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Syllable Priming With Pseudowords in the Lexical Decision Task

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This study investigated the processes underlying the effect of masked syllable priming in French with pseudoword primes and word targets. Two lexical-decision task (LDT) experiments examined whether the syllable priming effect depends on syllable frequency and might rely on a general abstract structure. The results of Experiment 1 revealed an inhibitory priming effect, with pseudoword primes and word targets sharing a high-frequency first syllable, which was not due to the abstract syllable structure. In contrast, no inhibition was observed with a low-frequency first syllable in Experiment 2. Syllable frequency appears to be an important factor determining the speed of target processing in masked priming. This is attributed to variations in the respective contributions of sublexical activation and lexical inhibition processes.

Keywords: visual word recognition, syllable frequency, syllable priming, pseudoword prime, lexical competition

In recent decades, a growing body of evidence has shown that phonology plays an important role in visual word recognition (see Frost, 1998, and Rastle & Brysbaert, 2006, for reviews). From the 1970s, the syllable unit became the focus of special interest to address the issue of phonological activation in reading. Preliminary studies in English investigated the potential use of syllable and nonsyllable letter strings in word identification and showed that the reader was sensitive to syllable structure (e.g., Mewhort & Beal, 1977; Spoehr & Smith, 1973; Taft & Forster, 1976). By manipulating the spatiotemporal arrangements of groups of letters, it was found that both the availability of a horizontal spatial dimension and a syllable-consistent temporal presentation of the letters were necessary conditions to exploit the syllable structure in word identification (Mewhort & Beal, 1977; Mewhort & Campbell, 1980). Since these seminal experiments, many studies have been conducted in several languages to examine whether the syllable is a functional unit in visual word recognition. However, the nature of the syllable effects and processes underlying these phenomena are still issues under investigation. These last two decades, syllable frequency and syllable priming have become important variables for elucidating these issues.

Since the work of Carreiras, Álvarez, and de Vega (1993) on syllable frequency in Spanish, it is generally assumed that syllable neighbours, or words sharing the first syllable with the stimulus (e.g., neighbours of *ve.na* are *ve.la, ve.lo, ve.llo*), play a role in visual word recognition.[1] In the lexical-decision task (LDT), words and pseudowords with a first syllable of high frequency took longer to respond to than those with a first syllable of low frequency. The inhibitory effect of syllable frequency was further replicated in Spanish (Perea & Carreiras, 1998) and in several other alphabetic languages (in French, Mathey & Zagar, 2002; in German, Conrad & Jacobs, 2004, but see Macizo & Van Petten, 2007, for facilitation in English). This inhibitory effect has been mainly interpreted in interactive activation models of visual word recognition sharing the core assumption of McClelland and Rumelhart (1981), which posits that a set of lexical candidates are coactivated and compete with each other during word recognition. Current models of interactive activation incorporate a syllable level between the letter and the word level to explain syllable effects (see Carreiras et al., 1993; Conrad, Carreiras, Tamm, & Jacobs, 2009; Mathey, Zagar, Doignon, & Seigneuric, 2006), and it has been assumed that words with a high-frequency first syllable activate many syllable neighbours, thereby delaying the processing of the stimulus representation compared with words with a low-frequency syllable. Syllable frequency effects therefore result from early facilitatory sublexical activation and inhibition at the lexical level. The facilitatory syllable frequency effect observed in English can also be explained by activation of lexical candidates based on syllable codes. However, owing to less clearly marked phonological syllable boundaries, activation might spread more slowly than in other languages, so the cohort of syllabic neighbours might not be activated strongly enough to interfere with the lexical matching process (Macizo & Van Petten, 2007). In addition, in

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[1] Hereafter, the dots mark syllable boundaries, though the items presented did not contain the dots.

Spanish and French, event-related potentials have consistently shown two temporally distinct effects of syllable frequency (Barber, Vergara, & Carreiras, 2004; Chetail, Colin, & Content, 2012), which were interpreted in the theoretical framework of interactive activation. At the P200 time window, words with a low-frequency first syllable elicited a larger positivity than those with a high-frequency syllable. This was taken as an indicator of the initial activation of a larger number of lexical candidates produced by high-frequency syllables. A later effect appeared at the N400 time window, showing that words with a high-frequency syllable elicited a larger negativity than those with a low-frequency first syllable. This was considered as the electrophysiological correlate of lexical competition between the coactivated candidates. Finally, evidence has been provided in favour of the phonological nature of syllabic processing in visual word recognition (e.g., Álvarez, Carreiras, & Perea, 2004; Carreiras, Ferrand, Grainger, & Perea, 2005), so syllables are generally considered as phonological units. A widespread assumption is that syllabic representations are located in the phonological route of an interactive competition model, mediating the activation of phonological word representations (e.g., Conrad et al., 2009; Dominguez, de Vega, & Cuetos, 1997; Ferrand, Segui & Grainger, 1996; Mathey et al., 2006).

Although interactive activation is a widely used framework to explain word recognition effects, this theory has limitations. Especially, evidence converges to indicate that the letter-channel structure is not flexible enough to take into account letter spacing (Campbell & Mewhort, 1980), letter positional uncertainty (e.g., Mewhort & Johns, 1988), and the effects of addition and deletion orthographic neighbours (e.g., Davis, Perea, & Acha, 2009). Several proposals have been formulated to solve inconsistencies relative to letter coding (e.g., for discussions, see Davis et al., 2009; Grainger & Ziegler, 2011; Massaro, 1988; Mewhort & Johns, 1988; Mozer, 1987; Whitney, 2001). Despite these limitations, current findings show that the core principle of a simple interactive activation model—parallel activation of multiple similar representations and competition for selection—still provides a relevant framework to accommodate the effects of lexical similarity (Chen & Mirman, 2012). Importantly, net facilitatory and inhibitory effects of lexical neighbours can be accounted for and simulated by interactive activation competition models (e.g., Chen & Mirman, 2012; Davis, 2003; Mathey & Zagar, 2000). Furthermore, both facilitatory and inhibitory syllable frequency effects have also been simulated by an extended version of the interactive activation model incorporating syllable units (Conrad, Tamm, Carreiras, & Jacobs, 2010).

