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The syllable frequency effect in visual recognition of French words: a study in skilled and beginning readers

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Abstract The present study addressed the issue of syllable activation during visual recognition of French words. In addition, it was investigated whether word orthographic information underlies syllable effects. To do so, words were selected according to the frequency of their first syllable (high versus low) and the frequency of the orthographic correspondence of this syllable (high versus low). For example, the high-frequency syllable /ã/ is frequently transcribed by the orthographic cluster *an*, but infrequently transcribed by *han* in French. A lexical decision task was performed by skilled readers (Experiment 1) and beginning readers in Grade 5 (Experiment 2). Results yielded an inhibitory effect of syllable frequency in both experiments. Moreover, the reliable interaction between syllable frequency and orthographic correspondence frequency indicated that the syllable frequency effect was influenced by orthographic characteristics of syllables. Finally, data showed that the interaction between phonological and orthographic variables was modified with reading experience. The results are discussed in current models of visual word recognition.

Keywords Syllable units · Syllable frequency effect · Syllable orthographic correspondence · Beginning reading · Skilled reading · Lexical decision task

Introduction

Over the last decade, there has been a growing interest for the issue of syllable activation during visual word recognition. More precisely, many studies have been conducted to investigate whether syllables are units involved in the sublexical and lexical processes underlying word identification. One reason for this interest is that

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there is now a strong body of evidence that phonological codes are automatically activated during tasks involving silent reading, even though phonological output is not required (see Frost, 1998). In languages with clear syllable boundaries such as French or Spanish, studies have shown that phonological syllables are relevant units of speech processing (e.g. Bradley, Sanchez-Casas, & Garcia-Albea, 1993; Cutler, Mehler, Norris, & Segui, 1986). Given this major role in speech perception and production, the syllable could be a privileged phonological unit which would keep on being activated automatically during visual word processing in skilled reading, especially in syllable-timed languages (i.e. languages for which syllables are primary rhythmic units of prosodic structure, see Schiller, Costa, & Colomé, 2002). Since the seminal study of Carreiras, Alvarez, and de Vega (1993), evidence has been provided in favour of the syllable activation hypothesis, mainly in Spanish (e.g. Alvarez, Carreiras, & de Vega, 2000; Alvarez, Carreiras, & Perea, 2004; Carreiras & Perea, 2002; Perea & Carreiras, 1998), French (e.g. Carreiras, Ferrand, Grainger, & Perea, 2005; Mathey & Zagar, 2002; Mathey, Zagar, Doignon, & Seigneuric, 2006), and German (e.g. Conrad & Jacobs, 2004; Conrad, Stenneken, & Jacobs, 2006; Hutzler, Conrad, & Jacobs, 2005; Stenneken, Conrad, & Jacobs, 2007). According to this hypothesis, visual word processing in skilled reading involves not only a letter level and a word level (e.g. McClelland & Rumelhart, 1981), but also an intermediate phonological level that is syllabically structured. Secondly, the growing attention for syllable units in visual word recognition is related to the study of polysyllabic word processing. As emphasized by Stenneken et al. (2007), the investigation of processes underlying visual word processing has been restricted until now to monosyllabic words. Thus, it seems now crucial to shed more light on polysyllabic word processing, given that such items represent the largest pool of words in most languages.

In beginning reading also, the role of phonological syllable units is worth studying since phonology plays a critical role. It is now well established that efficient phonological abilities are required to attempt successful reading, given that the basis of reading acquisition consists in learning principles that make it possible to establish the connection between letter sequences and words stored in their phonological form in long-term memory (see Share, 1995). According to the dual-route model (Coltheart, Rastle, Perry, & Ziegler, 2001), the link between letter sequences and word phonological forms is based on grapheme-to-phoneme conversion rules (GPC rules), which make it possible to convert a given grapheme in the corresponding phoneme. When the string of phonemes is assembled, the word representation is contacted in the phonological lexicon and the word meaning is retrieved. The GPC procedure would be the primary procedure used by beginning readers, and would be fundamental for the establishment of the orthographic lexicon. The reading progress is characterized by the use of an additional procedure, whereby letter strings are processed without any phonological recoding. Word representations are directly activated in the orthographic lexicon via letter activation. This second procedure, referred to as the lexical procedure, implies an increase in reading speed and allows to read irregular words correctly. In addition, when reading by the lexical procedure, the more frequent a word is, the faster word identification occurs, since the word representations in the orthographic lexicon are

frequency-sensitive. As underlined by Sprenger-Charolles, Colé, Béchennec, and Kipffer-Piquart (2005), the dual-route model is a reliable framework to investigate the reading acquisition process and to account for reading progress as a function of word exposure. According to this model, phonemes are central units of word phonological processing from early beginning reading. However, several studies have shown that phonemes are not intuitive units and that syllable-sized units are easier to process for children (e.g. Liberman, Shankweiller, Fischer, & Carter, 1974) and even for skilled readers (see Bastien-Toniazzo, Magnan, & Bouchafa, 1999). Thus, the identification of phonemes in words would only occur after the perception of syllables that contain these phonemes. Moreover, accurate word syllabic segmentation of letter strings is essential for correct word pronunciation, and hence, for efficient access to meaning (Doignon & Zagar, 2006). For example, the words *manteau* and *manège* share the first three letters but their syllable boundary, hereafter denoted by a dot, is not located in the same place, *man.teau* (/mã.to/) and *ma.nège* (/ma.nɛʒ/). An incorrect syllabic segmentation (respectively /man/+/to/ and /mã/+/ɛʒ/) would fail to match the letter string to the correct word phonological representation. In sum, syllables could be functional units easily and necessarily accessible during reading acquisition and beginning reading. However, very few studies have examined the role of syllables in visual word recognition in developing readers. In French, Colé, Magnan, and Grainger (1999) investigated the syllable congruency effect in children in Grade 1 using a visual adaptation of the monitoring task (see Mehler, Dommergues, Frauenfelder, & Segui, 1981). In their study, participants had to detect a letter segment in a written word. This segment shared the first letters with the target word, and corresponded to the first syllable of the word in the congruent condition (e.g. *pa* in *pa.lace*, *pal* in *pal.mier*) but not in the incongruent condition (e.g. *pal* in *pa.lace* and *pa* in *pal.mier*). A syllable congruency effect was obtained for good readers, showing that the segments were detected faster when they matched the first syllable of the word target rather than not. When this task was used with children in Grade 5, Colé and Sprenger-Charolles (1999) found a syllable congruency effect for low-frequency words. According to the authors, these results argue for syllable activation on the GPC route. Using the illusory conjunction task in French, Doignon and Zagar (2006) showed that the colour perception of a letter in a word is influenced by the syllabic segmentation. In this study, children were briefly presented with letter strings printed in two colours that either correspond to the syllabic segmentation (e.g. *FI.chu*, upper and lower cases representing two different colours) or not (e.g. *FI.Chu*). They had to detect a letter in these items and report the colour of the letter. The children made more errors in answering that the letter *c* was written in the same colour as the letters *hu* in *FI.Chu* rather than the letters *fi* in *FI.chu*. Similarly, participants made more errors in answering that the letter *r* was written in the same colour as the letters *pa* in *PAr.ti* rather than the letters *ti* in *PAR.ti*. In other words, the error rates showed that the colour of the central letter (*C* for *FI.Chu*, *R* for *PAr.ti*) was assimilated to the colour of the two other letters forming the syllable (*FI.chu*, *PAR.ti*). This result was found for children in Grades 1–5. The authors concluded that letter clusters corresponding to oral syllables are rapidly detected and automatically used by beginning readers in visual word identification, as found in skilled readers (Doignon & Zagar, 2005).

