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### ► **To cite this version:**

Norbert Maïonchi-Pino, Annie Magnan, Jean Écalle. Syllable frequency effects in visual word recognition: Developmental approach in French children. *Journal of Applied Developmental Psychology*, 2010, 31 (1), pp.70-82. <10.1016/j.appdev.2009.08.003>. <hal-02963800>

**HAL Id: hal-02963800**

**<https://hal.science/hal-02963800v1>**

Submitted on 5 Apr 2024

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# Syllable frequency effects in visual word recognition: Developmental approach in French children

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## Abstract

This study investigates the syllable's role in the normal reading acquisition of French children at three grade levels (1st, 3rd, and 5th), using a modified version of Colé, Magnan, and Grainger's (1999) paradigm. We focused on the effects of syllable frequency and word frequency. The results suggest that from the first to third years of reading instruction, children process high-frequency syllables as syllable units while processing low-frequency syllables as phoneme units. In fifth graders, syllable-based processing is extended to both high and low syllable frequencies, primarily due to CVC structures with high-frequency syllables. Lexical frequency does not significantly influence syllable processing. These findings reveal that the syllable is an early prelexical unit modulated initially by syllable frequency, and subsequently by grapheme-to-phoneme correspondences. High-frequency syllables did not produce inhibitory effects. Consequently, results are compatible with Levelt and Wheeldon's (1994) mental syllabary hypothesis. Implications for specific reading training and syllable based remediation are discussed.

## Keywords

Syllable compatibility effect; Syllable frequency; Reading; Visual word recognition; French word frequency; Phonological training

## Introduction

Over the past decades, psycholinguistic and experimental evidence has been collected to support the theory that the size of sublexical units used during reading can vary across languages as a function of the orthographic transparency (for a review, see Ziegler & Goswami, 2005). These studies have been primarily conducted with adults, particularly in Spanish (e.g., Álvarez, Carreiras, & Perea, 2004) and French (e.g., Conrad, Jacobs, & Grainger, 2007), while relatively few studies have concerned children or the specific role of the syllable in French—especially the syllable frequency effect—during reading acquisition. Indeed, data about the syllable frequency effect are extremely rare (Chetail & Mathey, 2009); French studies have focused essentially on the nature of the syllabic code — phonological and orthographic (e.g., Bijeljac-Babic, Millogo, Farioli, & Grainger, 2004; Doignon & Zagar, 2006), the acoustic–phonetic properties within the syllabic boundary (e.g., Fabre & Bedoin, 2003), or the printed word frequency (e.g., Colé, Magnan, & Grainger, 1999; Colé & Sprenger-Charolles, 1999).

Our study assessed the roles of syllable and word frequency as well as their respective influence on the use of the syllable as a privileged sublexical reading unit in normally developing French children (i.e., first, third and fifth graders). To undertake our assessment, we used a revisited version of the paradigm proposed by Colé et al. (1999) to determine whether syllable and word frequency contribute jointly or independently to the size of the reading units, and more particularly how they contribute to the use of syllable-sized units. We modified the paradigm to study children's phonological recoding ability using an upgraded French word frequency database dedicated to children (Lété, Sprenger-Charolles, & Colé, 2004), which is better suited to children's lexical knowledge than the orthographic frequency-scale used by Colé et al. (1999) (i.e., Dubois-Buyse's scale; Ters, Mayer, & Reichenbach, 1977). The major novelty of this study was the study of the initial syllable frequency using a recent French syllable frequency database dedicated to children (Peerman, Lété, & Sprenger-Charolles, 2007).

## Linguistic arguments for syllable sensitivity in French

An extended large-scale study conducted in fourteen European languages recently demonstrated that reading skills were dependent on the level of orthographic transparency in each language (Seymour, Aro, & Erskine, 2003). Specifically, readers of transparent languages (i.e., languages with regular grapheme-to-phoneme correspondences, or GPC) such as Italian or German performed better in pseudoword reading accuracy than readers of opaque languages such as English<sup>1</sup>, and to a lesser extent, French. These results were compatible with previous studies conducted by Frith, Wimmer, and Landerl (1998) as well as Goswami, Gombert, and Fraca de Barrera (1998), which showed weaker performances in reading accuracy of pseudowords in English children<sup>2</sup> compared to Spanish or German children. As Goswami (2002) and Ziegler and Goswami (2005) emphasized, phonemic awareness and GPC are developed faster in transparent languages than in opaque languages. Data obtained by Seymour et al. (2003) were also consistent with the use of rather small units in transparent languages such as German, and rather large units in opaque languages such as French and English (see also Goswami, Ziegler, Dalton, & Schneider, 2003 for similar conclusions). Indeed, English is characterized by the irregularity of its small units (Ziegler, Stone, & Jacobs, 1997) but by the stability of its rime unit (80% according to Treiman, Mullenix, Bijelbac-Babic, & Richmond-Welty, 1995). Some studies have shown that English readers preferentially resort to rime units to read monosyllabic words (e.g., Treiman, Fowler, Gross, Berch, & Weatherspoon, 1995) while other studies have spotlighted that beginning English readers use lexical and grapheme-to-phoneme correspondences in learning to read (e.g., Berninger et al., 2000), and lexical and onset-rime units when learning to spell new words (e.g., Berninger et al., 1998). In French, despite the relative irregularity at the level of small units, the rime unit does not seem to be the preferred reading unit, probably because it is too irregular (Ziegler, Jacobs, & Stone, 1996). This in turn would seem to suggest the use of a more appropriate reading unit for French such as the syllable. Indeed, French syllable timing and clear-cut boundaries for syllables suggest that the syllable may constitute an important unit (see also the high rate of polysyllabic words; 83%; Content, Mousty, & Radeau, 1990). Furthermore, the first syllable is unstressed in French in contrast to English, where stress is often put on the first syllable. Acoustically phonemes are also difficult to identify in French because of the co-articulation of the phones (e.g., Altmann, 1997). Thus, French speakers would hypothetically use a more global syllabic code rather than a phonemic code.

## Developmental framework for the role of the syllable

It has been proven that learning to read and to spell English or French depends on the focus on spelling-to-sound correspondences learning rather than solely on whole word repetition (e.g., Levy, & Lysynchuk, 1997; Morais, 2003; Share, 1995, 1999). Most children proceed from being explicitly taught GPC rules to recoding written words phonologically. Nevertheless, there is still much debate on the exact nature of the phonological codes used by children, particularly concerning the size of the first units used during reading acquisition (see Ziegler & Goswami, 2005).

