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Segmentation of Written Words in French

Fabienne Chetail and Alain Content
Université Libre de Bruxelles, Belgium

Abstract
Syllabification of spoken words has been largely used to define syllabic properties of written words, such as the number of syllables or syllabic boundaries. By contrast, some authors proposed that the functional structure of written words stems from visuo-orthographic features rather than from the transposition of phonological structure into the written modality. Thus, the first aim of the study was to assess whether the explicit segmentation of written words in French was consistent with syllabification patterns for spoken words previously reported. Second, given that spelling does not map perfectly with phonology, we examined how readers segmented printed words with grapheme/phoneme misalignments. The examination of the whole patterns of written segmentation produced by participants showed that, though written segmentation followed spoken segmentation for words matched for phonological/orthographic forms, discrepancies were found in cases of mismatch, therefore suggesting that readers rely on orthographic cues to parse printed strings of letters. This conclusion was confirmed with an on-line letter detection task.

Keywords
Grapheme/phoneme misalignments, number of syllables, syllable boundaries, written syllabification

I Introduction

How does the language system organize letter strings into functional units? The question has been of interest since the earliest experimental studies of the reading process. To quote Erdmann and Dodge (1898, p. 185), "[…] we never find a letter-to-letter reading process in the sense that attention is paid to individual letters in succession. In this case the reading process rather operates on letter groups of different extent which are organized into speaking syllables or other 'grammatical groups of letter sounds'". As the quotation suggests, syllable-sized units appeared as a natural and plausible solution to early investigators. The hypothesis that the processing of long words entails the organization of the letter sequence into chunks grossly corresponding to the spoken syllables

Corresponding author:
Fabienne Chetail, Laboratoire Cognition Langage et Développement (LCLD), Université Libre de Bruxelles –
Av. F. Roosevelt, 50, CP 191, 1050 Brussels, Belgium.
Email: fchetail@ulb.ac.be

has attracted much attention during the past decades and there is now a consistent body of evidence that such syllable-sized units might be functional during written word processing. Three major lines of evidence have been put forward in recent years. First and most prominently, inhibitory effects of syllable frequency have been reported by several groups (e.g., Carreiras, Alvarez, & de Vega, 1993; Chetail & Mathey, 2009b; Conrad, Grainger, & Jacobs, 2007; Conrad & Jacobs, 2004; Perea & Carreiras, 1998). Second, facilitatory syllabic priming effects have also been observed in lexical decision and naming tasks (e.g., Alvarez, Carreiras, & Perea, 2004; Chetail & Mathey, 2009a). Finally, some studies have reported increased naming and lexical decision latencies with the number of syllables (e.g., Ferrand & New, 2003; Stenneken, Conrad, & Jacobs, 2007), particularly with low-frequency words, suggesting a sequential processing component based on syllable-sized units.

In most of these studies, the units that have been considered or manipulated in the written modality have been implicitly assumed to correspond to spoken syllables. Yet, other authors have proposed to define orthographic functional units based on purely orthographic properties such as letter sequence constraints (e.g., Prinzmetal, Treiman, & Rho, 1986; Taft, 1979) rather than phonological structure. As shown below the two approaches do not always lead to the same groupings. The aim of the present study was to determine the nature of the structure extracted from letter strings by examining explicit written segmentation patterns produced by adult readers.

At first, it seems perfectly natural to define orthographic syllables as the letter groups that correspond to phonological syllables given that syllables are phonological units in essence. This strategy has been applied in most quantitative analyses of lexical corpora. Thus, Venezky and Suraj (1993) proposed a syllabification algorithm of written words according to which each word is first converted into its phonemic form, and then syllabified based on phonotactic constraints. More recently, Chetail and Mathey (2010) developed a database of correspondences between phonological and orthographic syllables in French. To do so, the parsing of written words was obtained by aligning letter strings with phoneme strings for each syllable, based on the syllabified phonological forms from Lexique (New, Pallier, Brysbaert, & Ferrand, 2004). For example, the word *purger* was segmented as *pur-ger* based on /pyʀ-ʒe/ whereas the word *pureté* was segmented as *pure-té* from /pyʀ-te/. Thus, in both the Venezky and Suraj (1993) and the Chetail and Mathey (2010) proposals, the syllabified phonological word form was explicitly superimposed on word spelling via grapheme-phoneme correspondences.