However, in the studies reported above for the French language, participants performed letter detection tasks, so the stage of lexical access was not investigated specifically.

In the next sections, we report data and interpretation of the syllable frequency effect in adults and children. This effect was mainly tested with the lexical decision task, which is currently used to investigate lexical access processes. Then, we present recent studies that further investigate the syllable activation hypothesis and suggest that orthographic information influences syllable effects in adults and children. Finally, the issue of the present study is introduced.

The syllable frequency effect

A widely studied effect to test the syllable activation hypothesis in skilled reading is the syllable frequency effect. Words with a first syllable of high frequency are compared to words with a first syllable of low frequency, all other things being equal. Carreiras et al. (1993) were the first to report an inhibitory effect of syllable frequency in the lexical decision task. Words were recognized more slowly when the first syllable was of high frequency rather than of low frequency. The syllable frequency effect has been replicated mainly in Spanish (e.g. Alvarez, Carreiras, & Taft, 2001; Alvarez, de Vega, & Carreiras, 1998; Alvarez et al., 2000; Carreiras, Mechelli, & Price, 2006; Perea & Carreiras, 1998) and in German (e.g. Conrad & Jacobs, 2004; Conrad et al., 2006; Hutzler et al., 2005; Stenneken et al., 2007). In French, a recent study was conducted specifically on the syllable frequency effect (Conrad, Grainger, & Jacobs, 2007). Previous studies (Mathey & Zagar, 2002; Mathey et al., 2006) have focused on higher frequency syllabic neighbours (i.e. words of higher frequency than the stimulus that shares the first syllable) and reported an inhibitory effect of syllable neighbourhood. Perea and Carreiras (1998) showed that syllable frequency and number of syllable neighbours are correlated variables, indicating that words with a high-frequency syllable have more syllable neighbours than those with a low-frequency syllable. Thus, the inhibitory syllable frequency effect has generally been accounted for by a competition process at the word level between syllabic neighbours (e.g. Alvarez et al., 2001; Conrad et al., 2006). When a word with a high-frequency syllable is displayed, the corresponding syllable unit would be activated at the phonological level, which would in turn fire a large and frequent set of lexical candidates. Because of lexical inhibition between word units, these candidates would slow down word target recognition. This interpretation suggests that syllables are phonological units of lexical access, automatically activated during word processing (Alvarez et al., 2004; Carreiras, et al., 1993; Mathey & Zagar, 2002; Mathey et al., 2006). This hypothesis has been developed in the interactive model with syllables (IAS model, Mathey et al., 2006), a model based on the interactive activation framework (McClelland & Rumelhart, 1981). According to the model, there are two ways to reach a word representation. The first one is an orthographic access to word units by means of direct connections between connected adjacent letter units and word units. The second one is a phonological access to word units, in which activation from the letter level spreads to a syllabic level, and then spreads to the lexical level by means of direct

connections between syllables and word units. At the syllable level, activation ensues from a resting level based on syllable frequency. Thus, syllable units are assumed to be activated directly following letter activation, in the same way that word units can be directly activated following letter activation.

As previously mentioned, syllable activation in beginning reading has received little attention, as is the case for the syllable frequency effect. In Spanish, Gonzalez and Valle (2000) reported a facilitatory effect of syllable frequency in children in Grade 1. Words with low-frequency syllables were processed more slowly than those with high-frequency syllables. According to the authors, this reversed effect compared to that obtained in skilled readers reflected the activation of syllable units during the GPC procedure. For low-frequency syllables, the conversion rules between letters and sounds would be poorly consolidated compared to those implied for high-frequency syllables. Hence, less frequent syllables would take longer to convert, so the processing of words containing such syllables is slowed down. This result is consistent with previous studies arguing that syllables are phonological units of recoding process (e.g. Bastien-Toniazzo et al., 1999; Colé et al., 1999). However, no data are available about the syllable frequency effect in more advanced beginning readers, such as children at the end of elementary education. For such readers, the construction of the orthographic lexicon could be sufficiently mature for the lexical procedure to be the predominant procedure to read words, though this route might not be as quickly and automatically involved as in skilled reading.