There are in fact two opposing theoretical frameworks which view the role of large units (e.g., rime or syllable) and phonemes differently (for the results of a meta-analysis for English speaking children in the USA that shows the fundamental importance of phoneme awareness and alphabetic principle for GPC, see Ehri et al., 2001). On one hand, Goswami and Bryant (1990) suggested that children first refer to larger units such as onset-rime before being able to decompose into smaller units such as phonemes. They claimed that spelling-to-sound relationships are directly influenced by sensitivity to large oral units, from an awareness of onset-rime to phonemes. On the other hand, Duncan, Seymour, and Hill (1997) proposed that phonological awareness does not systematically follow a large-to-small sequence and that the phoneme is the initial unit involved during reading acquisition. According to their research, children's first attempts to use phonology rely on the letter-sound correspondences established when they are taught GPC. In contrast with the previous theory, Seymour and Duncan (1997) hypothesized a developmental progression in children's use of units that goes from the smallest (e.g., phoneme) to the largest (e.g., onset-rime, syllable).

## Empirical arguments for the emergence of the syllable's use in French

To test Seymour and Duncan's (1997) hypothesis in French children, Colé et al. (1999) visually tested the Mehler, Dommergues, Frauenfelder, and Segui's (1981) paradigm. According to Mehler et al.'s (1981) paradigm, a "syllable compatibility effect" exists, which highlights the sensitivity of French adult listeners to syllabically segment speech streams. In Mehler et al.'s (1981) study, French adult listeners heard a syllable (CV or CVC) and had to decide whether the same syllable appeared at the beginning of a test-word whose first syllable was either CV or CVC. They determined that French adult listeners detected a syllable more quickly when it matched the first syllable of a subsequently presented word exactly (e.g., PA in PARADE or PAR in PAR.TIR rather than PA in PAR.TIR or PAR in PA.RADE).

Colé et al. (1999) also assessed the progression in children's reading ability after six months of GPC teaching and after one year of GPC teaching. In first graders, after 6 months of GPC learning, results showed a target length effect (CV targets were detected faster than CVC targets whatever the word structure). This result was interpreted as grapho-phonemic processing instead of

<sup>1</sup> Despite the myth that English is non-transparent, linguistic analysis has shown that it is transparent when the alternations (small set of alternative phonemes for a 2-letter or 1-letter grapheme) are taken into account (Venezky, 1970, 1999). Also English spelling is transparent when multi-letter units (such as rimes in high-frequency words or morpheme syllables) rather than single letter units are taken into account (e.g., Berninger, 1998; Nunes & Bryant, 2006).

<sup>2</sup> The poor pseudoword reading in English may be the result of lack of teacher knowledge for teaching it rather than a property of the language (see Joshi et al., 2009).

letter-by-letter processing because all of the children were taught with a GPC-based method. After one year of GPC learning, results showed a crossover interaction between targets and words whatever the word frequency, but this crossover interaction was dependent on the reading level (i.e., only in good readers). This result supports the conclusion that a “syllable compatibility effect” explains children’s use of phonological grapho-syllabic processing. Data were therefore compatible with a probable developmental course based on the model of Seymour and Duncan (1997). According to Colé et al. (1999), children must clearly master the rules of the alphabetic principle to be able to code letter strings phonologically. The explicit teaching of GPC allows children to develop the necessary connections between letters and sounds. As soon as children can use this grapho-phonemic processing automatically, they try to extract units larger than phonemes (e.g., grapho-syllabic processing) on the basis of the early implicit syllable awareness developed during contact with spoken language (e.g., Goslin & Floccia, 2007) and the phonemic awareness developed with the explicit GPC teaching.

From a cognitive point of view, it would be less constraining to segment into syllables than into phonemes; it is much easier to segment the word *mardi* (Tuesday) into two distinct syllables *mar* and *di* rather than into five phonemes *m + a + r + d + i*. When children begin learning to read, they would systematically use phonological grapho-phonemic processing whatever the word frequency. Progressively, phonological grapho-syllabic processing would intervene, initially only for high-frequency words and then eventually it would be applied to both high- and low-frequency words. Later, phonological grapho-syllabic processing would remain only for low-frequency words, and a direct matching processing would predominate for high-frequency words. This step would reflect the abilities of skilled reading. This result is also consistent with the Bastien-Toniazzo, Magnan, and Bouvhafa’s (1999) study that argued that children progressively reallocate their attentional resources from small to large phonological syllable units using their GPC learning, as well as their knowledge of spoken syllables developed through repetitive exposures to spoken language.

Resolving the controversy over phonological units will probably depend on the language spoken by the beginning reader. For reasons already discussed, the syllable is likely to be a fundamental phonological unit in learning to read French.

#### Data about the syllable frequency effect in reading

In skilled readers, recent findings have shown that words with low-frequency first syllables are recognized faster than words with high-frequency first syllables. This inhibitory effect of first syllable frequency in the lexical decision task has been replicated in different languages (e.g., in Spanish, Álvarez, Carreiras, & De Vega, 2000; Álvarez, Carreiras, & Taft, 2001; in French, Conrad et al., 2007; Mathey & Zagar, 2002; in German, Conrad, Stenneken, & Jacobs, 2006; Stenneken, Conrad, & Jacobs, 2007). The effect has been interpreted in terms of lexical competition; that is, words with initial high-frequency syllables automatically trigger a set of phonological syllables, which in turn releases high-frequency words. Therefore, the higher the syllable frequency, the more words are activated, which explains why recognition times are slower for these words.

However, the syllable frequency effect in beginning readers has received little attention. For instance, a rare study conducted in Spanish (e.g., González & Valle, 2000) demonstrated that high-frequency first syllable actually had a facilitatory effect on word recognition. They reported that words with high-frequency syllables were processed faster than words with low-frequency syllables. They interpreted this effect as an early activation of syllable-sized units through GPC. However, with low-frequency syllables, they argued that GPC would be more poorly consolidated than GPC implied with high-frequency syllables. The conversion process of low-frequency syllables is also slower as compared with words with high-frequency syllables.

As suggested in this introduction, experimental evidence about the syllable frequency effect during reading acquisition is not available for the French language. Only Chetail and Mathey (2009) have addressed the issue of syllable frequency during visual word recognition in French children. They highlighted a reliable inhibitory effect of syllable frequency in fifth graders. However, a facilitatory effect of syllable orthographic correspondence emerged: words with high-frequency orthographic correspondences (e.g., /ti/ in ‘tissu’) were recognized more quickly than words with low-frequency orthographic correspondences (e.g., /ti/ in ‘tyran’). They argued that such results were compatible with theoretical frameworks that describe reading acquisition as a progressive and gradual improvement of the connections between phonological and orthographic sublexical units. They also hypothesized that implicit knowledge about statistical regularities might progressively influence how explicit orthographic and phonological units might be processed. As they concluded, this result is compatible with previous data showing that phonological syllable effects partially depend on the orthographic syllable features (see also Doignon & Zagar, 2005; 2006). These data strengthen the syllable’s role as phonological functional reading unit, but no developmental study has been conducted, nor has a specific database for syllable frequency been used.

