The role of stem frequency in morphological processing

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1. Introduction

In usage-based models, it is generally acknowledged that the frequency of use of a lexical item influences its representation in long term memory, its organization in lexical storage and its processing mechanism during lexical access, since repeated exposures to an item lead to its entrenchment in the minds of the speakers (e.g., Bybee 2003; Bybee and Beckner 2010; Croft and Cruse 2004; Tomasello 2003). When it comes to morphologically complex words, processing mechanisms and lexical access are crucially determined by the relative frequency of the derived word and of its morphological components (both the stem and the affix). The results of thirty years of psycholinguistic research, mostly from lexical decision tasks, have demonstrated that, since frequent derived words have a strong lexical representation and are therefore highly entrenched in the speakers' minds, they are more likely to be processed holistically, i.e., as whole words. On the contrary, low frequency derived words made up of frequent morphological components would be more prone to be processed through a parsing process, i.e., by the activation of their morphological constituents. Starting from these results, an intense debate has sparked (as will be discussed in § 1.1): more precisely, researchers do not unanimously agree on the role of the stem during the processing of derived words. According to some studies (e.g., Taft and Foster 1975; Taft 1979), every morphologically complex form would be decomposed and consequently accessed through the stem whereas other researchers argue that this would only happen under specific conditions (Caramazza, Laudanna and Romani 1988).

An interesting contribution to this debate has come from psycholinguistic studies exploiting the masked priming experimental design combined with a lexical decision task (see §.1.2). What distinguishes this experimental protocol is the fact that, since the time given to access the derivative (usually used as a prime) is limited, a more sophisticated picture of the automatic and unconscious processing mechanisms of derived words is provided. Focusing on the very early stages of lexical access, this methodology highlights different nuances of frequency effects in comparison with traditional experimental tasks (lexical decision tasks with no priming). More precisely, it could be argued that the data coming from the latter might be evidence of a post-lexical effect, and therefore might reflect the organization of the lexicon in the mind, rather than the mechanisms involved during access to it.

In order to explore in more detail the role of the stem in the processing of morphologically complex words, we conducted a masked priming experiment on Italian, where we manipulated the frequency of the stem, while keeping constant that of the derived prime. More precisely, we contrasted stems which were on average twice as frequent as the derivatives (e.g., *trasferimento* 'transfer' (112) vs. *trasferire* 'to transfer' (284); target/prime ratio: 2,53) to stems which were on average half as frequent as the derivatives (e.g., *motivazione* 'motivation' (98) vs. *motivare* 'to motivate' (44); prime/target ratio: 2,22).

On the one hand, an influence of the stem frequency in the magnitude of priming effects would point towards a decompositional interpretation, i.e., a segmentation process at a prelexical level could be hypothesized. On the other hand, if the stem frequency was found to have no effect, this would mean that access occurs through the whole form. A similar finding would not necessarily mean denying the role of the stem frequency in the organization of the lexical architecture; rather, it would be consistent with a view which hypothesizes that the mechanisms involved in lexical access are crucially different from the criteria of organization involved in lexical representation.

2. Background

2.1. Frequency effects in lexical decision tasks

In traditional psycholinguistic research, frequency effects have been observed mainly by means of visual lexical decision tasks (from now on LDT), i.e., experiments where the subjects are asked to decide whether the letter string they are briefly exposed to is a word of their language or not. Generally, these experimental studies oppose derived or inflected words of comparable surface frequency, but crucially differing in their stem frequency (high vs. low). In this kind of studies, when reaction times (RTs) are found to be a function of the stem frequency, this is considered as evidence of the fact that word recognition implies the activation of the stem.

Research on frequency effects has flourished after the seminal – though controversial – proposal put forward by Taft and Forster (1975) and Taft (1979), according to which affixes (precisely, prefixes and inflectional suffixes) would be ‘stripped off’ their stem prior to lexical access, which proceeds from the stem.