It can be argued that at a theoretical level, showing syllable-like effects does not imply that the syllable should be represented as a unit per se. Indeed, several models of written word identification have been shown to be sensitive to syllable-like structure, even though they did not explicitly represent the corresponding units (e.g., Kwantes & Mewhort, 1999; Seidenberg & McClelland, 1989). Although such models make it possible to explain facilitation from syllable-like structure or frequency, they are less suitable to accommodate the inhibitory effects of lexical neighbours because they do not comprise a mechanism of lateral inhibition (see also Conrad et al., 2009). Therefore, at least in Spanish and French, interactive activation competition networks incorporating syllable units and a word level with bidirectional inhibitory connections might provide an appropriate framework to accommodate syllable frequency effects (see Álvarez et al., 2004; Carreiras et al., 1993; Conrad et al., 2009, 2010; Mathey et al., 2006).

In addition to syllable frequency effects, syllable priming effects allow a detailed examination of the issue of similarity between words. With the masked priming paradigm (Forster & Davis, 1984), in which a prime is presented before the target word to be processed, it is possible to activate a defined lexical candidate prior to the target presentation, thus allowing its influence on target processing to be examined (see Forster, 1999). Thus, the same target word can be submitted separately to the potential influence of a phonologically or orthographically similar prime and compared with an unrelated prime. In interactive activation competition models in which a set of lexical neighbours is activated, the higher frequency neighbour of a word is its strongest competitor. Hence, preactivation of this lexical neighbour via the priming procedure enhances the neighbour competition, which delays the target word identification (see Davis, 2003). Conversely, pseudoword or partial primes generally produce facilitatory priming because the target is preactivated and competition does not occur or does not have time to develop enough to delay the target identification. This paradigm sheds light on how sublexical and lexical similarities influence visual word recognition, and on the way facilitatory and inhibitory processes develop and contribute to lexical access. Specifically, several priming experiments investigating the syllable influence on word identification have been conducted by using primes and targets that were matched or mismatched on the first syllable and on the first letters (i.e., syllable congruency procedure), which makes it possible to disentangle syllable and orthographic overlap influences. In other experiments, syllable characteristics have been manipulated to investigate how they influence priming (e.g., orthographic transcription of the phonological syllable, syllable frequency). As presented next in a short review of priming experiments investigating syllable effects, most of these studies have used partial primes or pseudoword primes and have been conducted in French and Spanish.

To investigate syllable priming effects, Ferrand et al. (1996) proposed a visual adaptation of the syllable detection task (Mehler, Dommergues, Frauenfelder, & Segui, 1981) combined with masked priming. Target words were primed by partial primes that corresponded either to their first syllable or not, such as *bal%%%-BAL.CON*, and *ba%%%%-BAL.CON*, respectively (prime duration, 29 ms; stimulus-onset-asynchrony [SOA], 43 ms). The interest of the syllable congruency procedure lies in the possibility to orthogonally manipulate the syllable matching between primes and targets, while keeping constant the orthographic overlap. No syllable congruency effect was found in the LDT, which was attributed to too short a prime exposure duration. Consistently, a reliable facilitatory effect was found with a 67-ms prime duration by using pseudoword primes (e.g., *bal.nat-BAL.CON*, *ba.lave-BAL.CON*; Chetail & Mathey, 2009).[2] The effect was accounted for by an interactive activation model with syllables (Mathey et al., 2006). In this framework, when a pseudoword is presented, it is assumed that activation is sent from the letters to the corresponding phonological syllable units (i.e., the prime *bal.nat* strongly activates the syllable /bal/, whereas the prime *ba.lave* strongly activates the syllable /ba/). When the target word is presented, activation would

[2] When not specified in the text, the SOA corresponds to prime exposure duration.

be sent from the letter level to both the lexical level and the syllable level. Therefore, in the congruent priming condition, the critical syllable is preactivated by the prime, which explains faster target identification and, thus, facilitatory syllable priming effects. Using phonological syllables with several spellings, Carreiras et al. (2005) specifically investigated the phonological nature of the syllable priming effect with a 59-ms prime duration. Faster lexical decision times were found when the pseudoword prime shared only the first phonological syllable with the target (e.g., *fo.mie-FAU.CON*), compared with initial phoneme primes (e.g., *fé*.mie-FAU.CON) or with unrelated primes (e.g., *pé*.mie-FAU.CON). This showed that the syllable effect obtained was phonological and could not be attributed to orthographic factors. As a whole, facilitatory syllable priming effects can be interpreted in interactive activation frameworks, in terms of preactivation of the phonological syllable of the target word (e.g., Conrad et al., 2009; Mathey et al., 2006).