#### Present study

This experiment was designed with three main aims. Firstly, we wanted to study how lexical frequency and syllable frequency influence the size of the sublexical units (e.g., phoneme vs. syllable) used during reading acquisition in normal developing French children in first, third and fifth grade. We adopted the theoretical view that large-to-small progression is overstated for French and therefore assumed that children follow a developmental course during learning to read from the smallest units (i.e., phonemes) to the largest units (i.e., syllables) as claimed by Seymour and Duncan (1997) and partially demonstrated by Colé et al. (1999) as well as Colé and Sprenger-Charolles (1999). Our second aim was to show that no inhibitory effect caused by lexical competition emerges in children. We hypothesized that early and implicit auditory knowledge about syllables would in fact help children to connect oral syllables to the frequent shape of

letter groupings in larger units such as written syllables. Performances were predicted to be influenced by grade level; from first to fifth grade, we expected that response times would significantly decrease as evidence of reading automation. Similarly, as reading exposure increases and skilled reading is developing, we predicted that lexical and syllable frequency effects would occur in third and fifth grades.

Finally, our last aim was to show that syllable frequency modulates the phonological processes prior to word frequency, as initial syllables operate as intermediate pre-lexical unit to access the mental lexicon. A silent word recognition task could allow the use of phonological decoding as children were learning GPC rules. The use of a phonological decoding or a purely orthographic process should respectively be evidenced as a function of the presence of a "syllable compatibility effect" or a "target length effect". We expected to highlight that syllabic processing (represented by a crossover interaction between Target and Test-Word which reflects a "syllable compatibility effect") is influenced by syllable frequency from first grade to fifth grade. However, as syllable-sized units are mastered subsequent to GPC, in first and third grades, we expected to observe phonemic processing with low-frequency targets (represented by a target length effect; that is, CV syllables detected faster than CVC syllables) but a "syllable compatibility effect" with high-frequency targets; whereas in fifth grade, we assumed a "syllable compatibility effect" with low-frequency targets but a target length effect with high-frequency targets which would reflect the use of a purely orthographic processing and direct lexical access to the lexicon.

## Method

### Participants

Sixty French children from an urban elementary school participated in this study. Twenty children were from first grade (M age = 81 months, SD = 4 months), twenty children were from third grade (M age = 104 months, SD = 3 months), and twenty children were from fifth grade (M age = 128 months, SD = 4 months). All of the children were native French speakers, middle class, right-handed and were attending their grade at the regular age. They had normal or corrected-to-normal vision. They were taught reading with GPC rules and were all tested once in May.

### Word reading test

Children individually completed a French standardized word reading test to ensure that they had no reading disorder. We used TIMÉ 2 (Écalte, 2003) with children from 1st and 3rd grades and TIMÉ 3 (Écalte, 2006) with children from 5th grade. These tests assessed the reading accuracy and the orthographic knowledge level. No analysis was conducted on the scores. In each group, the scores showed that chronological age corresponded to the expected reading age-based ability.

### Materials and design

The experimental lists included twenty-four six or seven letter disyllabic test-words; half had an initial CV syllable structure and the other half had an initial CVC syllable structure. All of the test-words had the three initial letters with regular spelling-to-sound correspondences. CV and CVC test-words were subdivided into high- and low-frequency test-words. We also selected six high- ( $\mu = 47$ ) and six low-frequency ( $\mu = 3$ ) CV test-words, and six high- ( $\mu = 42$ ) and six low-frequency ( $\mu = 1$ ) CVC test-words using the U1-to-U5 frequency range from Manulex database (Lété et al., 2004)<sup>3</sup> which supplies an accurate grade-level word-frequency for French elementary-school readers from 1st to 5th grade.

We also chose twenty-four targets whose half had a CV syllable structure and the other half had a CVC syllable structure. We selected six high- ( $\mu = 2969$ ) and six low-frequency ( $\mu = 848$ ) CV targets, and six high- ( $\mu = 822$ ) and six low-frequency ( $\mu = 198$ ) CVC targets using the U1-to-U5 frequency range from Manulex-infra database (Peereman et al., 2007)<sup>4</sup> which provides printed syllable frequency in the initial position in words for French readers from 1st to 5th grade.

Test-words and targets were visually presented twice. A same target (CV or CVC) was either presented with a test-word sharing the same initial syllable structure (e.g., PA with PA.RADE or PAR with PAR.TIR) or differing in the initial syllable structure (e.g., PA with PAR.TIR or PAR with PA.RADE). When a target matched the initial syllable structure of a test-word, we labeled as "syllable compatibility" condition and when a target did not match the initial syllable structure of a test-word, we labeled as "syllable incompatibility" condition.

Furthermore, we combined target, target frequency, test-word, and word frequency factors. Half of the high-frequency CV targets was presented with high-frequency CV ("syllable compatibility" condition) and CVC ("syllable incompatibility") test-words, whereas the other half of the high-frequency CV targets was also associated with low-frequency CV and CVC test-words; half of the low-frequency CV targets was presented with low-frequency CV and CVC test-words, the other half of the low-frequency CV targets was also presented with high-frequency CV and CVC test-words. In the same way, half of the high-frequency

<sup>3</sup> Despite the myth that English is non-transparent, linguistic analysis has shown that it is transparent when the alternations (small set of alternative phonemes for a 2-letter or 1-letter grapheme) are taken into account (Venezky, 1970, 1999). Also English spelling is transparent when multi-letter units (such as rimes in high-frequency words or morpheme syllables) rather than single letter units are taken into account (e.g., Berninger, 1998; Nunes & Bryant, 2006).

<sup>4</sup> The syllable and word frequency extracted from Manulex (Lété et al., 2004) and Manulex-infra (Peereman et al., 2007) databases were the occurrences per million from first to fifth grade (i.e., U1-to-U5 column).

CVC targets was presented with high-frequency CV and CVC test-words, the other half of the high-frequency CVC targets was also associated with low-frequency CV and CVC test-words; half of the low-frequency CVC targets was associated with low-frequency CV and CVC test-words, whereas the other half of the low-frequency CVC targets was associated with high-frequency CV and CVC test-words. Experimental conditions are exemplified in Table 1. Finally, we just controlled oral syllable frequency (Wioland, 1985) (see Appendix A for targets and test-words frequency).

The design of the experiment was composed of four experimental lists. Each list contained six trials from the “syllable compatibility” condition and six trials from the “syllable incompatibility” condition. There were forty-eight experimental trials. Forty-eight distractor trials (e.g., GU with PA.LACE) were also added and fairly distributed in each experimental list: their role was to trigger negative answers and balance the number of positive and negative answers. Their response times and errors were not taken into account. Children encountered all of the experimental conditions. Each experimental list was separated by a pause. The order of the presentation of the stimuli in each experimental list and the order of the presentation of each experimental list were randomized. The software automatically recorded response times and errors. The experimenter never intervened during the experiment.

## Procedure

Children completed the task in single, individual sessions. The experiment was designed on a Macintosh iBook. The script was built with PsyScope 1.2.5 (Cohen, MacWhinney, Flatt, & Provost, 1993). Children sat roughly at a distance of 57 cm from the screen. Printed material was presented in format “Chicago” and size “48”. Target and test-word were presented in lower-case letters.