As for Italian, Burani and Caramazza (1987) investigated derived suffixed forms (verbal roots combined with highly productive suffixes such as *-mento*, *-tore*, *-zione*) by opposing stimuli matched for whole-word frequency, but differing in root frequency (Exp. 1), to stimuli matched for root frequency but differing in whole-word frequency (Exp. 2). Their aim was to find out whether reaction times in lexical decisions were determined by the frequency of the root-morpheme or rather by the frequency of the whole-word and thus to verify Taft and Forster’s proposal. Since their results indicated that RTs were influenced by both root and whole-word frequencies (faster RTs were obtained for items containing a high frequency root in Exp. 1 and for higher whole-word frequency items in Exp. 2), the authors suggested that the access procedure crucially operates with both whole-word and morpheme access units. This kind of results led them to elaborate a ‘dual-route’ model, i.e., the Augmented Addressed Morphology Model (AAM, proposed in Caramazza, Laudanna and Romani 1988), which includes both prelexical morphological computation and whole-word lexical representation of complex words. According to this model, the activation of an access unit corresponding to the whole word is a faster and more efficient procedure for familiar words, while the activation of morpheme access units is exploited for the recognition of items which do not have a global lexical representation, i.e., novel words, neologisms or pseudo-words. To sum up, what this model shares with Taft’s is the assumption that there is a lexical component where the words are decomposed into morphemes. However, while in Burani and Caramazza’s activation model access to lexical representations for previously experienced words takes place via a whole word procedure, Taft proposes a serial architecture where the search process is always conducted via the root.

Frequency effects have been observed also in French by Colé, Beauvillain and Segui (1989), who similarly considered derived words matched for surface frequency but differing in their cumulative root frequency (e.g., *jardinier* ‘gardener’, containing a high frequency root, vs. *policier* ‘policeman’, containing a low frequency root). Since a clear cumulative root effect was observed only for suffixed words (but not for prefixed ones), Colé and colleagues suggest that only the former are accessed through decomposition via the root.

However, it is in Schreuder and Baayen's Race Model that frequency is acknowledged to play a crucial role in determining processing mechanisms: in this model morphological parsing would not be limited to unknown or new complex words (as in the AAM), but would be extended also to less frequent words, which contain commonly used roots (Schreuder and Baayen 1995 and Baayen and Schreuder 1999 for the evolution into the Parallel Dual-Route Model).

In the same line of reasoning, Burani and Thornton (2003) conducted a study on the interplay between the frequency of the root, the frequency of the suffix and the whole-word frequency in processing Italian derived words. More precisely, in Exp. 3, they considered low frequency suffixed words which differed with respect to the frequency of their morphemic constituents. As expected, the results showed that lexical decisions were faster and more accurate when the derived words included two high-frequency constituents (e.g., *pensatore* 'thinker') and slowest and least accurate when both constituents had low frequency (e.g., *luridume* 'filth'). Interestingly, when the derived words included only one high-frequency constituent (either the root or the suffix), the lexical decision rate was found to be a function of the frequency of the root only, irrespective of suffix frequency. The authors conclude that access through activation of morphemes is beneficial only for derived words with high frequency roots, while lexical decision latencies to suffixed derived words are a function of their surface frequency when they contain a low frequency root.

To sum up, frequency effects have been considered as a diagnostic for determining whether an inflected or derived form is recognized through a decompositional process that segments a word into its morphological constituents or through a direct look-up of a whole-word representation stored in lexical memory. Frequency has therefore played a crucial role in the debate which opposed full parsing models, which assume a prelexical treatment of the morphological constituents with a consequent systematic and compulsory segmentation of all complex words (Taft and Forster 1975, Taft 1979), and full listing models, which defend a non-prelexical processing of the morphological structure and a complete representation of all morphologically complex words (McClelland and Rumelhart 1981).

2.2. Frequency effects and masked priming

More recently, frequency effects have been investigated using the masked priming experimental paradigm associated with a LDT, which gives a slightly different picture of such effects on word recognition. This experimental paradigm is usually employed to verify the existence of a facilitation effect between a derivative word (i.e., the prime word) and its stem (i.e., the target word). The advantage of this technique is that, since the prime is presented on the screen for a very short time (usually between 45 and 60ms), subjects are not aware of its presence and any observed facilitation cannot therefore be considered to derive from a conscious recognition of the prime-target relationship. Moreover, as the activation of the prime is constrained by strictly determined time limits, this technique allows for observation of the very early stages of lexical access, during which other bits of information possibly encoded in the lexicon are not yet available to the subjects.

Despite the introduction of this experimental methodology, the dichotomy between decompositional and holistic approaches has not been reconciled yet and the results of masked priming studies have not been univocally interpreted. We shall now briefly consider the main contributions to this debate. Giraudo and Grainger (2000) in a series of masked priming experiments investigated the role of surface and base frequencies using French material. More precisely, they manipulated the surface frequencies of derivatives used as primes for the same target (HF *amitié* 'friendship' - *ami* 'friend'; LF *amiable* 'friendly' - *ami* 'friend'). They found an interaction between priming effects and the prime surface frequency (Exp.1), but no effect for the base frequency. Experiments 1 and 3 demonstrated that the surface frequency of morphological primes affects the size of morphological priming: high surface frequency derived primes showed significant facilitation relative to orthographic control primes (*amidon* 'starch' - *ami* 'friend'), whereas low frequency primes did not. The results of Experiment 4 revealed, on the contrary, that cumulative root frequency does not influence the size of morphological priming on free root targets. Suffixed word primes facilitated the processing of free root targets with low and high cumulative frequencies. These data suggest that during the early processes of visual word recognition, words are accessed via their whole form (as reflected by surface frequency effects) and not via decomposition (since the base frequency did not interact with priming).