Influence of orthographic information on syllabic effects

Several studies have shown that the cognitive system learns the orthographic regularities of its language (e.g. Pacton, Perruchet, Fayol, & Cleeremans, 2001). This learning would be an implicit and fundamental process in reading acquisition and might influence early written word processing. According to Seidenberg and McClelland (1989), exposure to print enables the encoding of statistical regularities of letter sequences. Consequently, the greater the exposure to print, the greater the awareness of letter co-occurrences in words. Recent studies demonstrated that knowledge about orthographic properties of words could influence syllabic activation. Data suggested that the activation of phonological syllables is underlied by the co-occurrence frequencies of letter clusters, these clusters corresponding or not to oral syllables. For example, Mathey et al. (2006) showed that the inhibitory effect of phonological syllabic neighbourhood was obtained in the lexical decision task when the word beginning was frequent (i.e. when the first letter cluster was frequent), but the effect was facilitatory when the word beginning was less frequent. Doignon and Zagar (2005, 2006) investigated the influence of the bigram trough pattern on the syllable effect using the illusory conjunction task. The bigram trough refers to an orthographic pattern of words according to which the letter clusters straddling the syllabic boundary of a word tend to be more frequent than the letter clusters that precede and follow this boundary (Seidenberg, 1987). Results showed that the syllable effect was reduced in the absence of a bigram trough, that is when phonological and orthographic information did not converge. The data were highly similar for skilled readers (Doignon & Zagar, 2005) and developing readers

(Doignon & Zagar, 2006). To account for the constraints of orthographic properties on syllable effects, Mathey et al. (2006) assumed that adjacent letters at the letter level in the IAS model are mutually connected, so that letter units are more reactivated when they belong to frequent clusters than when they belong to less frequent ones. Hence, when a written word has a frequent initial cluster, the strength of syllable activation would be increased, since the letter activation directly spreads to the syllable level by means of direct connections. In sum, syllable activation at the phonological level is assumed to ensue from both the frequency-based resting level of syllables and activation received from the letter level, which is highly dependent on the statistical properties of written language.

Given the data showing an influence of orthographic information on syllable effects, it is important to determine to what extent the syllable frequency effect, considered as a relevant effect for understanding syllable activation during lexical access, is related to the orthographic properties of syllables. More precisely, does the frequency of a syllabic letter cluster underlie the activation of a frequent or less frequent phonological syllabic unit? This question has been widely ignored in previous studies, mainly because these two measures are highly correlated, at least in French and German (Stenneken et al., 2007). High-frequency syllables are usually transcribed by frequent letter clusters. For example, the first syllable of the word *ca.deau* (/ka/) is a frequent syllable in French, and the orthographic correspondence of this syllable (*ca*) is also frequent in French compared to other clusters (e.g. *ka* in *ka.yak*, *cha* in *cha.os*). In a recent study carrying on the effect of orthographic defined syllables (Conrad et al., 2007), results showed that the typical inhibitory effect of syllable frequency was obtained when the frequency of phonological syllables was varied while the frequency of orthographic syllable was held constant. On the contrary, no effect was reported when the frequency of orthographic syllables was varied while the frequency of phonological syllables was held constant. According to the authors, the data converged to the view that phonology is the source of the syllable frequency effect, which confirmed previous works (e.g. Alvarez et al., 2004; Carreiras et al., 2005). Hence, these findings are consistent with theoretical frameworks assuming that the competition process between syllable units, responsible for the inhibitory effect of syllable frequency, is directly dependent on the activation sprung from syllables and stored as phonological units (e.g. Alvarez et al., 2004; Carreiras & Perea, 2002; Mathey et al., 2006). Nevertheless, the study of Conrad et al. (2007) did not explicitly investigate to what extent the frequency of orthographic correspondence of syllables (i.e. frequency of orthographic syllables) might participate in the inhibitory syllable frequency effect (i.e. frequency of phonological syllables) since these two variables were not manipulated in a single experiment.

The present study

Two lexical decision task experiments were conducted to investigate further the syllable activation hypothesis in French. In Experiment 1, the syllable frequency effect was tested in skilled readers, and in Experiment 2, the effect was tested in beginning readers in Grade 5. Furthermore, the study aimed at investigating to what

extent orthographic characteristics of syllables underlie the activation of phonological syllables. To do so, the frequency of phonological first syllables and the frequency of the orthographic correspondence of first syllables were orthogonally manipulated. Thus, the experimental design consisted of words with a high-frequency phonological syllable such as *an.tenne* and *han.tise* (the syllable /ã/ is a high-frequency syllable in French), and words with low-frequency phonological syllables such as *ti.ssu* and *ty.ran* (the syllable /ti/ is a low-frequency syllable in French). This first variable make it possible to test the typical inhibitory effect of syllable frequency. Moreover, the manipulation of the frequency of the syllable orthographic correspondence meant that for half of the words, the orthographic correspondence of syllable was frequent, such as *antenne* and *tissu* (the syllables /ã/ and /ti/ are frequently transcribed by *an* and *ti* in French, respectively), while for the other half, words had a low-frequency orthographic correspondence of syllable, such as *hantise* and *tyran* (the syllables /ã/ and /ti/ are infrequently transcribed by *han* and *ty* in French, respectively). In that way, it would be possible to investigate whether and how orthographic information contained by syllable units in written words influences the activation of syllable units at a phonological level. According to the IAS model (Mathey et al., 2006), the inhibitory effect of syllable frequency (phonological units) should be influenced by the frequency of the orthographic correspondence of syllables (orthographic information). The study was conducted in both skilled readers and beginning readers so that it would be possible to test whether the orthographic influence on syllable activation varies according to reading efficiency.

Experiment 1

The aim of the present experiment was to test the joined effect of syllable frequency and syllable orthographic correspondence frequency on word recognition latencies in skilled readers. According to previous studies, an inhibitory syllable frequency effect should be found in the lexical decision task (e.g. Carreiras et al., 1993). Moreover, it was expected that this effect would be modified according to the frequency of orthographic correspondence of syllables. Indeed, skilled readers are sensitive to statistical regularities of orthographic information (Seidenberg, 1987) and these regularities would underlie the emergence and strength of syllable effects (e.g. Mathey et al., 2006). Thus, an interaction between the syllable frequency effect and the frequency of orthographic correspondence of syllables was expected in Experiment 1.

Method

Participants

Forty-three volunteer students from the University of Bordeaux participated in this experiment. They were all native French speakers and reported having corrected-to-normal vision.