A fixation point was presented during 800 ms in the center of the screen. Immediately after disappearance of the fixation point, the target was displayed in the center of the screen for 1000 ms before the test-word appeared below. Target and test-word remained on the screen until the child’s response. The next sequence followed after 500 ms delay. Children were instructed to decide as quickly and as accurately as possible whether the target occurred at the beginning of the test-word. For the response mode, children had to press the button “a” if the target appeared at the beginning of the test-word or the button “p” if not (see Fig. 1). Before beginning the experimental lists, children were trained with a practice list containing eight different trials.

## Results

An analysis of variance (ANOVA) was performed on the data using subjects (F) as a random variable. Only correct detection times were included in the analyses. The correct response times were standardized (i.e., for each subject, response times more or less than two standard deviations away from the mean were replaced by the mean response time of each subject; approximately 4.7% of the data). No analysis was conducted on the errors (approximately 1.7% of the data). Descriptive data are summarized in Table 2.

## Comparison of the three groups

A four within-subject factors (Target: CV vs. CVC; Test-word: CV vs. CVC; Target frequency: high vs. low; and Word frequency: high vs. low) and one between-subject (Group: 1st, 3rd and 5th grade) factor repeated measures ANOVA was conducted on mean response times. The analysis revealed a main effect of Group,  $F(2, 57) = 25.50, p < .0001, \eta^2 = 0.47$ . Planned comparisons showed that 1st graders (1774 ms) responded significantly more slowly than 3rd graders (1079 ms); 1st graders also responded more slowly than 5th graders (834 ms),  $F(1, 38) = 37.73, p < .0001$ . In addition, the response time difference between 3rd and 5th graders was significant,  $F(1, 38) = 9.37, p < .004$ . Finally, a significant Group  $\times$  Target  $\times$  Test-word  $\times$  Target frequency interaction emerged,  $F(2, 57) = 3.25, p < .05, \eta^2 = 0.10$ . Thus, we analyzed the Target  $\times$  Test-word  $\times$  Target frequency triple interaction for each group (i.e., 1st, 3rd and 5th grades).

Table 1  
Description of the experimental conditions.

			Phonological structure and frequency of the Target			
			CV		CVC	
			High	Low	High	Low
Phonological structure and frequency of the Test-word	CV	High	Pa	Ba	Par	Bal
			Parole	Balance	Parole	Balance
		“Speech”	“Wage”	“Speech”	“Wage”	
		Low	Ca	Do	Car	Dor
	Carafe		Dorure	Carafe	Dorure	
	CVC	High	“Carafe”	“Gilt”	“Carafe”	“Gilt”
			Pa	So	Par	Sol
		Low	Parfum	Soldat	Parfum	Soldat
“Perfume”			“Soldier”	“Perfume”	“Soldier”	
		Mo	Pu	Mor	Dur	
		Mortel	Purger	Mortel	Purger	
		“Lethal”	“Purge”	“Lethal”	“Purge”	

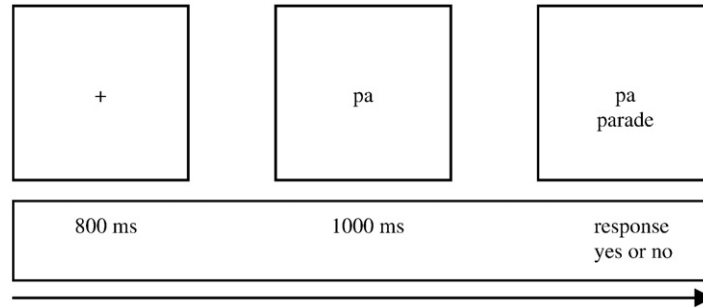


Fig. 1. Illustration of the setup of the experiment.

### First grade

The ANOVA revealed a significant Target  $\times$  Test-word  $\times$  Target frequency interaction,  $F(1, 19) = 4.28, p < .05, \eta^2 = 0.18$  (see Fig. 2). This triple interaction allowed us to analyze separately the critical Target  $\times$  Test-word interaction for high- and low-frequency targets. When considering high-frequency targets, the Target  $\times$  Test-word interaction was significant,  $F(1, 19) = 4.16, p < .05, \eta^2 = 0.18$ . Planned comparisons revealed that Target and Test-word interacted because “CVC target–CVC word” was processed faster than “CV target–CVC word”,  $F(1, 19) = 4.02, p = .05$ . Besides, “CVC target–CVC word” was marginally processed faster than “CVC target–CV word”,  $F(1, 19) = 3.34, p = .08$ . A significant effect of target length emerged from the ANOVA performed on low-frequency targets,  $F(1, 19) = 5.12, p < .04, \eta^2 = 0.21$ ; CV targets (1705 ms) were detected faster than CVC targets (1865 ms). Neither a Word frequency effect nor a Target frequency effect was found.

### Third grade

The Target  $\times$  Test-word  $\times$  Target frequency interaction reached significance,  $F(1, 19) = 6.16, p < .02, \eta^2 = 0.25$  (see Fig. 3). This triple interaction allowed us to study separately the Target  $\times$  Test-word interaction for high- and low-frequency targets. The Target  $\times$  Test-word interaction analysis was only significant for high-frequency targets,  $F(1, 19) = 4.22, p < .05, \eta^2 = 0.18$ . Planned comparisons showed that Target and Test-word interacted because “CV target–CV word” was processed faster than “CV target–CVC word”,  $F(1, 19) = 5.49, p < .03$  and “CVC target–CVC word” was processed faster than “CV target–CVC word”,  $F(1, 19) = 4.74, p < .04$ . A significant effect of target length was significant with low-frequency targets,  $F(1, 19) = 13.47, p < .004, \eta^2 = 0.42$ ; CV targets (1059 ms) had faster response times than CVC targets (1232 ms). The 3rd graders exhibited a main effect of Word frequency,  $F(1, 19) = 55.96, p < .0001, \eta^2 = 0.75$ , and a main effect of Target frequency,  $F(1, 19) = 23.57, p < .0001, \eta^2 = 0.55$ ; high-frequency targets (1004 ms) and words (1027 ms) were responded to faster than were low-frequency targets (1146 ms) and words (1123 ms).

### Fifth grade

First, the 5th graders showed a main effect of Word frequency,  $F(1, 19) = 4.44, p < .05, \eta^2 = 0.19$  and a main effect of Target frequency,  $F(1, 19) = 12.35, p < .002, \eta^2 = 0.39$ . High-frequency targets (806 ms) were detected faster than low-frequency targets (863 ms) and high-frequency words (819 ms) had faster response times than low-frequency words (849 ms). Furthermore, the Target  $\times$  Test-word  $\times$  Target frequency interaction was found,  $F(1, 19) = 4.81, p < .04, \eta^2 = 0.20$  (see Fig. 4).

Table 2  
Statistical descriptive data in 1st, 3rd, and 5th grades as a function of the experimental design.

