family size and frequency of the target) we manage to modulate inflectional morphological priming, in a way that hints at influences of lexical competition.

The immediate consequence of lexical competition influences on morphological effects is that the morphological level of processing should be situated above the lexical-orthographic level of processing, exactly as in the supra-lexical model of Giraudo & Grainger (2000, 2001, 2003), in which it is the lexical-orthographic level that activates the morphological level of processing and not the other way round. This approach is opposed to a purely sublexical view (Taft 1981; Taft & Forster 1975), which holds that activation of the lexical entry is enabled by stripping the affix from the whole word. In our view, and according to the supralexical model of morphological processing, the access to morphologically complex forms does not simply consist of activating its lexical representation; the system has to make the right 'choice' as to which candidate should be activated most (or first). When the target is not already the most activated member of the paradigm (exp. 1b), then, we can have a closer look at lexical competition effects in the orthographic-whole word level. It seems thus, that the presence of numerous antagonists on the lexical-orthographic level interferes with processing of the target, leading to the absence of morphological effects. It is commonly admitted that the surface frequency of the stimuli plays an important role in interactive activation (McClelland & Rumelhart 1981) as well as in serial (Forster 1976) models. It determines the 'resting level' or residual activation of a given lexical unit, and consequently, the amount of activation needed to reach the identification threshold. Nevertheless, what the majority of masked priming studies report as morphological effects is the facilitation induced by a morphologically related prime on the base form target, i.e., the member of the morphological family that has the greatest residual activation because of its frequency, generally higher than that of other morphologically related forms.

To assume that inflected verb forms in general and low frequency ones in particular are stored in the mental lexicon is a natural stance in a supra-lexical morphology (and in a word and paradigm morphology in general), but it is far from being uncontroversial. In a sub-lexical account for regular inflections, (Pinker 1991; Taft 1994) low-frequency inflections are parsed and do not have their own traces in memory. Nevertheless, the different pattern of results between experiments 1a and 1b can only be explained by the modification of the relative frequencies between primes and targets, since all the other factors were kept constant. What would be difficult to explain in our results for a decompositional morphological model, would be the ability of low frequency inflections of high frequency verbs to induce morphological priming equivalent to high frequency inflections of exactly the same verbs, if and only if, these verbs happen to come from small pseudo-families. It would not be very easy for a decompositional model of morphological processing to incorporate data that suggest influence of lexical competition effects on morphological processing, under conditions depending on the relative frequencies between the stimuli used.

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