Materials

Ninety-two bisyllabic words were selected in the Brulex French database (Content, Mousty, & Radeau, 1990) according to the orthogonal combination of two factors: first-syllable frequency (high, low) and orthographic correspondence frequency of the first syllable (high, low). Thus, four experimental conditions were constructed (see Table 1). In the first condition, words had a high-frequency first phonological syllable, and the orthographic correspondence of this syllable was frequent (e.g. *antenne,* the syllable /ãl/ is a high-frequency syllable in French, frequently transcribed by *an*). In the second condition, words had a high-frequency first phonological syllable although the orthographic correspondence of this syllable was not frequent (e.g. *hantise*, the syllable /ãl/ is a high-frequency syllable, infrequently transcribed by *han*). In the third condition, words had a low-frequency first phonological syllable although the orthographic correspondence of this syllable was frequent (e.g. *tissu*, the syllable /ti/ is a low-frequency syllable, frequently transcribed by *ti*). In the fourth condition, words had a low-frequency first phonological syllable, and the orthographic correspondence of this syllable was not frequent (e.g. *tyran*, the syllable /ti/ is a low-frequency syllable, infrequently transcribed by *ty*). Syllable frequencies were computed from the syllable segmentation provided by Vocolex (Dufour, Peereman, Pallier, & Radeau, 2002). The word printed frequency and the frequency of the first-syllable structure were controlled across the four conditions, and none of the stimuli had any higher frequency orthographic neighbours. Ninety-two orthographically legal and pronounceable nonwords were added for the requirements of the task.

Procedure

Participants performed a lexical decision task individually on a portable computer using the DMDX software (Forster & Forster, 2003). Each trial began by the

Table 1 Syllable frequency characteristics of the words used in Experiment 1

	First syllable frequency			
	High		Low	
Example	High orthographic correspondence *antenne*	Low orthographic correspondence *hantise*	High orthographic correspondence *tissu*	Low orthographic correspondence *tyran*
First syllable frequency				
Mean	16,113.58	16,113.58	428.51	428.51
Min	2,481.36	2,481.36	84.42	84.42
Max	66,415.52	66,415.52	939.16	939.16
Orthographic correspondence frequency of the first syllable				
Mean	9,923.43	275.51	272.92	17.21
Min	100.81	10.63	27.71	0.25
Max	44,983.52	1,214.78	908.52	73.76

Note: Token frequency counts are given in occurrences per million

presentation of a fixation point for 500 ms on the centre of the screen, which was replaced by a lowercase target item. The target remained on the screen until the participants responded or 2,500 ms had elapsed. Participants had to decide as quickly and as accurately as possible whether the target was a French word or not by pressing one of two buttons on an external keyboard. Visual feedback was provided when they failed to respond or when 2,500 ms had elapsed. Reaction times (in milliseconds) were measured from target onset until the participant responded. All participants performed 12 practice trials before receiving the 184 trials in a different random order.

Results

The mean correct reaction times and mean error rates averaged over participants for words are presented in Table 2. Reaction times outside the range of two standard deviations from the individual mean of participants were excluded (3.8% of the data). Two words were excluded from the analyses because of a high error rate and the associated words were also eliminated. The data were submitted to analyses of variance on the participant means with first syllable frequency (high, low) and orthographic correspondence frequency of the first syllable (high, low) as main factors.

Word reaction times

The analysis showed a statistically significant inhibitory effect of syllable frequency, $F(1, 42) = 11.69$, $p < .01$. Words with a high-frequency syllable were responded to 11 ms more slowly than words with a low-frequency syllable. A statistically significant facilitatory effect of orthographic correspondence frequency of syllable was obtained, $F(1, 42) = 26.18$, $p < .001$, showing that words with a high-frequency orthographic correspondence of syllable were responded to 17 ms faster than words with a low-frequency orthographic correspondence. More importantly, the interaction between syllable frequency and orthographic correspondence frequency of syllable was statistically significant, $F(1, 42) = 34.26$, $p < .001$. Planned comparisons showed that the syllable frequency effect was statistically significant for words with low-frequency orthographic correspondence of syllable (−27 ms), $F(1, 42) = 38.05$, $p < .001$, but not for words with high-frequency orthographic correspondence (+6 ms), $F(1, 42) = 2.07$, $p > .10$.

Table 2 Mean reaction times (in ms) and percentage of errors (in parentheses) on target words in Experiment 1

Orthographic correspondence frequency of the first syllable	First syllable frequency	
	High	Low
High	613 (1.6)	619 (2.0)
Low	646 (5.4)	619 (3.3)

Word error rates

The syllable frequency effect was not statistically significant, $F(1, 42) = 2.45$, $p > .10$. The main effect of orthographic correspondence frequency of syllable was statistically significant, $F(1, 42) = 16.39$, $p < .001$. The interaction between syllable frequency and orthographic correspondence frequency of syllable was statistically significant, $F(1, 42) = 5.70$, $p < .05$. Planned comparisons showed that the syllable frequency effect was statistically significant for words with low-frequency orthographic correspondence of syllable, $F(1, 42) = 4.86$, $p < .05$, but not for words with high-frequency orthographic correspondence of syllable, $F < 1$.

Discussion

As expected, the results of Experiment 1 showed a reliable inhibitory effect of syllable frequency. These data replicated previous studies in Spanish and German (e.g. Alvarez et al., 2000; Carreiras et al., 1993; Conrad & Jacobs, 2004; Stenneken et al., 2007) and suggested that the syllable frequency effect is also a reliable effect in French (Conrad et al., 2007). Moreover, a facilitatory effect of orthographic correspondence frequency of syllable was obtained. By manipulating this variable, we varied the frequency of the word beginning. Thus, words with a high-frequency first cluster were recognized more quickly than words with a low-frequency beginning cluster. This was consistent with studies showing that word beginning frequency is beneficial to lexical access (e.g. Inhoff & Tousman, 1990). More importantly, a reliable interaction was found between these two variables, suggesting that orthographic information of syllables significantly influences phonological syllable activation. The inhibitory effect of syllable frequency was found only for syllables with low-frequency orthographic correspondence. To accommodate for these results, it can be assumed that when the syllable orthographic correspondence is very frequent, that is when the letters frequently co-occur to transcribe an oral syllable, the activation at the letter level is fast enough to reach the word level before the syllable level has time to intervene in the word recognition process. On the contrary, when the syllable orthographic correspondence is of low frequency, the syllable level would have time to be activated, and the effect of syllable frequency would appear, arising out of the competition process between syllabic neighbours at the word level. Mathey et al. (2006, Experiment 2) showed that the competition effect of higher frequency syllabic neighbourhood was obtained only for words with a high-frequent beginning cluster. In that study, the syllable neighbourhood was manipulated, but the syllable frequency, which was the variable of interest in our study, was not taken into account. In addition, a post-hoc analysis on the word materials showed that the frequency of the syllable orthographic correspondence of the words with a frequent initial cluster was statistically significantly higher in our experiment (4,038 occurrences per million) than in the experiment by Mathey et al. (708 occurrences per million), $t(76) = 2.02$, $p < .05$. This suggests that the orthographic activation within letters forming syllables is stronger in the words of the present study, which provides a potential explanation for the data. In the interactive activation framework with syllables (Mathey et al., 2006), it can be assumed that the spreading activation for words

containing a syllable with an orthographic correspondence of high frequency is quicker between letter and word units rather than between letter and syllable units. In that case, syllables would not have time to influence visual word processing significantly.