By contrast with the facilitation observed in French, mixed findings have been reported in Spanish. Inhibitory syllable priming effects were found with word primes and 64- to 80-ms prime exposure durations (Carreiras & Perea, 2002). Words primed by a syllable neighbour word of higher frequency (e.g., *bo.ca-BO.NO*) took longer to identify than words primed by an unrelated word (e.g., *ca.ja-BO.NO*). The effect was facilitatory with pseudoword primes (e.g., *bo.pa-BO.NO* vs. *ca.ya-BO.NO*), which is consistent with other findings (in French, Carreiras et al., 2005, and Chetail & Mathey, 2009; in Spanish, Álvarez et al., 2004). This effect of prime lexicality was interpreted in an interactive activation framework, in terms of activation and inhibition processes that develop during prime and target processing. Only word primes would produce enough activation of the lexical competitors at the word level to allow inhibitory processes to develop, whereas pseudoword primes would lead only to sublexical activation. However, inhibitory effects of syllable congruency with nonlexical primes were also reported in the primed LDT. For example, using an unmasked priming paradigm, Dominguez et al. (1997) showed that target words were recognised more slowly when they were preceded for 200 ms (with a 250-ms SOA) by a pseudoword sharing the first syllable (e.g., *man.io-MAN.TA*) rather than by a pseudoword that shared the first letters but not the first syllable (e.g., *ma.nio-MAN.TA*), compared with unrelated primes (respectively, *til.po-MAN.TA*, *se.ruo-MAN.TA*). A similar pattern of results was found with word primes, so the effect was not due to prime lexicality. These findings were attributed to lexical competition processes between the syllable neighbours activated by pseudoword and word primes. The question arises as to how the finding of an inhibitory priming effect with both word and pseudoword primes may be explained. In interactive activation frameworks, within-level inhibition processes clearly overcome facilitatory processes with word primes because a syllable neighbour competitor is directly preactivated by priming, which is not the case for pseudoword primes (Carreiras & Perea, 2002). It is clear that a pseudoword per se does not have any lexical representation in the lexicon and cannot produce direct lexical inhibition. However, a net inhibitory effect might also occur in some cases with pseudoword primes when inhibition outweighs facilitation (for a similar proposal in the field of orthographic priming, see Burt, 2009, and van Heuven, Dijkstra, Grainger, & Schriefers, 2001). According to Dominguez et al. (1997), it can be assumed that a pseudoword initially activates a cohort of syllable neighbours and that these activated neighbours produce lexical inhibition. Therefore, the representation of the target is activated among the set of syllable neighbours, which all compete with each other. In this way, the target response is delayed. By using a partial prime procedure with a 200-ms exposure duration, Álvarez, de Vega, and Carreiras (1998) found an inhibitory effect of syllable frequency in the LDT. This was further observed with a shorter prime duration of 50 ms (Álvarez, Carreiras, & de Vega, 2000). Words primed by their first syllable were recognised more slowly when they had a high-frequency first syllable rather than a low-frequency one. Therefore, it appears that nonlexical primes can produce inhibitory syllable priming effects. In an interactive activation framework, this suggests that competition between activated syllable neighbours sometimes has time to develop enough to interfere with target identification.

Altogether, previous priming studies suggest that the syllable is a functional unit of visual word recognition, at least in Spanish and French. It has also been shown that priming provides a fruitful paradigm to investigate syllable effects. However, only a few studies have been conducted in French, and several issues merit further investigation to better understand the processes underlying syllable effects. In the present study, we focused on the effects of syllable priming with pseudoword primes in two LDT experiments examining the role of syllable frequency and the abstract syllable structure. We used pseudoword primes rather than word primes because they offer the possibility to better control the experimental materials.

Although syllable frequency has been shown to be an important factor influencing unprimed lexical decision times, and even partial priming responses, its effect has never been directly investigated in previous studies with syllable neighbour primes. In an interactive activation competition model with syllables (Mathey et al., 2006; see also Conrad et al., 2009), it can be assumed that syllable frequency influences the activation speed of syllable units and, therefore, the development of lexical inhibition between syllable neighbours. In this framework, only high-frequency syllable primes would allow lexical inhibition to develop enough to overcome facilitation from the sublexical units. To examine the role of syllable frequency in priming, we designed two experiments by selecting pseudoword–word pairs with either high-frequency syllables (Experiment 1) or low-frequency syllables (Experiment 2). In particular, the other lexical and sublexical characteristics of the materials were matched across the two experiments for purposes of comparison. It was expected that syllable inhibitory priming would be evidenced in Experiment 1 and disappear or be reversed in Experiment 2. In addition, we examined the role of the abstract structure of the syllable in order to determine whether syllable effects depend on syllable identity or might rely on a more general abstract structure in terms of consonants and vowels (e.g., CV, consonant–vowel–consonant [CVC]; see Dominguez et al., 1997). A 67-ms prime duration was used to promote the activation of prelexical syllable units, given that previous research using the masked priming procedure with pseudoword primes have shown syllable congruency effects with prime exposure durations higher than 60 ms (in Spanish, Carreiras & Perea, 2002; in French, Chetail & Mathey, 2009).

Experiment 1

The aim of this experiment was to examine whether an inhibitory syllable priming effect can be observed with pseudoword primes. Given that syllable frequency is an important factor determining visual word recognition processes in the French language (e.g., Mathey & Zagar, 2002), it can be assumed that it plays a role in the emergence of an inhibitory priming effect. To examine this issue, we selected word targets and pseudoword primes sharing a high-frequency first-syllable (e.g., *BA*), which should trigger a strong competition. Additionally, we compared related and unrelated prime conditions to examine whether the syllabic structure per se (e.g., CV vs. CVC) is involved in the syllable priming effect (see also Dominguez et al., 1997; Ferrand & Segui, 1998; Schiller, 2000, in word production). Therefore, word-prime relatedness and the abstract structure of the syllable were factorially varied.

In the related condition, the prime was a pseudoword sharing the first two letters with the target, which either corresponded to the first syllable of the target (e.g., *ba.riul-BA.GAGE*) or not (e.g., *bau.tul-BA.GAGE*). We expected an inhibitory effect attributable to lexical competition from the syllable neighbour words. In this condition, the first syllable of congruent syllable primes naturally had the same abstract structure as the target (e.g., CV prime–CV target), which was never the case for incongruent syllable primes (e.g., CVC prime–CV target). A further question was whether sharing the abstract structure of the syllable, which is strictly confounded in the syllable conditions, might be involved in the effect of syllable priming. Thus, we also used an unrelated condition in which the same target was preceded by a pseudoword that did not share any positional letter or syllable with the target, while the first syllable structure of the prime was either similar or different to that of the target (e.g., CV–CV structure in *mi.rien-BA.GAGE* vs. CVC–CV structure in *min.von-BA.GAGE*). If syllabic priming effects do not ensue from abstract syllabic structure, an inhibitory syllable priming effect should be observed in the related condition (*ba.riul-BA.GAGE* vs. *bau.tul-BA.GAGE*) but not in the unrelated condition (*mi.rion-BA.GAGE* vs. *min.von-BA.GAGE*).