		Frequency	CV word		CVC word	
			High	Low	High	Low
1st grade	CV target	High	1577 (129) 1.7%	1656 (162) 1.7%	1853 (201) 0.0%	1962 (255) 0.0%
		Low	1692 (192) 1.7%	1710 (175) 1.7%	1704 (181) 3.3%	1732 (173) 3.3%
	CVC target	High	1842 (238) 5.0%	1924 (215) 1.7%	1575 (121) 1.7%	1651 (149) 0.0%
		Low	1947 (193) 6.7%	1767 (158) 0.0%	1817 (164) 5.0%	1970 (145) 0.0%
3rd grade	CV target	High	901 (71) 0.0%	1000 (85) 1.7%	1041 (83) 0.0%	1003 (60) 6.7%
		Low	1008 (61) 1.7%	1179 (98) 0.0%	1025 (110) 0.0%	1056 (85) 3.3%
	CVC target	High	1032 (72) 1.7%	1111 (83) 1.7%	889 (52) 1.7%	1082 (65) 0.0%
		Low	1141 (68) 1.7%	1272 (112) 1.7%	1194 (63) 0.0%	1329 (84) 0.0%
5th grade	CV target	High	741 (58) 0.0%	873 (50) 3.3%	805 (55) 3.3%	919 (78) 1.7%
		Low	891 (50) 1.7%	817 (45) 1.7%	912 (69) 1.7%	870 (62) 0.0%
	CVC target	High	799 (61) 3.3%	860 (49) 1.7%	697 (47) 0.0%	753 (48) 0.0%
		Low	923 (41) 3.3%	968 (51) 0.0%	786 (45) 0.0%	736 (44) 0.0%

Note. Data are described in mean response times (in milliseconds), standard error (in parentheses), and below the error rate (in percentage).

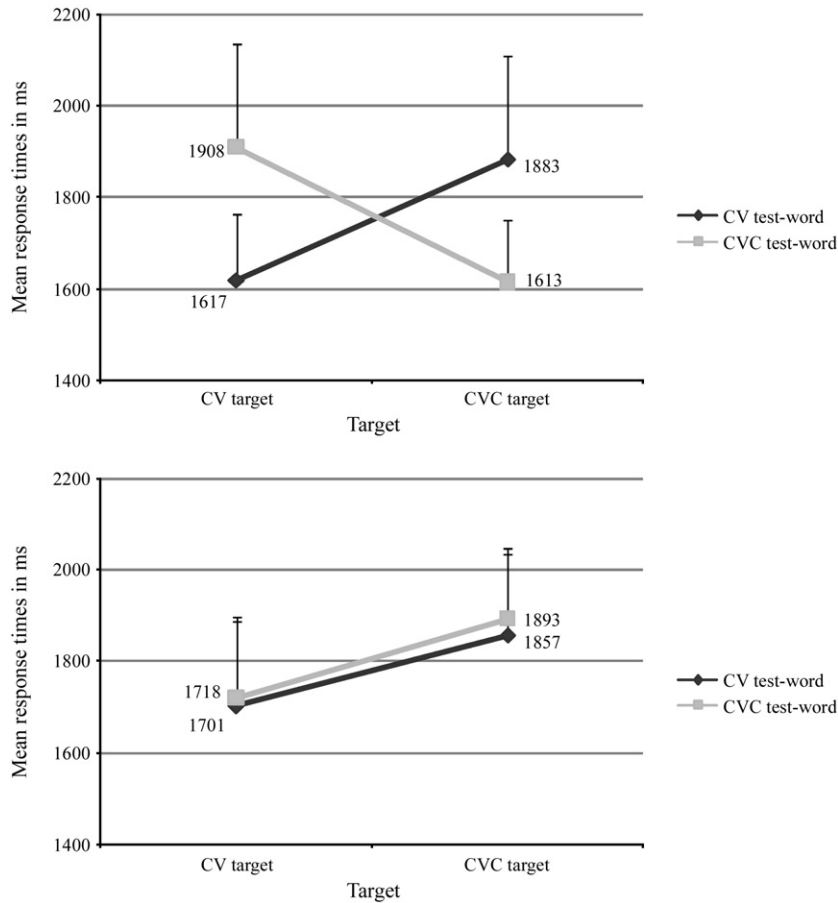


Fig. 2. Mean response times (in milliseconds) of high-frequency targets (upper panel) and low-frequency targets (lower panel) in first graders as a function of target and test-word in the split up Target  $\times$  Test-word  $\times$  Target frequency interaction.

This triple interaction allowed us to study separately the Target  $\times$  Test-word interaction for high- and low-frequency targets. Both analyses for high- and low-frequency targets revealed a significant Target  $\times$  Test-word interaction,  $F(1, 19) = 7.08, p < .02, \eta^2 = 0.27$  and  $F(1, 19) = 15.94, p < .0008, \eta^2 = 0.46$ , respectively. For high-frequency targets, planned comparisons revealed that Target and Test-word interacted because “CVC target–CVC word” entailed shorter response times than “CV target–CVC word”,  $F(1, 19) = 8.56, p < .009$ , “CVC target–CVC word” was processed faster than “CVC target–CV word”,  $F(1, 19) = 7.88, p < .01$ , and “CVC target–CVC word” was processed more quickly than “CV target–CV word”,  $F(1, 19) = 5.35, p < .03$ . For low-frequency targets, planned comparisons highlighted that Target and Test-word interacted because “CVC target–CVC word” was processed faster than “CV target–CVC word”,  $F(1, 19) = 67.34, p < .0001$ , “CVC target–CVC word” was processed faster than “CVC target–CV word”,  $F(1, 19) = 10.73, p < .004$ , “CVC target–CVC word” was processed more quickly than “CV target–CV word”,  $F(1, 19) = 11.22, p < .003$ , and “CV target–CV word” triggered shorter response times than “CV target–CVC word”,  $F(1, 19) = 8.50, p < .009$ . Finally, a main effect of target length emerged from the analysis for high-frequency targets,  $F(1, 19) = 4.90, p < .04, \eta^2 = 0.21$ ; CVC targets (815 ms) had faster response times than CV targets (854 ms) whatever the word frequency.

## Discussion

In this study, we used a visual word recognition task in French normal-readers from the first, third and fifth grades. We investigated the contribution of syllable frequency and lexical frequency on the size of the reading units used during reading acquisition. We studied how syllable frequency directly influences the phonological recoding processing and the nature of the reading units. We also tried to find evidence to support a developmental course in accordance with Seymour and Duncan’s (1997) hypothesis and with Colé and colleagues (Colé et al., 1999; Colé, & Sprenger-Charolles, 1999) previous results.