Experiment 2

The aim of this experiment was to test the influence of orthographic information of syllables on the syllable frequency effect in children in Grade 5. An interaction was expected between these two variables. For beginning readers in Grade 5, the development of the orthographic lexicon should be mature enough to allow the use of the lexical route in written word processing, but this route would not be as quickly and automatically involved as in skilled reading (Sprenger-Charolles & Colé, 2003). Consequently, contrary to skilled reader data, an inhibitory effect of syllable frequency should be found for words with high-frequency syllable orthographic correspondence. In that condition, orthographic activation at the letter level would not spread at the word level as rapidly as in skilled reading. The activation would spread to the syllable path before the word is processed via the direct letter-word connections, so that the competition process between syllable neighbours has time to occur. A different pattern of results was expected for words with a low-frequency orthographic correspondence of syllable. If beginning readers learn statistical regularities early between orthographic and phonological units, the strength of the connections between letter clusters and their related syllables would increase with exposure to print and reading progress (Booth, Perfetti, & MacWhinney, 1999). This explains why these connections are weaker for children than for adults. Therefore, in children, when words have a low-frequency syllable orthographic correspondence, orthographic and phonological units might not be connected enough to trigger off the inhibition process between syllabic neighbours. Thus, a weak or null effect of syllable frequency should be found in this condition.

Method

Participants

Thirty-five children in Grade 5 participated in this experiment (mean age: 10 years, 10 months). They came from three Bordeaux primary schools. All children were native speakers of French, reported having corrected-to-normal vision, and were attending their grade at the regular age.

Materials

Words were selected in the same way as those used in Experiment 1, except that they were derived according to their printed frequency from Manulex, a French lexical database for Grade 1 to Grade 5 readers (Lété, Sprenger-Charolles, & Colé,

Table 3 Syllable frequency characteristics of the words used in Experiment 2

	First syllable frequency			
	High		Low	
Example	High orthographic correspondence *équipe*	Low orthographic correspondence *héros*	High orthographic correspondence *dossier*	Low orthographic correspondence *dauphin*
First syllable frequency				
Mean	11,417.43	11,417.43	435.17	435.17
Min	2,156.22	2,156.22	73.20	73.20
Max	66,415.52	66,415.52	941.12	941.12
Orthographic correspondence frequency of the first syllable				
Mean	6,640.63	436.63	314.27	25.46
Min	535.97	10.05	33.16	1.06
Max	44,983.52	2,002.92	908.52	89.57

Notes: Token frequency counts are given in occurrences per million

2004). Eighty-four bisyllabic words were selected according to the orthogonal combination of the two factors: first-syllable frequency (high, low) and orthographic correspondence frequency of the first syllable (high, low) (see Table 3). The word printed frequency and the frequency of the first-syllable structure were controlled across the four conditions, and none of the stimuli had any higher frequency orthographic neighbours. Eighty-four orthographically legal and pronounceable nonwords were added for the requirements of the task.

Procedure

The same procedure as in Experiment 1 was used except that the participants performed a warm-up exercise prior to the lexical decision task experiment. This was done to ensure that the children understood the principle of the task and to give them examples of unreal words (see Castles, Davis, & Letcher, 1999). In this exercise, six cards displaying a letter string were presented one at a time by the experimenter to the participants. Children were asked to say whether or not the printed stimulus was a real word. They were given a feedback on accuracy of their responses. Then, the participants were told that they would have to perform the same game, except that they would give their responses not loudly but by means of two buttons on the keyboard.

Results

The mean correct reaction times and mean error rates averaged over participants for words are presented in Table 4. Reaction times outside the range of two standard deviations from the individual mean of participants were excluded (4.2% of the data). Two words were excluded from the analyses because of a high error rate and

Table 4 Mean reaction times (in ms) and percentage of errors (in parentheses) on target words in Experiment 2

Orthographic correspondence frequency of the first syllable	First syllable frequency	
	High	Low
High	835 (6.9)	799 (2.3)
Low	818 (3.6)	825 (8.7)

the associated words were also eliminated. The data were submitted to analyses of variance on the participant means with syllable frequency (high, low) and orthographic correspondence frequency of syllable (high, low) as main factors.

Word reaction times

The analysis showed a marginally significant inhibitory effect of syllable frequency, $F(1, 34) = 2.84$, $p = .10$. Words with a high-frequency syllable were responded to 15 ms more slowly than those with a low-frequency syllable. The effect of orthographic correspondence frequency of syllable was not statistically significant, $F < 1$. The interaction between syllable frequency and syllable orthographic correspondence frequency was statistically significant, $F(1, 34) = 11.33$, $p < .01$. Planned comparisons showed that the syllable frequency effect was not statistically significant for words with low-frequency orthographic correspondence of syllable (+7 ms), $F < 1$, but the effect was statistically significantly inhibitory for words with high-frequency orthographic correspondence (−36 ms), $F(1, 34) = 10.33$, $p < .01$.

Word error rates

The syllable frequency effect was not statistically significant, $F < 1$. The main effect of orthographic correspondence frequency of syllable was statistically significant, $F(1, 34) = 5.33$, $p < .05$. The interaction between syllable frequency and orthographic correspondence frequency of syllable was statistically significant, $F(1, 34) = 24.39$, $p < .001$. Planned comparisons showed that a facilitatory syllable frequency effect was obtained for words with low-frequency orthographic correspondence of syllable, $F(1, 34) = 13.88$, $p < .001$, while an inhibitory syllable frequency effect was obtained for words with high-frequency orthographic correspondence, $F(1, 34) = 13.87$, $p < .001$.