Method

Participants. Thirty-four students volunteered to participate. All were native speakers of French and reported having normal or corrected-to-normal vision.

Stimuli. Seventy-two target words of five to eight letters in length were selected in the French lexical database Brulex (Content, Mousty, & Radeau, 1990). The sublexical frequencies were computed on the whole corpus of words in Brulex. The main statistical characteristics of the word target materials are presented in Table 1. All words were bisyllabic, with no ambisyllabicity, and had a first phonological syllable of high frequency with a CV structure. They had no higher frequency orthographic neighbour. For each of these target words, four types of nonword primes were constructed (see the Appendix for the complete list of stimulus materials). In the related condition, the prime was a pseudoword sharing the two initial letters with the target, which either corresponded to the first syllable of the target (e.g., *ba.riul-BA.GAGE*) or not (e.g., *bau.tul-BA.GAGE*). In the unrelated condition, the pseudoword primes did not share any positional letter or syllable with the target. The abstract structure of the first syllable of the pseudoword was either similar to that of the target (e.g., CV structure: *mi.rien-BA.GAGE*) or different (CVC or CVV structure: *min.von-BA.GAGE*). *T* tests for paired samples were conducted to check that the frequency of the first syllable was matched across the related and unrelated conditions ($p > .10$). The first bigram frequency was also controlled ($p > .10$). Seventy-two pseudoword targets of five to eight letters with a first syllable of high frequency were added for the purposes of the LDT. All were pronounceable and orthographically legal. They were also preceded by a pseudoword prime. Four lists of stimuli were used so that, in each list, every stimulus appeared once in one of the four prime conditions.

Procedure. Participants were tested individually in a quiet room and performed an LDT after providing written consent. Each trial consisted of a sequence of three stimuli presented in isolation on the centre of the screen of a personal computer using the DMDX software (Forster & Forster, 2003). A forward mask consisting of a row of hash marks matched for length with prime and target was presented for 500 ms, followed by a lowercase prime for 67 ms, which was then replaced by an uppercase target that remained on the screen until the participant responded (for a similar procedure, see Chetail & Mathey, 2009). Participants were instructed to decide as quickly and as accurately as possible whether the target was a word or not by pressing one of two buttons on the keyboard. No mention was made of the primes. Visual feedback was provided when participants gave an incorrect response or when 2500 ms had elapsed. Participants were randomly assigned to one of the four experimental lists, with one fourth of the target words presented in each of the four priming conditions. The presentation of the 144 stimuli was randomized for each participant. Twelve practice trials were conducted before the experiment started. Reaction times (RTs) were measured from

Table 1
Main Characteristics of Materials in Experiment 1

		Related primes		Unrelated primes	
	Targets	Same structure	Different structure	Same structure	Different structure
Example	BAGAGE	bariul	bautul	mirien	minvon
LogF	3.10	—	—	—	—
F Syllable 1	257,162	257,162	227,453	247,820	218,353
F Bigram 1	309,204	309,204	309,204	335,772	335,772

Note. LogF = mean word frequency per 100 million (in logarithms). F syllable 1 = token frequency of first syllable. F bigram 1 = token frequency of first bigram. Syllable and bigram frequencies are given in number of occurrences per 100 million.

target onset until the participant responded. It was checked that none of the participants saw the prime consciously by interviewing them after the experiment.

Results and Discussion

We treated RTs below 300 ms or above 2,000 ms as outliers, and these were excluded from the analyses (0.04% of the correct word data). The mean correct response latencies and error rates averaged over participants for words are presented in Table 2. The data were submitted to separate analyses of variance on the participant means and item means with Prime Type (related vs. unrelated prime) and Syllable Structure (same vs. different) as within-participant factors (F1 analyses) and within-item factors (F2 analyses).

Analysis of the RTs showed that the interaction between prime type and syllable structure was significant, $F1(1, 33) = 6.20$, $p = .02$, $f = 0.48$, and $F2\ (1, 71) = 7.60$, $p = .007$, $f = 0.35$. An inhibitory priming effect of syllable structure was found in the related condition (+27 ms) but not in the unrelated condition (−1 ms). Planned comparisons indicated that the syllable priming effect was reliable in the related condition, $F1(1, 33) = 8.07$, $p = .008$, $f = 0.57$, $F2(1, 71) = 9.60$, $p = .003$, $f = 0.40$, whereas there was no effect in the unrelated condition, $F1$ and $F2 < 1$.There was no main effect of prime type (Fs < 1). The main effect of syllable structure was significant in the item analysis only, $F1(1, 33) = 2.57$, $p = .12$, $f = 0.29$; $F2(1, 71) = 3.83$, $p = .05$, $f = 0.24$.

Analysis of the error rates showed a significant prime type effect, $F1(1, 33) = 6.40$, $p = .02$, $f = 0.49$; $F2(1, 71) = 5.10$, $p = .03$, $f = 0.28$. No other effects were significant (all Fs < 1).

The main finding of this experiment is that we found an inhibitory syllable priming effect with pseudoword primes. In the related condition, when the first syllable shared by the word target and the pseudoword prime was of high frequency (e.g., *ba.riul-BAGAGE*), an inhibitory priming was observed, compared with a bigram-overlap condition (e.g., *bau.tul-BA.GAGE*), thus providing additional evidence that the syllable congruency effect is a reliable one in the French language. Importantly, this effect of syllable structure did not appear in the unrelated condition, showing that the syllable priming effect was not due to the abstract syllable structure per se (CV, CVC). This is consistent with the hypothesis of incorporating syllable representations in models of visual word recognition (e.g., Carreiras et al., 1993; Conrad et al., 2009; Mathey et al., 2006).