In line with our predictions, results show that mean response times decrease as a function of the grade; the more the children are experienced with reading, the more the response times decrease. As we suggested, this result highlights that phonological recoding becomes automatic to gain in processing speed. Our hypothesis that children from each grade process targets and test-

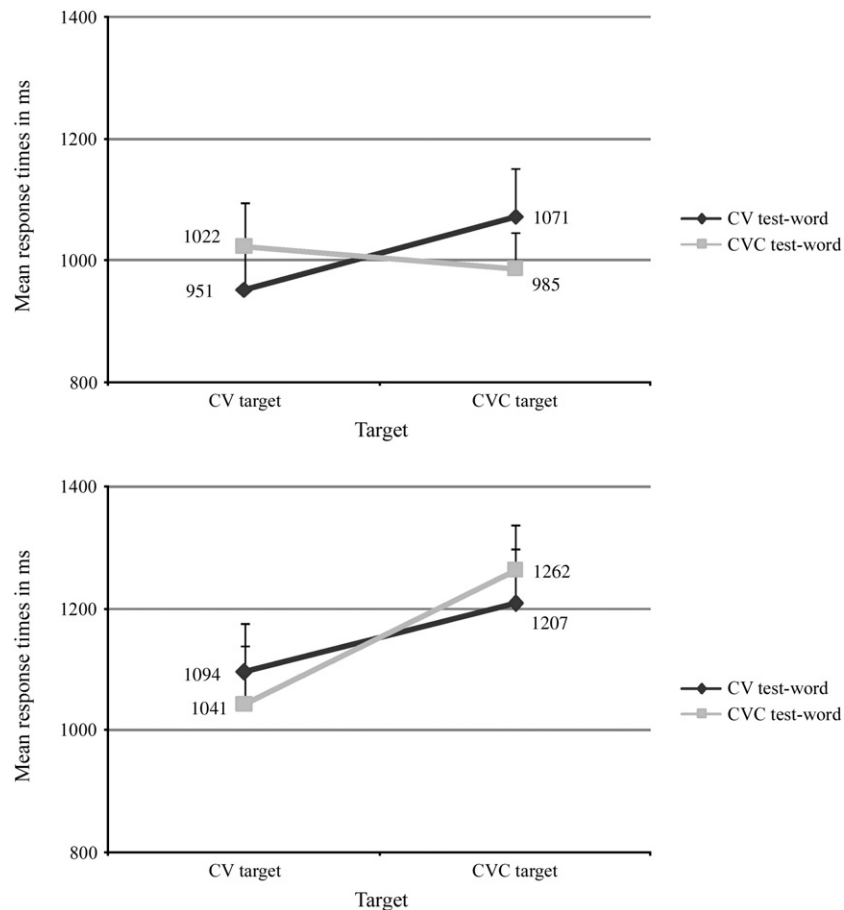


Fig. 3. Mean response times (in milliseconds) of high-frequency targets (upper panel) and low-frequency targets (lower panel) in third graders as a function of target and test-word in the split up Target  $\times$  Test-word  $\times$  Target frequency interaction.

words differently as a function of the target frequency was validated (i.e., the Group  $\times$  Target  $\times$  Test-word  $\times$  Target frequency interaction) and allowed us to study each group separately (see Table 3 for a summary of the results).

#### Progressive syllable frequency effect on phonological processing

From the end of the first year to the third year of schooling, response times indicate that children use phonological grapho-syllabic processing to recode printed words. As shown in Figs. 2 and 3, children are affected differently as a function of syllable frequency. The Target  $\times$  Test-word interaction indicates a phonological “syllable compatibility effect” that emerges when children encounter high-frequency syllables, especially with the “CVC target–CVC word” couple. However, the response times are a function of the target length with low-frequency syllables; children answer quickly when the displayed target is a CV syllable whatever the initial test-word structure (i.e., CV or CVC). The target length effect with low-frequency syllables reflects a serial left-to-right sequence processing already evidenced in adults with low-frequency words or pseudowords (see Ferrand & New, 2003; Stenneken et al., 2007; Weekes, 1997). In children, this effect can be interpreted either phonologically or orthographically. We hypothesize that to perform the matching process (i.e., orthographic processing), children generate a string of phonemes based on the use of GPC (i.e., phonological processing) rather than a purely letter-by-letter identification. A teaching method based on GPC most likely influences the reading strategies (see Leybaert & Content, 1995). During the first grade, teaching emphasizes the GPC to learn how to read. Our results also demonstrate that children efficiently and successfully learned to associate graphemes with phonemes. As asserted by Colé et al. (1999), when GPC is mastered well, children become able to shift their attentional focus to associate several graphemes into larger phonological structures such as syllables, notably because of the inconsistency of the small units in French. In fact, it remains less constraining to segment into syllables than into phonemes.

This first set of data is not incompatible with the theoretical view of Seymour and Duncan (1997). We suppose a developmental progression from a systematic use of GPC matching to a selective use of GPC processing restricted to low-frequency syllables. At this stage, the high-frequency syllables are recoded more quickly and are available and retrieved more readily than low-frequency

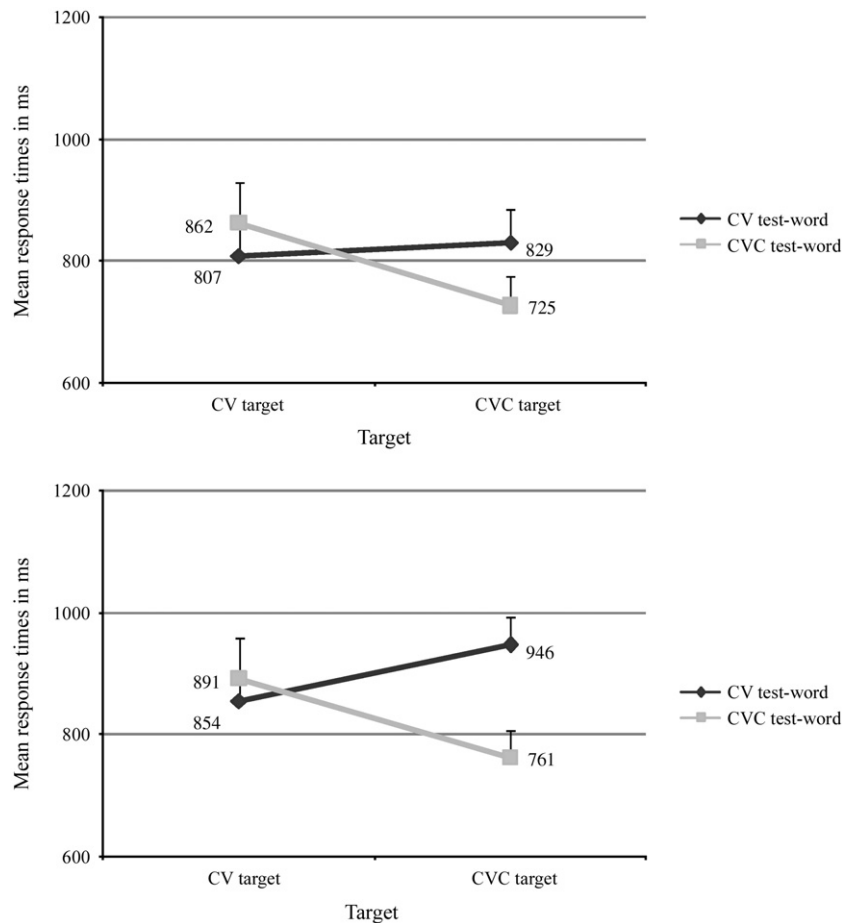


Fig. 4. Mean response times (in milliseconds) of high-frequency targets (upper panel) and low-frequency targets (lower panel) in fifth graders as a function of target and test-word in the split up Target  $\times$  Test-word  $\times$  Target frequency interaction.

syllables, probably because of the strength of syllabic representation developed through early exposure to spoken language and orthographic co-occurrences (e.g., Doignon & Zagar, 2006).