Discussion

The results of Experiment 2 confirmed our prediction in beginning reading. A statistically significant inhibitory effect of syllable frequency was found only for syllables with a high-frequency orthographic correspondence. In this condition, the spreading activation on the orthographic path (letter level to word level) might not be as quick as in skilled reading. This time-lag would allow the syllable units to be activated at the phonological level, triggering the competition process between

lexical units. In the condition of syllables with low-frequency orthographic correspondence, syllable units would be weakly activated at the phonological level owing to poorly consolidated connections between letter clusters and corresponding phonological units. Thus, competition between syllabic neighbours would not arise. This explains why word processing was not slowed down for high-frequency syllables compared to low-frequency ones.

General discussion

The present study was designed to test the syllable frequency effect in skilled and beginning reading in French and to investigate whether the frequency of syllable orthographic correspondence influences this effect. The findings can be summarised as follows. First, an inhibitory effect of syllable frequency was found for both skilled and beginning readers, though it was more reliable for skilled readers. Second, there was a facilitatory frequency effect of syllable orthographic correspondence. Third, these two factors interacted, but the interaction led to an opposite pattern of results in skilled and beginning reading.

The effect of syllable frequency has been considered as a robust effect in Spanish and German (Stenneken et al., 2007). The present data, added to those of a recent study in French (Conrad et al., 2007), extend this conclusion to the French language. Moreover, the effect was reported for the first time in beginning readers in Grade 5. According to the syllable activation hypothesis (Alvarez et al., 2004; Carreiras & Perea, 2002; Carreiras et al., 1993; Mathey & Zagar, 2002; Mathey et al., 2006; Perea & Carreiras, 1998), syllables are functional units of word processing, and visual presentation of polysyllabic words leads to the activation of the relevant syllabic units in a syllable-based phonological level. In an interactive-activation framework, syllable effects are assumed to ensue from two processes: a facilitative between-level process (i.e. connections between the syllable level and the word level) and an inhibitory within-level process (i.e. connections between word units at the word level). Hence, when written words are displayed, the corresponding phonological syllables are activated. Activation spreads to a cohort of syllabically consistent words by means of facilitative connections. Then, these candidates compete with each other via inhibitory connections. The process of word recognition is achieved when all the candidates are eliminated except the matched one. When words with high-frequency syllables are presented, the competition process is increased, owing to a larger number of syllable neighbours compared to words with low-frequency syllables. Therefore, item recognition is delayed (Carreiras et al., 1993; see also Alvarez et al., 2000; Conrad & Jacobs, 2004; Mathey & Zagar, 2002; Perea & Carreiras, 1998). Moreover, our data strengthen the view that syllables play a prominent role early during the stage of lexical access since the syllable effect was found for readers with only 5 years of reading experience. Such results extend those from previous studies showing that syllables are functional units of reading acquisition (Colé et al., 1999; Doignon & Zagar, 2006; Gonzalez & Valle 2000).

A facilitatory effect of syllable orthographic correspondence frequency was obtained. Words with a high-frequency orthographic syllable (e.g. *tissu*) were recognized more rapidly than those with a low-frequency orthographic syllable (e.g. *tyran*). Therefore, this means the more familiar the word beginning, the faster the word recognition. This finding is consistent with previous data suggesting that the cognitive system encodes orthographic regularities of its written language (e.g. Pacton et al., 2001; Seidenberg & McClelland, 1989) and that word recognition is facilitated by frequent word initial letter clusters (e.g. Inhoff & Tousman, 1990).

A critical finding of the present study is that the syllable frequency effect was influenced by the frequency of the orthographic correspondence of syllable in both adults and children. This is in line with previous works showing that syllable effects depend in part on word orthographic information (Doignon & Zagar, 2005, 2006; Mathey et al., 2006). Moreover, an opposite pattern of results was obtained according to reading efficiency. In skilled readers, the inhibitory syllable effect was found only for syllables with low-frequency orthographic correspondence (e.g. *hantise* versus *tyran*), while in beginning readers the inhibitory syllable frequency effect was found only for syllables with high-frequency orthographic correspondence (e.g. *antenne* versus *tissu*). Such data can be explained by an increase in speed and strength of spreading activation between sublexical and lexical units throughout reading experience. On the one hand, reading progress is assumed to ensue from a gradual increase in the connection strength between orthographic and phonological sublexical units, and between orthographic sublexical units and word units (Share, 1995; Sprenger-Charolles, Siegel, & Bonnet, 1998). On the other hand, it would be exposure to print which implicitly make it possible to abstract statistical regularities gradually between sublexical orthographic units and sublexical phonological units (Seidenberg & McClelland, 1989). Therefore, the activation of orthographic and phonological information is a function of reading skill, and fast and automatic orthographic and phonological processes are required to become a skilled reader (Booth et al., 1999). The present results support the view that syllables could be central phonological units by which, driven by exposure to print, connections between orthographic clusters and phonological syllable units are established (see also Colé et al., 1999; Doignon & Zagar, 2006). These links between orthographic and phonological representations could be strong enough to keep on significantly influencing visual word recognition process in skilled reading. However, contrary to Mathey et al. (2006), no syllable effect was found for words with a high-frequency first cluster in skilled readers. An interpretation in terms of speed of spreading activation can be put forward since we have shown that the word materials in the two experiments differed on the frequency of syllable orthographic correspondence. This factor is assumed to underlie the strength of activation spreading between orthographic and phonological units, so a variation of the syllable effect can be attributed to differences in this factor.

In the IAS model (Mathey et al., 2006), which is based on the syllable activation hypothesis, letters are mutually connected so that the orthographic regularities of language can be encoded. Thus, the model can account for the joined effect of syllable frequency and frequency of syllable orthographic correspondence found in both Experiments 1 and 2. More precisely, activation at the letter level is assumed to