It is worth noticing that in the traditional experiments carried out with the masked priming protocol, the usual prime-target configuration is one where the target word (i.e., a stem) is the most frequent member of the pair and thus the easiest-to-activate member of the morphological paradigm (e.g., *darkness*/ *dark*). The reverse situation has rarely been investigated, yet it is potentially very useful in order to understand the processing mechanisms, mainly with respect to the parsing/listing dichotomy. Interestingly, Voga and Giraudo (2009) reversed the traditional prime-target configuration and, considering French inflected forms, used the less frequent item as target word (e.g., *montons* 'we mount') and the most frequent one as prime (e.g., *monter* 'to mount') (Exp. 1b). Moreover, in order to better verify the strength of lexical representations, they also considered the 'environment' of the prime, i.e., its competitors, the number of words sharing the same letters of the stem without having a morphological relationship with it. Morphological priming was expected to be more efficient for verbs with a small pseudo-family (i.e., a limited number of antagonists). Their results confirmed that high frequency targets (usually the base or infinitive forms of inflectional paradigms) have a low threshold of activation and are therefore the easiest-to-activate form of the paradigm, independently of their antagonists (size of the pseudofamily). However, when the targets are not the easiest-to-activate forms because of their low frequency, the effect of pseudo-family size emerges, as the competition which takes place at the lexical-orthographic level influences what happens at the morphological level. In other words, it seems that the presence of many antagonists at the lexical-orthographic level interferes with the processing of low frequency targets, leading to the absence of morphological effects. According to the authors, this is the reason why morphologically related forms with no antagonists at the lexical level can facilitate the processing of the target, while forms with many pseudo-relatives fail to do so.

Another piece of evidence against the decompositional hypothesis comes from the study conducted by Orihuela and Giraudo (submitted), which considers the effects of the relative frequencies of complex primes and their base target opposing the configuration with high frequency primes / low frequency targets to the configuration with low frequency primes / high frequency targets in French. Their results reveal that, relative to both the orthographic and unrelated conditions, morphological priming effects emerge only when the surface frequency of the primes is higher than the surface frequency of the targets. Again, these data contradict the prediction of the classical decomposition hypothesis, according to which the reverse effects would be expected.

The interpretation of frequency effects with respect to psycholinguistic models, however, remains very controversial. McCormick, Brysbaert and Rastle (2009) defend a completely different position, in favour of an obligatory decomposition of all kinds of stimuli (even for the non-morphologically structured ones). They carry out a masked priming experiment manipulating the frequency of the prime, thus comparing high frequency, low frequency and non-word primes. Their hypothesis is that if morphological decomposition is limited to unfamiliar words, as predicted by the horse-race style of dual-route models, then priming should be limited to the last two conditions. On the contrary, if morphological decomposition is a routine, an obligatory process applying to all morphologically structured stimuli should occur in all three conditions. The results show that the priming effect observed with high-frequency primes is equivalent to the one observed with low-frequency primes and with non-word primes. Such findings seem to confirm the claim that a segmentation process is not restricted to low-frequency words or non-words, as assumed by horse-race models (e.g., Caramazza et al. 1988; Schreuder and Baayen 1995).

3. The present study

3.1. Method

3.1.1 Participants

38 Italian native speakers, 16 males and 22 females, aged 17 to 55 years (mean age: 29,39), with normal or corrected-to-normal vision, participated in the experiment. All of them had high-school or university education and took part in the experiment voluntarily.