The direction of the syllable priming effect we observed was not consistent with previous studies showing a facilitatory priming effect with pseudoword primes in French (e.g., Carreiras et al., 2005; Chetail & Mathey, 2009) and in Spanish (Álvarez et al., 2004; Carreiras & Perea, 2002), although it reproduced the pattern of results found with word primes in Spanish (Carreiras & Perea, 2002). Nevertheless, inhibitory priming effects have already been observed with nonlexical primes in Spanish. For example, Dominguez et al. (1997) reported inhibitory syllable priming with both pseudoword and word primes presented for 200 ms. In addition, studies by Álvarez and colleagues (1998, 2000) yielded inhibitory effects of syllable frequency with partial primes of short and long prime durations (50 and 200 ms). According to Dominguez et al. (1997), inhibitory priming effects can be accounted for by the hypothesis of lexical competition produced by the syllable neighbours. In that case, inhibitory priming effects with pseudoword primes would occur when inhibition overcomes facilitation (see also Burt, 2009; van Heuven et al., 2001).

In an interactive activation model of visual word recognition incorporating a phonological syllable with a resting level based on frequency (Mathey et al., 2006), syllable frequency determines the speed of activation of the syllable neighbours. When a prime is presented, activation spreads from the letter level to the phonological syllable level. When the first syllable is of high frequency, more activation is provided to the lexicon, which enhances inhibition from the neighbours. In the case of high-frequency syllables, it can be assumed that syllable activation occurs so fast that competition between coactivated syllable neighbours has time to develop even for pseudoword primes. This would explain the net inhibitory priming effect we observed.

However, such inhibition with pseudoword primes was not reported in previous studies in French in which syllable frequency was not taken into account (Carreiras et al., 2005; Chetail & Mathey, 2009). In a follow-up experiment, we therefore investigated the syllable frequency effect with primes and targets sharing first syllables of low frequency, in order to compare the findings with those of Experiment 1.

Table 2
Mean Reaction Times (in Ms) and Error Rates (Between Brackets) On Prime-Target Pairs With a High-Frequency First Syllable (Experiment 1)

Syllabic structure	Prime type: Related	Unrelated
Same	686 (5.6)	668 (3.3)
Different	659 (5.4)	669 (3.1)
Priming effect	+27 (+0.2)	−1 (+0.2)

Experiment 2

This experiment examined the syllable priming effect with word targets and pseudoword primes sharing a low-frequency first syllable (e.g., *RO*), in order to create a condition leading to no or little inhibition between syllabic neighbours. The experimental design was similar to that of Experiment 1, with a factorial manipulation of word-prime relatedness and abstract structure of the syllable. In the related condition, the prime was a pseudoword sharing the first two letters with the target, which either corresponded to the first syllable of the target (e.g., *ro.bane-RO.CHER*) or not (e.g., *roi.sie-RO.CHER*). In the unrelated condition, the same target was preceded by a pseudoword that did not share any positional letter or syllable with the target. The first syllable structure of the prime was either similar or different than that of the target (e.g., CV-CV structure in *pu.rand-RO.CHER* vs. CVC-CV structure in *pur.don-RO.CHER*).

In an interactive activation model incorporating syllables with a resting level based on frequency (Mathey et al., 2006), it can be assumed that when a pseudoword with a low-frequency first syllable is presented as a prime, the syllable is weakly activated. This activation would not be sufficient to activate the lexical competitors. This weak preactivation of the syllable might benefit the target activation and produce facilitation (see Carreiras & Perea, 2002), or even no facilitation if it is too weak. Thus, we expected the inhibitory syllable priming effect found in Experiment 1 to be reversed or disappear in Experiment 2.

Method

Participants. Thirty-two students volunteered to participate. All were native speakers of French, reported having normal or corrected-to-normal vision, and had not participated in the previous experiment.

Stimuli. Seventy-two target words with the same characteristics as in Experiment 1 were selected (see Appendix for the complete list of stimulus materials), except that they had a first phonological syllable of low frequency (see Table 3). Word targets were matched across Experiments 1and 2 according to length, lexical frequency, first bigram frequency, summed bigram frequency, frequency of the first trigram, the number of orthographic neighbours, the number of phonemic neighbours, and the number of words with a bigram trough corresponding to the syllabic boundary (*t* tests for independent samples, all $ps > .10$). The four types of primes also had the same characteristics as in Experiment 1, except they had a low syllable frequency that was matched with that of the targets (*t* tests for paired samples compared each prime condition with the target condition, all $ps > .10$). Primes and targets were matched on the first bigram frequency across the two experiments. Seventy-two pseudoword targets of five to eight letters with a first syllable of low frequency were added for the purposes of the LDT. All were pronounceable and orthographically legal. They were also preceded by a pseudoword prime.

Procedure. The procedure was similar to that of Experiment 1.

Results and Discussion

We treated RTs below 300 ms or above 2,000 ms as outliers, and these were excluded from the analyses (0.04% of the correct word data). One word was eliminated because of its high error rates (65%). The mean correct response latencies and error rates averaged over participants for words are presented in Table 4. The data were submitted to separate ANOVAs on the participant means and item means with Prime Type (related vs. unrelated prime) and Syllable Structure (same vs. different) as within-participant factors (F1 analyses) and within-item factors (F2 analyses).

Analysis of the RTs showed that the interaction between prime type and syllable structure was marginally significant, $F1(1, 31) = 2.87$, $p = .10$, $f = 0.32$, $F2(1, 70) = 3.32$, $p = .07$, $f = 0.22$, showing a small trend to facilitation in the related condition (−16 ms) but not in the unrelated condition (+ 9 ms). No other effect was significant in the RT analysis (all $ps > .10$). No effect was significant in the error analysis (all $ps > .10$).