be a function of the frequency of letter clusters due to mutual reinforcement of adjacent letters. Thus, when letters belong to a frequent cluster, as in the case of high-frequency orthographic correspondence of syllable, strong activation at the letter level would be produced. The activation spreads to the orthographic lexicon via two paths: an orthographic one and a phonological one. In the phonological path, the strength of activation springing from the letter level plays a part in the strength of activation of syllable units and significantly influences word recognition insofar as words would not have been directly processed on the orthographic path. Thus, in skilled reading (Experiment 1), when the orthographic pattern transcribing the first syllable of words was very frequent, orthographic activation produced at the letter level would have been so important that word units were quickly activated via direct connections between letter and word units (orthographic path). This fast lexical access would have shadowed a possible spreading activation toward phonological units. Therefore, no syllable frequency effect was found, since the word representation was contacted before the syllable activation reached the word level. On the contrary, when the orthographic pattern was of low frequency, the strength of connection between letter clusters and word units may have been weaker, and activation may have had time to spread to syllable units (phonological path), thereby triggering the competition process between syllable neighbours at the word level. In beginning reading (Experiment 2), activation at the letter level may also have been important in the condition of high-frequency syllable orthographic clusters. However, the strength of connection between letters and word representation may have been poorer compared to that of skilled readers, so activation may have had time to spread to the corresponding syllable units and significantly influence word processing. On the contrary, in the condition of low-frequency orthographic clusters, the link between letter clusters and corresponding phonological syllables may have been less consolidated, so the syllable units may have been weakly activated at the phonological level, or at least insufficiently to trigger the competition process at the word level. This interpretation is consistent with studies on time-course activation of phonological and orthographic information showing that the activation of orthographic information precedes the quick and early activation of phonological information (e.g. Ferrand & Grainger, 1993). Moreover, the data are consistent with those of previous studies suggesting that syllables do not systematically influence written word processing in skilled reading (Dominguez, de Vega, & Cuetos, 1997).

To sum up, the results of the present study provide evidence in favour of syllable activation in visual word recognition in both skilled and beginning readers. The data suggest that the activation of syllable units depends on the time course of the activation of orthographic and phonological information, itself arising from the strength of connections between these units (see also Doignon & Zagar, 2005; Mathey et al., 2006). This strength of connections might be reinforced by exposure to print, and thus by reading progress. Therefore, both orthographic and phonological information plays a fundamental role across reading experience (see Booth et al., 1999). In addition, given that syllables appear to be relevant units of word processing in developing readers, the syllable could be an important unit for reading acquisition, which argues in favour of phonics reading instruction based on

syllables. Thus, future experiments should be conducted in order to investigate further syllable effects in early reading acquisition, and more generally reading efficiency.

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References

Alvarez, C. J., Carreiras, M., & de Vega, M. (2000). Syllable-frequency effect in visual word recognition: Evidence of sequential-type processing. *Psicológica, 21*, 341–374.

Alvarez, C. J., Carreiras, M., & Perea, M. (2004). Are syllables phonological units in visual word recognition? *Language and Cognitive Processes, 19*, 427–452. doi:10.1080/01690960344000242.

Alvarez, C. J., Carreiras, M., & Taft, M. (2001). Syllables and morphemes: Contrasting frequency effects in Spanish. *Journal of Experimental Psychology. Learning, Memory, and Cognition, 27*, 545–555. doi:10.1037/0278-7393.27.2.545.

Alvarez, C. J., de Vega, M., & Carreiras, M. (1998). La sílaba como unidad de activación léxica en la lectura de palabras trisilabas. *Psicothema, 10*, 371–386.

Bastien-Toniazzo, M., Magan, A., & Bouchafa, H. (1999). Nature des représentations du langage écrit aux débuts de l'apprentissage de la lecture: Un modèle interprétatif. *Journal of Instructional Psychology, 34*, 43–58. doi:10.1080/002075999400096.

Booth, J. R., Perfetti, C. A., & MacWhinney, B. (1999). Quick, automatic, and general activation of orthographic and phonological representations in young readers. *Developmental Psychology, 35*, 3–19. doi:10.1037/0012-1649.35.1.3.

Bradley, D. C., Sanchez-Casas, R. M., & Garcia-Albea, J. E. (1993). The status of the syllable in the perception of Spanish and English. *Language and Cognitive Processes, 8*, 197–233. doi:10.1080/01690969308406954.

Carreiras, M., Alvarez, C. J., & de Vega, M. (1993). Syllable frequency and visual word recognition in Spanish. *Journal of Memory and Language, 32*, 766–780. doi:10.1006/jmla.1993.1038.

Carreiras, M., Ferrand, L., Grainger, J., & Perea, M. (2005). Sequential effects of phonological priming in visual word recognition. *Psychological Science, 16*, 585–589. doi:10.1111/j.1467-9280.2005.01579.x.

Carreiras, M., Mechelli, A., & Price, C. (2006). The effect of word and syllable frequency on activation during lexical decision and reading aloud. *Human Brain Mapping, 27*, 963–972. doi:10.1002/hbm.20236.

Carreiras, M., & Perea, M. (2002). Masked priming effects with syllabic neighbors in a lexical decision task. *Journal of Experimental Psychology. Human Perception and Performance, 28*, 1228–1242. doi:10.1037/0096-1523.28.5.1228.

Castles, A., Davis, C., & Letcher, T. (1999). Neighbourhood effects on masked form priming in developing readers. *Language and Cognitive Processes, 14*, 201–224. doi:10.1080/016909699386347.

Colé, P., Magnan, A., & Grainger, J. (1999). Syllable-sized units in visual word recognition: Evidence from skilled and beginning readers of French. *Applied Psycholinguistics, 20*, 507–532. doi:10.1017/S0142716499004038.

Colé, P., & Sprenger-Charolles, L. (1999). Traitement syllabique au cours de la reconnaissance de mots écrits chez des enfants dyslexiques, lecteurs en retard et normo-lecteurs de 11 ans. *Revue de Neuropsychologie, 9*, 323–360.

Coltheart, M., Rastle, K., Perry, C., Langdon, R., & Ziegler, J. (2001). DRC: A dual route cascaded model of visual word recognition and reading aloud. *Psychological Review, 108*, 204–256. doi:10.1037/0033-295X.108.1.204.

Conrad, M., Grainger, J., & Jacobs, A. M. (2007). Phonology as the source of syllable frequency effects in visual word recognition: Evidence from French. *Memory & Cognition, 35*, 974–983.

Conrad, M., & Jacobs, A. M. (2004). Replicating syllable frequency effects in Spanish in German: One more challenge to computational models of visual word recognition. *Language and Cognitive Processes, 19*, 369–390. doi:10.1080/01690960344000224.

Conrad, M., Stenneken, P., & Jacobs, A. M. (2006). Associated or dissociated effects of syllabe frequency in lexical decision and naming. *Psychonomic Bulletin & Review, 13*, 339–345.