In third and fifth graders, their increased reading experience explains the lexical frequency effect and the syllable frequency effect: the learning of the GPC, the use of the phonological mediation, and the increase of reading exposure progressively build the orthographic lexicon, which speeds-up the recognition of words frequently encountered. Moreover, the association of phonemes into larger units such as syllables to reduce cognitive load coupled with implicit knowledge about oral syllables decreases the speed of access to frequent written syllable configurations, whereas rare written syllable configurations require more time for access. In both cases, the amount of syllables and words stored in manners sensitive to word frequency and sensitive to syllable frequency is sufficient to improve speed of processing.

In fifth grade, the analyses identified a Target  $\times$  Test-word interaction which evidences a phonological “syllable compatibility effect” with low-frequency targets, in accordance with our predictions but also with high-frequency targets. However, the expected target length effect (i.e., CV targets detected more rapidly than CVC targets) with high-frequency targets did not emerge. Actually, we found additional and contradictory effects for high-frequency targets: a target length effect appeared but CVC structures were detected faster than CV structures. As can be seen in Fig. 4, we observe that the main effect with high-frequency targets is mainly due to the accelerated processing of the “CVC target–CVC word” couple. The CV target length effect that we had anticipated would have shown that children could process the high-frequency targets using direct orthographic processing, that is to say by deriving the letter information in a top–down manner from whole-word orthographic representations. Instead, the results suggest sub-phonemic processing of the syllables within the words.

#### Sensitivity to internal syllabic organization in older children

Children in fifth grade appeared to have developed an ability to refer to internal syllabic organization. This organization is reflected by the status of the pivotal consonant, which would in turn cue to segment words and facilitate phonological recoding (see Fabre, & Bedoin, 2003). Fifth graders maybe use the regularity of French linguistic characteristics to visually recognize words.

Table 3  
Summary of the interactions and main effects for 1st, 3rd, and 5th grades.

Grade	Triple interactions and main effects	Nature and description of the triple interactions and the main effects
1st grade	Target × Test-word × Target frequency (see Fig. 2)	Target × Test-word with high-frequency targets: ⇨ "CVC target–CVC word" < "CV target–CVC word" ⇨ "CVC target–CVC word" marginally < "CVC target–CV word" Target length effect with low-frequency targets: ⇨ CVC targets (815 ms) < CV targets (854 ms)
3rd grade	Target × Test-word × Target frequency (see Fig. 3)  Main effect of Word frequency Main effect of Target frequency	Target × Test-word with high-frequency targets: ⇨ "CV target–CV word" < "CV target–CVC word" ⇨ "CVC target–CVC word" < "CV target–CVC word" Target length effect with low-frequency targets: ⇨ CV targets (1059 ms) < CVC targets (1232 ms) High-freq. Word (1027 ms) < low-freq. Word (1123 ms) High-freq. Target (1004 ms) < low-freq. Target (1146 ms)
5th grade	Target × Test-word × Target frequency (see Fig. 4)  Main effect of Word frequency Main effect of Target frequency	Target × Test-word with high-frequency targets: ⇨ "CVC target–CVC word" < "CV target–CVC word" ⇨ "CVC target–CVC word" < "CVC target–CV word" ⇨ "CVC target–CVC word" < "CV target–CV word", Target × Test-word with low-frequency targets: ⇨ "CVC target–CVC word" < "CV target–CVC word" ⇨ "CVC target–CVC word" < "CVC target–CV word" ⇨ "CVC target–CVC word" < "CV target–CV word" ⇨ "CV target–CV word" < "CV target–CVC word" High-freq. Word (819 ms) < low-freq. Word (849 ms) High-freq. Target (806 ms) < low-freq. Target (863 ms)

According to linguistics, the best syllabic contact depends on the sonority profile (SP) of intervocalic structure (Clements, 1990); that is, the cohesion within a syllable is better when the end of the syllable is more sonorant than the beginning of a subsequent syllable (e.g., bal.con "balcony") (Murray & Vennemann, 1983). When considering this principle, we can better understand in Fig. 4 why the "syllable compatibility effect" emerges only between CVC targets and CVC words. Here, it seems especially pertinent to specify that in our material, all of the codas of the first syllable in CVC words are always sonorant whereas the onsets of the second syllable are always obstruent. We therefore interpret our results as a function of the children's development of sensitivity to the internal organization of the syllables. As this pattern does not appear in first or third graders, fifth grade would seem to be an important stage when the foundations of skilled reading emerge and more especially, when the sensitivity to the internal organization of syllables that goes beyond phonemes alone is developed. Additionally, this observation may be correlated to the specificities (i.e., regularity and redundancy) of CVC.CVC words. Generally, low-sonority consonants are frequent in syllable onset (Blevins, 1995), whereas high-sonority consonants are frequent in syllable coda (e.g., in French, 76.4% of words with CVC.CVC structure include a sonorous coda at the end of the first syllable; Content et al., 1990).

However, the best matching process between CVC targets and CVC test-words could be compared to results obtained in an auditory priming paradigm (for further details, see Spinelli & Radeau, 2004) where CVC primes were detected faster only when they corresponded to the CVC words, whereas CV primes similarly activated CV and CVC words. These authors explained that CVC primes limited the lexical competition because initial CVC words could not have an initial CV structure (no backward processing), whereas CV primes competed for CV and CVC words. In line with this, co-articulation of the pivotal consonant on the preceding vowel provided a more important acoustic similarity in /kap/-cap.sule than in /kap/-ca.puche, which decreased the activation of the lexical competitors.

#### Hypothesis of the non-inhibitory syllable frequency effect

Our results differ from recent findings released concerning reading in Spanish (e.g., Álvarez et al., 2000, 2001) and replicated in French (Mathey & Zagar, 2002). These results showed that words were processed faster when they were initially composed of low-frequency syllables rather than of high-frequency syllables. This inhibitory effect has been interpreted in terms of lexical competition, that is, the higher the syllable frequency, the higher the number of activated words. Yet, the syllable frequency effect is not inhibitory in speech production. Words with initial high-frequency syllables are uttered faster than words with initial low-frequency syllables (Carreiras & Perea, 2004), which is compatible with the results of Levelt and Wheeldon (1994).