To combine the results of Experiment 1 and Experiment 2 that were collected from different participants, raw RTs were converted into *z* scores. The data were submitted to a 2 (syllable structure) × 2 (prime type) × 2 (syllable frequency) factorial ANOVA. In both the participant (F1) and the item (F2) analyses, syllable frequency was used as a between factor, and prime type and syllable structure were within factors. Importantly, the Syllable Frequency × Prime Type × Syllable Structure interaction was significant in both the participant and item analyses, $F1(1, 64) = 8.68$, $p = .004$, $f = 0.40$; $F2(1, 141) = 9.18$, $p = .003$, $f = 0.26$. No other effects were reliable in the combined analysis. Additionally, in the combined error analysis, the Syllable Frequency × Prime Type interaction was marginally significant in the item means only, $F1(1, 64) = 2.25$, $p = .14$, $f = 0.19$; $F2(1, 141) = 3.12$, $p = .08$, $f = 0.15$. No other effects were significant (all $ps > .10$).

As expected, no inhibitory syllable priming effect was found with pseudoword primes with a low-frequency syllable in Experiment 2. A nonsignificant trend to facilitation was observed in the related condition. Contrary to previous findings in the French language (Carreiras et al., 2005; Chetail & Mathey, 2009), we did not find any clear facilitation. This might be due to the selection of syllables of very low frequency in Experiment 2. Only very weak sublexical activation would occur with such syllables, so the target would not reliably benefit from it and the response times would not be significantly improved. Finally, the main finding was that the combined analysis of Experiments 1 and 2 indicated that the effect of syllable priming significantly depended on syllable frequency.

Table 4
Mean Reaction Times (in Ms) and Error Rates (Between Brackets) On Prime-Target Pairs With a Low-Frequency First Syllable (Experiment 2)

	Prime type	
Syllabic structure	Related	Unrelated
Same	690 (4.2)	696 (4.1)
Different	706 (3.1)	687 (3.1)
Priming effect	−16 (+1.1)	+9 (+1.0)

Table 3
Main Characteristics of Materials in Experiment 2

		Related primes		Unrelated primes	
	Targets	Same structure	Different structure	Same structure	Different structure
Example	ROCHER	robane	roisie	purand	purdon
LogF	3.11	—	—	—	—
F Syllable 1	45,361	45,361	44,774	40,641	45,768
F Bigram 1	300,411	300,411	300,411	304,466	304,466

Note. LogF = mean word frequency per 100 million (in logarithms). F syllable 1 = token frequency of first syllable. F bigram 1 = token frequency of first bigram. Syllable and bigram frequencies are given in number of occurrences per 100 million.

General Discussion

This study investigated the processes underlying the syllable priming effect in the LDT in order to better understand how written words are processed. The results of Experiment 1 yielded an inhibitory syllable priming effect with pseudoword primes that was attributed to the first syllable of high frequency shared by pseudoword primes and word targets. Consistently, the results of Experiment 2 showed that the inhibitory effect was no longer found when the first syllable shared by pseudoword primes and target words was of low frequency. On the contrary, a nonsignificant facilitatory trend was observed. Taken together, the data from Experiments 1 and 2 suggest that the syllable priming effect we observed with pseudoword primes depended on syllable frequency and was not due to the abstract syllable structure.

The most important finding of this study is that syllable priming depended on syllable frequency. The joint manipulation of syllable frequency and syllable congruency enabled us to highlight the processes underlying syllable priming effects and to explain their direction. Indeed, we observed a reliable inhibitory syllable priming effect with pseudoword primes, but only when the first syllable was of high frequency. This effect could be due to lexical competition from the neighbours of the target, which would be preactivated by the pseudoword prime (see also Dominguez et al., 1997). These data suggest that syllable frequency is an important factor determining the speed of target processing in masked priming with pseudoword primes. A straightforward way to explain our data is to postulate that syllables are mentally represented units and that their activation depends on their frequency. This assumption has been made in interactive activation models of visual word recognition incorporating an intermediate layer between the letter and word levels, which contains phonological syllable representations, with a resting level based on frequency (Mathey et al., 2006). In this theoretical framework, it can be assumed that, on the one hand, high-frequency syllables are activated more rapidly than low-frequency ones, which also speeds the activation of a cohort of syllable neighbour words in unprimed situations. Although in priming it is generally assumed that syllable neighbour pseudoword primes produce facilitation at a sublexical level (Carreiras & Perea, 2002; see also Carreiras et al., 2005; Chetail & Mathey, 2009), it can be assumed that when syllable processing is rapid (in the event of high-frequency syllables), pseudoword syllable primes can also activate a cohort of lexical competitors that are responsible for the inhibitory syllable priming effect. On the other hand, when syllable processing is slow (in the event of low-frequency syllables), lexical inhibition would not have time to take place. This explains the results of Experiment 2. To go further, the results of Experiments 1 and 2 offer a rationale in terms of syllable frequency and show that high-frequency syllables determine the emergence of lexical competition, at least in French. In addition, we demonstrate that the syllable priming data of Experiments 1 and 2 cannot be attributed to the abstract syllable structure (e.g., CV, CVC), which strengthens the claim that syllable priming effects are subsumed by specific syllable representations. Therefore, in the theoretical framework of interactive activation competition, we assume that syllable frequency is one of the factors determining the respective amount of between-level activation and intralevel inhibition processes that come into play in syllable priming with pseudoword primes.