3.1.2 Stimuli and design

We selected 80 critical items to be used as target stimuli for this experiment and divided them in two subsets: 40 of them were high frequency words (mean frequency: 238,23) and 40 were low frequency words (mean frequency: 42,30). For each stimulus we created a morphological, an unrelated and an orthographic prime. Since we were interested in the effects of the manipulation of the stem frequency, the frequency of the morphological primes was kept constant in the two subsets (mean frequency in the HF subset: 87,75; LF subset: 95,33). The orthographic and the unrelated primes were matched as well (mean frequency in the HF subset: orthographic: 92,78; unrelated: 90,63; mean frequency in the LF subset: orthographic: 136; unrelated: 96). Moreover, all of the three primes were matched for letter length (mean length in the HF subset: morphological: 10,90; orthographic: 8,03; unrelated: 9,15; mean length in the LF subset: morphological: 11,13; orthographic: 8,03; unrelated: 9,43). We made sure that the ratio between the frequencies of primes and targets was comparable in the two subsets: in other words, in the HF subset the target was 2,71 as frequent as the prime, while in the LF one the prime was 2,25 as frequent as the target. Frequency values were extracted from the CoLFIS database. The targets were either verbs or nouns, with respectively deverbal nouns and denominal adjectives as morphological primes. We created four experimental lists in which the targets were rotated across the four priming conditions by means of a Latin square design, so that participants saw each target only once in one of the possible four conditions. The experimental design is summarized in the tables below:

CONDITIONS	PRIME	FREQ.	HF TARGET	FREQ.	TARGET/PRIME RATIO
Identity	*trasferire*		*trasferire*		
Morphological	*trasferimento*	112	*trasferire*	284	2,53
Orthographic	*trasparenza*		*trasferire*		
Unrelated	*sacrificio*		*trasferire*		

CONDITIONS	PRIME	FREQ.	LF TARGET	FREQ.	PRIME /TARGET RATIO
Identity	*motivare*		*motivare*		
Morphological	*motivazione*	98	*motivare*	44	2,22
Orthographic	*motorino*		*motivare*		
Unrelated	*orizzonte*		*motivare*		

Table 1: Experimental design (HF *vs* LF targets)

3.2. Procedure and apparatus

The experiment was run on a PC using the DMDX software (Forster and Forster 2003). Each trial consisted of three visual events: the first was a forward mask made up of a series of hash marks that appeared on the screen for 500ms. The mask was immediately followed by the prime, which appeared on the screen for 50ms. The target word was then presented and remained on the screen until participants responded. Both primes and targets were presented in lowercase; however, they differed in size and font. Prime stimuli were presented in Arial 12 and target stimuli in Cambria 16. Participants were seated 50 cm from the computer screen and were instructed to decide as quickly and accurately as possible whether the target stimuli they saw were words or not, by pressing the appropriate buttons on the keyboard. They were not aware that a prime word was presented. After 20 practice trials, participants received the 160 items in two blocks.

4. Results

Correct response times (RTs) were averaged across participants after excluding outliers (RTs >1500ms, 0,65% of the data). Results are presented in Table 2. An ANOVA was performed on the data with prime type factor (identity, morphologically related, orthographic and unrelated controls) and frequency factor (high frequency targets and low frequency targets) as within-participant factors. The list factor was included as a between-participant factor in order to extract any variance associated with this variable and turned out to be not significant ($F<1$). A Latin Square design was used in the present experiment; therefore, as recommended by Raaijmakers, Schrijnemakers and Gremmen 1999, we did not perform separate subject and item analyses, but only a F1 statistic test.

The analysis of RTs latencies showed a main effect for Frequency, $F1(1,37)=43.17$, $p<.0001$ and Prime Type, $F1(3,111)=29.53$, $p<.0001$. The interaction of frequency by prime was not significant, $F1(3,111)=1.04$, $p > .10$. Main comparison differences (significant at $p<.05$) are indicated in Table 2. An analysis of the error rates showed no main effect (All $Fs < 1$).

				Net priming effects				
	Prime type	RTs (SD)	Errors	I-M	O-M	I-U	M-U	O-U
Low Frequency targets	Identity	660 (124)	2 (0,52%)	+7		+47*		
	Morphological	653 (121)	4 (1,05%)		+24*		+44*	
	Orthographic	677 (107)	12 (3,15%)					+20*
	Unrelated	697 (113)	10 (2,63%)					
High Frequency targets	Identity	623 (113)	4 (1,05%)	-2		+57*		
	Morphological	625 (111)	4 (1,05%)		+33*		+55*	
	Orthographic	658 (123)	3 (0,78%)					+22*
	Unrelated	680 (115)	9 (2,36%)					

Table 2. Reaction Times and SD (in milliseconds), error rates (in %) for lexical decisions to word targets in each frequency and priming condition, with net priming effects relative to the identity, orthographic and the unrelated prime conditions. * : $p < .05$

We found significant morphological effects for both HF and LT targets: morphologically related primes yielded faster RTs with respect to the unrelated condition, independently of the prime/target frequency ratio. Moreover, morphological primes did not differ from the identity primes, suggesting comparable magnitudes of morphological facilitation. These equivalent effects indicate that the activation strength of the morphological primes is the same because their surface frequency was equal. This is in line with the results of Giraudo and Grainger

(2000) according to which the priming effect is a function of the surface frequency of the prime (as a whole-word) and not of its stem frequency. Finally, both morphological primes differed from their orthographic controls (+29 ms on average), while both orthographic controls induced faster RTs than the unrelated primes (+21 ms on average). This indicates that while orthographic primes produced mere formal facilitation effects, morphological primes induced genuine morphological effects reflecting form and meaning correlations between primes and targets.