Content, A., Mousty, P., & Radeau, M. (1990). BRULEX: Une base de données lexicale informatisée pour le français écrit et parlé. *L' Annee Psychologique, 90*, 551–566. doi:10.3406/psy.1990.29428.

Cutler, A., Mehler, J., Norris, D., & Segui, J. (1986). The syllable's differing role in the segmentation of French and English. *Journal of Memory and Language, 25*, 385–400. doi:10.1016/0749-596X(86)90033-1.

Doignon, N., & Zagar, D. (2005). Illusory conjunctions in French: The nature of sublexical units in visual word recognition. *Language and Cognitive Processes, 20*, 443–464. doi:10.1080/01690960444000269.

Doignon, N., & Zagar, D. (2006). Les enfants en cours d'apprentissage de la lecture perçoivent-ils la syllabe à l'écrit? *Revue Canadienne de Psychologie, 60*, 258–274.

Dominguez, A., de Vega, M., & Cuetos, F. (1997). Lexical inhibition from syllabic units in Spanish visual word recognition. *Language and Cognitive Processes, 12*, 401–422. doi:10.1080/016909697386790.

Dufour, S., Peereman, R., Pallier, C., & Radeau, M. (2002). VoCoLex: Une base de données lexicales sur les similarités phonologiques entre les mots français. *L' Annee Psychologique, 102*, 725–746. doi:10.3406/psy.2002.29616.

Ferrand, L., & Grainger, J. (1993). The time course of orthographic and phonological code activation in the early phases of visual word recognition. *Bulletin of the Psychonomic Society, 31*, 119–122.

Forster, K. I., & Forster, J. C. (2003). DMDX: A Windows display program with millisecond accuracy. *Behavior Research Methods, Instruments, & Computers, 35*, 116–1124.

Frost, R. (1998). Toward a strong phonological theory of visual word recognition: True issues and false trails. *Psychological Bulletin, 123*, 71–99. doi:10.1037/0033-2909.123.1.71.

Gonzalez, J. E. J., & Valle, I. H. (2000). Word identification and reading disorders in the Spanish language. *Journal of Learning Disabilities, 33*, 44–60. doi:10.1177/002221940003300108.

Hutzler, F., Conrad, M., & Jacobs, A. M. (2005). Effects of syllables-frequency in lexical decision and naming: An eye-movement study. *Brain and Language, 92*, 138–152. doi:10.1016/j.bandl.2004.06.001.

Inhoff, A. W., & Tousman, S. (1990). Lexical priming from partial word previews. *Journal of Experimental Psychology. Learning Memory and Cognition, 16*, 825–836. doi:10.1037/0278-7393.16.5.825.

Lété, B., Sprenger-Charolles, L., & Colé, P. (2004). MANULEX: A grade-level lexical database from French elementary school readers. *Behavior Research Methods, Instruments, & Computers, 36*, 156–166.

Liberman, I. Y., Shankweiller, D., Fischer, F. W., & Carter, B. (1974). Explicit syllable and phoneme segmentation in young child. *Journal of Experimental Child Psychology, 18*, 201–212. doi:10.1016/0022-0965(74)90101-5.

Mathey, S., & Zagar, D. (2002). Lexical similarity in visual word recognition: The effect of syllabic neighbourhood in French. *Current Psychology Letters, 8*, 107–121.

Mathey, S., Zagar, D., Doignon, N., & Seigneuric, A. (2006). The nature of syllabic neighbourhood in French. *Acta Psychologica, 123*, 372–393. doi:10.1016/j.actpsy.2006.02.003.

McClelland, J. L., & Rumelhart, D. E. (1981). An interactive activation model of context effects in letter perception: Part 1. An account of basic findings. *Psychological Review, 88*, 375–407. doi:10.1037/0033-295X.88.5.375.

Mehler, J., Dommergues, J., Frauenfelder, U., & Segui, J. (1981). The syllable's role in speech segmentation. *Journal of Verbal Learning and Verbal Behavior, 20*, 298–305. doi:10.1016/S0022-5371(81)90450-3.

Pacton, S., Perruchet, P., Fayol, M., & Cleeremans, A. (2001). Implicit learning out of the lab: The case of orthographic regularities. *Journal of Experimental Psychology. General, 130*, 401–426. doi:10.1037/0096-3445.130.3.401.

Perea, M., & Carreiras, M. (1998). Effects of syllable frequency and syllable neighbourhood frequency in visual word recognition. *Journal of Experimental Psychology. Human Perception and Performance, 24*, 134–144. doi:10.1037/0096-1523.24.1.134.

Schiller, N. O., Costa, A., & Colomé, A. (2002). Phonological encoding of single words: In search of the lost syllable. In C. Gussenhoven & N. Warner (Eds.), *Laboratory phonology* (Vol. 7, pp. 35–59). Berlon: Mouton de Gruyter.

Seidenberg, M. S. (1987). Sublexical structures in visual word recognition: Access units or orthographic redundancy? In M. Coltheart (Ed.), *Attention and performance, XII: The psychology of reading*. Hillsdale, NJ: Erlbaum.

Seidenberg, M. S., & McClelland, J. L. (1989). A distributed, developmental model of word recognition and naming. *Psychological Review, 96*, 523–568. doi:10.1037/0033-295X.96.4.523.

Share, D. L. (1995). Phonological recoding and self-teaching: Sine qua non of reading acquisition. *Cognition, 55*, 151–218. doi:10.1016/0010-0277(94)00645-2.

Sprenger-Charolles, L., & Colé, P. (2003). *Lecture et dyslexie. Approche cognitive*. Paris: Dunod.

Sprenger-Charolles, L., Colé, P., Béchennec, D., & Kipffer-Piquard, A. (2005). French normative data on reading and related skills from EVALEC, a new computerized battery of tests (end Grade 1, Grade 2, Grade 3, and Grade 4). *Revue Européenne de Psychologie Appliquée, 55*, 157–186. doi: 10.1016/j.erap. 2004.11.002.

Sprenger-Charolles, L., Siegel, L. S., & Bonnet, P. (1998). Reading and spelling acquisition in French: The role of phonological mediation and orthographic factors. *Journal of Experimental Child Psychology, 68*, 134–165. doi:10.1006/jecp.1997.2422.

Stenneken, P., Conrad, M., & Jacobs, A. M. (2007). Processing of syllables in production and recognition tasks. *Journal of Psycholinguistic Research, 78*, 36–65.