The issue of syllable inhibition with pseudoword primes might also be related to findings in the field of research on orthographic priming, as the syllable neighbourhood interpretation is directly derived from that of orthographic neighbourhood (see Barber et al., 2004; Carreiras et al., 1993), which is generally defined as the set of words sharing all but one letter with the stimulus (Coltheart, Davelaar, Jonasson, & Besner, 1977). With a prime duration of 60 ms, it was found that the facilitation produced by pseudoword primes on word targets with a low number of orthographic neighbours disappeared when the number of orthographic neighbours was high (Forster, Davis, Schoknecht, & Carter, 1987). This was later attributed to the number of neighbours shared by the prime and the target (van Heuven et al., 2001; see also Davis, 2003). According to van Heuven et al. (2001; see also Davis & Lupker, 2006), masked pseudoword primes can even exert inhibitory effects when the prime and the target share orthographic neighbours. When using the traditional definition of syllable neighbours (Carreiras et al., 1993), as in most of the experiments in the literature, the neighbours of the primes are the same as those of the target because they all share the first syllable. Thus, because there is evidence to suggest that orthographic priming effects depend on the number of shared orthographic neighbours, it seems reasonable to assume that syllable priming also depends on the number of syllable neighbours. A correlation analysis run on the data of Experiments 1 and 2 revealed that the syllabic priming effect computed in the related condition (RT same structure – RT different structure) was significantly correlated with the number of syllable neighbours (r = .21, p = .01). Thus, inhibitory priming was increased when syllable frequency was increased, which can be explained by the increase in lexical competition between syllabic neighbours. In the field of orthographic priming, recent findings reporting an inhibitory priming effect from unmasked pseudoword primes have also been interpreted in terms of lexical competition (Burt, 2009). All these arguments therefore converge to support the claim that the inhibitory priming effect we found was genuinely due to lexical competition stemming from the syllable neighbours (see also Dominguez et al., 1997).

To conclude, this study adds support to the view that the syllable is a functional phonological unit of visual word recognition. More importantly, it shows that syllable frequency is an important factor determining the speed of target processing in masked priming with pseudoword primes, which can be attributed to variations in the respective contributions of sublexical activation and lexical inhibition processes. Further research should be designed to investigate whether syllable frequency also influences the syllable priming effect with word primes, and whether the relative frequency of word primes and their syllable neighbour targets word also determines the strength of the effect (see also Chetail et al., 2012). Finally, future experiments should examine whether the same is true for languages other than French in order to investigate the role of the degree of spelling-sound regularities in syllable effects.

Résumé

Cette étude se penche sur les mécanismes sous-jacents à l'effet de l'amorçage masqué au moyen de syllabes, en français, avec des pseudo-mots amorces et des mots cibles. Deux expériences reposant sur deux tâches de décision lexicale visaient à examiner si l'effet d'amorçage d'une syllabe dépend de la fréquence de cette syllabe et relève peut-être d'une structure abstraite générale. L'Expérience 1 a révélé un effet inhibiteur de l'amorçage, les pseudo-mots amorces et les mots cibles partageant une première syllabe selon une fréquence élevée, qui n'était pas attribuable à la structure abstraite de la syllabe. En revanche, aucun effet inhibiteur n'a été constaté dans l'Expérience 2, où la fréquence de la première syllabe était faible. La fréquence de la syllabe semble constituer un facteur important en ce qui a trait à la détermination de la vitesse du traitement de la cible dans l'amorçage masqué. Cette constatation serait attribuable aux variations dans l'apport respectif d'une activation sublexicale et des mécanismes d'inhibition lexicale.

Mots-clés : reconnaissance visuelle des mots, fréquence des syllabes, syllabe amorce, pseudo-mot amorce, compétition lexicale.

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(*Appendix follows*)

Appendix

List of Target Words (in Uppercase) and Pseudoword Primes in Experiments 1 and 2

Experiment 1

BALAI, bavol, bauvé, midos, mindu, BANAL, baluc, baulu, vedoi, verca, BARON, batul, bauto, milur, minva, BAZAR, bacie, bauci, miroc, minso, BAGAGE, bariul, bautul, mirien, minvon, BANANE, basiol, bauvil, velion, verdan, BARèME, bagiet, baugel, misanc, minsac, BARRER, badeve, bausan, milune, minlue, BASSIN, barinc, baurac, mirial, minrac, BAVARD, bassau, bausso, midinc, mindif, BAVEUX, barral, baural, mitoin, mintoi, BAVURE, bachié, bauchi, miciel, mincal, BABOUIN, bassove, bausone, mitanre, mintane, BAFOUER, balunne, baulace, mirinve, mincive, BAGARRE, baneuil, bauseil, michond, minchan, BALANCE, bacourt, bauvoux, miguiel, minguil, BALLADE, barieux, bauseau, midieur, mindrer, BARRAGE, bachiet, bauchet, misiour, minsour, BASSINE, bariaud, bauraud, mineaur, mindeau, BAGUETTE, bachiaux, bauchaux, michiaux, mincheau, CADET, carul, cauro, milic, minli, CABINE, caroun, caubon, micoil, mincoi, CADRAN, caveil, caunil, mitile, mintil, CARAFE, caduir, cautir, misiec, minrec, CADEAU, caruve, cauvue, mirève, minvée, CADENCE, cassoué, caussié, miliant, mincian, CAGOULE, cachort, cauchot, michior, mincher, CAPRICE, calleau, cauleau, midourt, minguel, CAPUCHE, carrair, caurain, microir, minfrir, CAROTTE, caphion, caupiau, migriel, mindoir, CARREAU, caguèle, caugole, missore, minsure, CARRURE, calioux, cauloux, miciand, mincand, CACHETTE, caguieux, cauchoin, migroins, mingreau, CARRIèRE, cagueuil, caugueil, michaint, minchiot, CANIF, cafru, caupu, velou, verla, CANARD, camour, caumor, veduce, verdau, CANICHE, carranc, caufran, veleuil, vercoil, CITER, civoi, cinci, sapué, sampi, CIVET, cimio, cinro, samic, sampu, CIVIL, cisan, cinfa, suroc, surta, CIGARE, cichin, cinchi, saboin, sambor, CIMENT, civial, cinval, surile, surmil, CITRON, ciriet, cincri, surace, surdié, CIGOGNE, ciriaut, cindian, meseurt, meillir, CIVIQUE, ciguion, cingoin, suboins, surpoin, CISAILLE, cicheins, cincheux, sabrourt, samblour, DOCILE, doreau, donran, venort, vermuc, MICRO, milec, minvé, balos, bauli, MIGNON, mitrie, mintue, bamaie, baumai, MIRAGE, minoul, mindor, bathué, bautri, MIROIR, minave, mingué, baguel, baugué, MICROBE, minninc, minchou, bannair, bauchar, MILLIER, mirulle, mindule, barasse, baurase, MISSION, micanve, mincave, bannule, baunale, MIGRAINE, michouin, mingueux, bachiout, bauchout, RADAR, ranim, rainé, mirol, minfo, RADIO, ravom, raisi, mirul, minru, RACINE, rasaif, raisuf, migran, mingal, RAFALE, ramert, raimur, micort, mincor, RAGEUR, rachie, raichi, milone, mindée, RADIEUX, racaibe, raicabe, migonne, mingine, RASER, racui, raicu, cidan, cindo, RAVIR, rafué, raifo, cisen, cinsa, RAPACE, racien, raivur, cilloc, cinfet, RAPIDE, raneul, rainel, civoit, cinvot, RAPPEL, raduce, raidul, cician, cincie, RASADE, ranoin, rainan, cironc, cinruc, RASOIR, ramice, raidée, cilien, cinlué, SALIVE, sabeul, sambel, meneil, meillo, SIRèNE, siguir, simbir, capouc, caupoc, SIROP, simue, simpu, cagué, caugé, VEDETTE, velieux, vertaur, racieur, raiceux.