As expected, overall we obtained faster RTs for HF targets, as their activation threshold is lower than the threshold of LF targets.

5. Discussion

The present data show that full morphological priming effects are obtained whatever the frequency of the targets (high or low). Accordingly, the frequency of the base contained in the derived primes (e.g., *trasferire* in *trasferimento*) does not interfere with morphological facilitation: primes whose base had a high frequency did not induce stronger facilitation than primes with a low frequency base. As a consequence, contrary to a decompositional approach of lexical access to complex words, the prior presentation of a complex prime whose stem has a high surface frequency does not accelerate the access to its lexical representation relative to primes whose stem frequency is low.

Moreover, in the present experiment both morphological primes induced full priming (i.e., same priming effects for morphological and identity condition) and both differed significantly from orthographic and unrelated controls. Hence, morphological primes are as efficient for the recognition of their base target as the repetition of the target itself. This suggests that morphological families are not accessed through stem activation but through the activation of each of its members and without being segmented into stem + affix. Such findings replicate the results found in Giraudo and Grainger study (Exp. 4) in which the cumulative frequency of the targets (high vs. low) was manipulated with French materials. The results of their Exp. 4 showed that cumulative root frequency did not influence the size of morphological priming on free root targets. Suffixed word primes facilitated the processing of free root targets with low and high cumulative frequencies. Thus, a manipulation designed to modulate the involvement of morphological processing (according to a generic dual-route model) did not lead to variations in morphological priming.

The present data do not, however, contradict the results found by Colé et al. (1989) in French or by Burani and Caramazza (1987) and Burani and Thornton (2003): rather, they are not in line with their interpretation. These authors found a root frequency effect which has been interpreted as evidence in favour of the activation of the stem during lexical access. Since we did not find a base frequency effect using masked primes, this suggests that lexical access does not take place via the automatic activation of the stem of suffixed words.

The important difference between these studies and ours resides indeed in the experimental designs employed to examine morphological processing. While Burani et al. used a simple lexical decision task, we combined it with a masked priming paradigm. While the former provides information on the time needed to consciously process a visual target, the latter, constraining the duration of the prime exposure, allows for the observation of very early stages of unconscious processing. Moreover, this paradigm does not examine the entire process of word recognition as the LDT does, but explores a transfer of activation between a prime and a target. More precisely, it questions whether the information extracted from the prime representation during a very reduced time is able to spread towards other representations thanks to links or shared representations. As a consequence, we can say that in the LDT the observed RTs reflect an overall process of lexical access resulting from two types of activation: the time required to activate the lexical representation depends on its lexical/surface frequency and on the activation of its synagonists (i.e., morphologically related words that facilitate the recognition of the target as demonstrated by the robust family size effect, see De Jong, Schreuder and Baayen 2000). Masked priming effects, on the other hand, depend much more on the lexical frequency of the prime (that determines its activation threshold) given the fact it is presented for a limited time. Hence, masked priming corresponds to a small window in the overall process of word recognition. Accordingly, this paradigm is much better suited to constrain the process engaged while accessing the mental lexicon. This, however, does not mean that priming effects only correspond to pre-lexical effects, otherwise morphological priming effects would not differ from orthographic priming effects. This significant difference has been extensively demonstrated in the literature on masked morphological priming (see Baayen 2014 for a review) and there is no doubt that masked priming also reflects lexical effects. We would like to highlight here that the prime exposure duration is a parameter that constrains the access to lexicon.

Therefore, we claim that our data clearly show that the stem frequency does not interfere with the access to the mental lexicon. Moreover, morphological priming effects reveal that, as soon as a lexical representation is activated within the mental lexicon, such a representation automatically triggers the activation of all its family members. The result of the overall activation of the morphological family is revealed in those LDT experiments in which it has been observed that both the lexical and the base frequency determine the recognition latencies of suffixed words. Only models that consider the word as the main unit of analysis, be it morphological (e.g., Giraudo and Voga 2014) or not (e.g., Baayen et al. 2011), are able to account for our data and the previous findings.

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