Levelt and Wheeldon (1994) hypothesized the existence of a mental syllabary that only provides precompiled syllabic articulatory gestures for high-frequency syllables. The mental syllabary would be independent from the lexicon. This motor repertory would permit the speedy retrieval of syllabic representations instead of building the syllabic representations in speech production on-line. In our point of view, while learning to read, the stock of lexical candidates is not sufficiently large to inhibit the role of high-frequency syllables. The repetitive exposure to frequent syllabic structures would facilitate the mapping of these frequently encountered structures with the beginning of words whose number is still restricted (i.e., a limited mental lexicon). Conversely, low-frequency syllables would be decomposed via a grapho-phonemic processing to match its smallest constituents

to the initial syllable of words. The fact that children are sensitive to high-frequency syllables when processing printed words allows us to hypothesize an eventual storage of high-frequency syllables, which could be represented early in a specific lexicon designed to stock pre-structured syllables encountered during the A.B.C. stage teaching. This lexicon would help to avoid perpetual constraints on the association of phoneme strings with syllable-sized units and inconsistency constraints that are problematic in French; that would explain why children are sensitive to syllabic frequency and why they use grapho-syllabic processing with high-frequency targets.

As an alternative, but analogical, explanation of our results that is compatible with the mental syllabary proposed by Levelt and Wheeldon (1994), we could assume that high-frequency syllables are stored as precompiled articulatory gestures developed through the subvocal repetition; only frequent phoneme associations are compiled into syllabic gestures whereas rare phoneme associations would benefit from GPC. If that were the case, it would constitute an additional source of evidence for the involvement of the syllable in utterance (see Davis & MacNeilage, 1995), even in silent reading. However, we did not observe if all of the younger children (i.e., first and third graders) systematically resorted to motor output.

Our hypothesis is also clearly compatible with the interactive bimodal model built by Colé et al. (1999) who argued that the phonological lexicon and the orthographic lexicon must be connected in skilled reading through an interface consisting of connections between phonological and orthographic units developed by the GPC teaching and reading exposure. Implicit knowledge about spoken syllables would guide the associations with larger orthographic units. In our point of view, the more some spoken syllabic structures would have been encountered, the more the printed equivalent syllabic structures would be quickly and efficiently available, giving evidence for the syllable frequency effect and the resort to a more phonological grapho-syllabic code. We acknowledge that we need to deepen this hypothesis, especially to understand our data in fifth graders and to detect the moment when syllabic processing switches to low-frequency targets. However, we have noticed that high-frequency syllables are not inhibitory as recently evidenced and, on the contrary, our results tend to demonstrate that high-frequency syllables improve the syllabic overlap detection.

Interestingly, this set of results clearly points out that French children resort early to phonological grapho-syllabic processing of printed words, even if the grain size of the phonological recoding units seems to be dependent on printed syllable frequency. Our demonstration supports the idea of an intermediate pre-lexical access to mental lexicon based on syllable-sized units. As syllable awareness is an early ability developed during contact to spoken language and, as the phonological codes based on syllabic units quickly emerge, it opens perspectives for training (e.g., computer-assisted learning, CAL) focusing on large units such as the syllable in low-progress or reading-disabled children. However, although training programs are used to support and improve the acquisition of reading, the grain size of the phonological codes used by children still causes discrepancies (see Ziegler & Goswami, 2005). In fact, phonological recoding strategies would be influenced, on one hand by the transparency of the GPC and, on the other hand by linguistic characteristics of the language, in particular the rhythmic class. Romance languages such as Spanish, Italian, Portuguese or French are classified as syllable-timed language whereas English or Dutch are ranked as stress-timed language. In accordance with this point of view, Duncan, Colé, Seymour, and Magan's (2006) cross-linguistic experiments in French and English children highlighted an important difference: only French children manipulated syllabic units consistently. So, the efficiency of training programs could be related to the size of the phonological units dependent on the language. It is also necessary to take into account the nature of the phonological codes and especially the importance of the syllable in French.

#### Implications for specific reading training

Recent meta-analyses of experimental training studies (e.g., Bus & Van IJzendoorn, 1999; Ehri et al., 2001) have demonstrated a more consistent and robust causal impact of phonemic training on reading skills when the training of letter knowledge is included. It was proposed that CAL programs could offer the possibility of audio-visual training aimed at improving children's reading skills by helping them to decode words using phonological grapho-syllabic processing skills. This point of view, coupled with our results, is fully compatible with the recently published data by Magan, Écalte, and Calmus (2008) which confirmed that a training program focusing attention on syllabic units in French children did indeed improve their reading skills. As demonstrated by Écalte, Magan, and Calmus (2009) with a print-to-sound mapping CAL program, French children trained with CAL focusing on syllable-based segmentation outperformed children who did not benefit from such training. Phonological recoding performances were also long-lasting. This result suggested that learning based on the syllabic unit seemed to be the best option for improving the phonological recoding process, but the authors acknowledged that further research was required to better understand how syllable-sized units could contribute to better phonological performances.

In our opinion, the syllable as a privileged unit during reading acquisition has to be investigated more deeply as far as it could be involved in gains in phonological awareness. In light of our results, further training on phonological awareness based on the syllable should consider the role of syllable frequency and sub-phonemic characteristics such as sonority of the pivotal consonant to propose a fully integrated framework. In particular, future research on training based on syllable-sized units could be extended to languages presenting common characteristics to French, such as Spanish or Portuguese.

#### Acknowledgements

We would like to thank Nathalie Bedoin, Bernard Lété and Ram Frost for having reviewed an early draft of the manuscript. We also would like to thank gratefully anonymous reviewers for their extensive and insightful comments, and Victoria Surtees for having proofread the manuscript.

## Appendix A. List of stimuli and their respective frequencies

Items structure matched by pairs and frequencies							
Pairs of frequent words		Pairs of rare words		Pairs of frequent targets		Pairs of rare targets	
CV and CVC		CV and CVC		CV and CVC		CV and CVC	
Parole (54)	Parfum (38)	Carafe (8)	Carbone (0)	Pa (2720)	Par (6149)	Ba (1257)	Bal (174)
Carotte (34)	Carton (66)	Corail (6)	Cordon (5)	Ca (2800) ×2	Car (1035) ×2	So (1089)	Sol (260)
Malade (114)	Malgré (86)	Morale (3)	Mortel (1)	Ma (4638)	Mal (1142)	Vo (1010)	Vol (197)
Volant (19)	Volcan (20)	Torero (0)	Tornade (1)	Mo (3072)	Mor (436)	Do (981)	Dor (328)
Solide (37)	Soldat (23)	Purine (0)	Purger (0)	Co (3454)	Cor (463)	To (286)	Tor (195)
Balance (26)	Balcon (19)	Dorure (0)	Dorsal (0)			Pu (465)	Pur (34)

Note. Frequencies are extracted from Manulex-infra (targets; Peereman et al., 2007) and from Manulex (test-words; Lété et al., 2004).

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