Experiment 2

BOBINE, bossis, boissé, tavouc, tarvuc, BONNET, bocian, boicie, tabrie, tarbie, BOSSU, bonil, boino, tabim, tarca, BOTTINE, bochair, boichor, tamiaux, tarmaux, BOVIN, bomut, boini, tanol, tarco, BOXEUR, boviel, boinel, tacèle, tarcel, FOLIE, forac, fonro, tabur, taubo, FORAGE, fonoil, foncil, tamint, taumir, FORAIN, foloux, fondou, tacève, taucet, FORêT, fosul, fonga, tanul, tauvu, FOSSé, foros, fonva, taviu, tauva, FOSSETTE, fochiant, fonchart, tachiert, tauguier, FOSSILE, foniert, foncran, tarieux, taureux, FORUM, fonil, fonli, taceu, taucé, GAFFER, garuce, garduc, foliée, fonvie, GAGNANT, gassire, garcive, fossuve, fonsive, GALèRE, gagiel, gargel, fossur, fonsur, GALOP, garit, garga, focin, fonsi, GAMELLE, garroin, gardoin, forioux, fonrain, GAMIN, gasur, garsu, bocui, bouca, GAZETTE, gagueil, garceil, bomiaur, boutaur, GAZEUX, gamare, garmar, bomive, boutié, GAZON, garuc, garvo, bogar, boumo, GALANT, ganour, garnou, bomure, boumas, JOCKEY, jolire, joumie, gadace, gardac, JOVIAL, jollur, joufer, garome, garnod, LOCAL, losiu, loisu, purot, purci, LOGIQUE, loneurt, loinien, purrans, purmeau, LOTERIE, losieur, loiseur, purreux, purpaux, LOTUS, lonni, loini, pucie, purno, PIGEON, pimmie, pimbie, tomuce, tombuc, PILOTE, pimius, pimpus, torian, tompar, PIQUER, pisale, pimbul, tonise, tombic, PIRATE, pivoix, pimpoi, tociel, tompel, PIROGUE, piveuil, pimpion, tomiarc, tombian, PITANCE, pissain, pimbail, lonerts, loisset, PIVERT, piruée, pimbée, loniée, loivée, PISCINE, pichars, pimphar, lomiard, loinnon, PUCERON, pudisse, purgive, foralle, fongale, PUDEUR, puniée, purvin, folire, fonlin, PUPILLE, pussien, purdien, focheau, fonchet, PUNAISE, purraux, pursaux, bocroir, boucrir, PUNIR, purou, purcu, bomul, boumu, ROBOT, ronié, roiné, pumar, purma, ROCHER, robane, roisie, purand, purdan, ROSACE, rocion, roidon, pummir, purmif, ROSéE, romur, roivi, purac, pursi, ROSIER, rocave, roinul, punoin, purnoi, TABAC, taruc, tauré, purol, purlo, TABLEAU, taranne, tauvane, pusanne, pursace, TABLETTE, tachieux, taucheul, puchieur, purchier, TAILLER, tarisse, taurice, pumorre, purmoix, TALENT, tamire, taumie, pisour, pimpou, TAPAGE, tarien, taurer, pimmec, pimbec, TAPER, tavié, tauvi, piroc, pimbu, TAPIS, tamol, taumu, pinan, pimpu, TATOUER, tanesse, taunèse, piraive, pimpove, TABOU, tanuc, taudo, pimée, pimbo, TOMATE, totrin, toitin, pusinc, purlin, TONNEAU, torente, toissie, purière, purvier, TONNERRE, tochiaux, toicheau, pucheuil, purcueil, TONUS, tocié, toicé, pusar, pursu, TOXINE, toleau, toilau, punnar, purnar, TORRENT, tomoice, toivoce, pinusse, pimbuse, TORRIDE, tomiaux, toisaux, pipiaur, pimpair, VACCIN, valiou, vambau, lomiet, loimer, VALET, vamur, vampu, lorri, loiro, VALISE, varroc, vampic, lotuic, loituc, VARICE, vamoix, vambel, lovoin, loiron, VASEUX, valioc, vampoc, lorane, loivan, VACANT, valios, vamber, lorèce, loicré, VALLéE, vasoin, vampoi, lodiel, loidel.

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