Similar reliance on phonology also appears in psycholinguistic studies. For example, measures of syllable frequency used to investigate syllabic effects in written word processing are usually computed from syllabified phonological word forms. Thus, the frequency count for the first syllable of the words *purger* and *pureté* is assumed to be identical and cumulates all words starting with /pyʀ/. The same logic applies to measures of syllabic length in visual word recognition studies (e.g., Ferrand & New, 2003). For example, the French word *palace* is phonemically coded /palas/ and syllabified /pa/+/las/. The written word *palace* is therefore supposed to have two syllables.

However, even though spelling reflects speech, written and spoken modalities are not perfectly matched in many languages. This is particularly true in French and such mismatches should be taken into account. For example, based on orthographic considerations, one might argue that *palace* actually entails three orthographic syllables (*pa-la-ce*). Furthermore, the transposition of syllabic structure from the spoken modality to the written modality is not sufficient to entirely determine the structure of written words. Phonology does not help to determine the segmentation in cases of silent letters (e.g., *baptiser*, /batize/: the letter *p* has no phonological counterpart), of letters participating in two oral syllables (e.g., *crayon*: the letter *y* contributes both to the syllable /kʀɛ/ and to the syllable /jõ/), of double letters (e.g., *ballon*, /balõ/), and of multiphonemic letters (e.g., *taxi*: the letter *x* is pronounced /ks/). Moreover, there is no complete consensus on spoken syllabification among linguists (see Goslin & Frauenfelder, 2001), and psycholinguistic studies on speakers' preferences indicate that oral syllabification is far from simple and unambiguous (e.g., Content, Kearns, & Frauenfelder, 2001; Goslin, Content, & Frauenfelder, 1999; Goslin & Floccia, 2007; Schiller, Meyer, & Levelt, 1997; Treiman, Bowey, & Bourassa, 2002; Treiman & Danis, 1988; Treiman & Zukowski, 1990).

By contrast, some authors have explored the possibility that the functional structure of written words stems from visuo-orthographic features rather than from the transposition of phonological structure into the written modality. For example, Hansen and Rodgers (1965) proposed that words would be parsed into orthographic units, which they named "vocalic centre groups" (VCG, see also Spoehr & Smith, 1973). They assumed that the parsing is driven by the distinction between the two major classes of letters, consonants and vowels (henceforth C and V, respectively), and that the resulting structure conditions phonological transcoding. The procedure begins with the detection of vowel letters in the string. If there are several non-consecutive vowels, the letter string contains more than one group. Dominant segmentation rules are tried first (e.g., VCCV strings are parsed into VC+CV). If the parsing fails, minority rules are subsequently applied (e.g., V+CCV). However, as noted by Coltheart (1978), the rules proposed by Hansen and Rodgers (1965) would predict two groups in phonologically monosyllabic words that include a final *e* such as *force* (due to two non-contiguous vocalic centers). More generally Coltheart's analysis demonstrated that contrary to Hansen and Rodgers's hope, the VCG structure is of limited use in disambiguating phonological conversion. Taft (1979) additionally underlined that Hansen and Rodgers' algorithm (1965) may conflict with certain orthotactic and morphological constraints. For example, the word *gentle* would be parsed as *gen-tle*, while it should be *gent-le*, because the bigram *tl* violates orthotactic regularities (i.e., no word begins with the letters *tl* in English). Hence, Taft defined the BOSS unit (basic orthographic syllabic structure), derived from the application of another segmentation principle also based on letter category: "include in the first syllable as many consonants following the first vowel of the word as orthotactic factors will allow without disrupting the morphological structure of that word" (1979, p. 24). Interestingly, in languages with a majority of open syllables such as French, the BOSS principle predicts a different segmentation than phonologically-based rules (for the word *plumer* /plyme/, respectively *plum-er* vs. *plu-mer*). Contrary to what has happened in English (e.g., Taft, 1979, 2001), direct empirical attempts to adjudicate between the two hypotheses in French have produced mixed results (see Rouibah & Taft, 2001; Taft & Radeau, 1995).

Another major source of evidence in favor of the notion of an early orthographic chunking mechanism is based on the illusory conjunction task (e.g., Prinzmetal et al., 1986; see also Doignon & Zagar, 2005; Prinzmetal, Hoffman, & Vest, 1991; Rapp, 1992). Especially, Prinzmetal et al. (1986) showed that syllable-sized units extracted from English written words were mainly determined by orthographic and morphological factors and that phonology did not seem to play a role. Further experiments (Seidenberg, 1987) confirmed that phonological structure is not a major factor determining illusory conjunctions since similar patterns of conjunctions were obtained for bisyllabic items such as *naive* and monosyllabic items such as *waive* (but see Rapp, 1992).

To sum up, two different approaches have been proposed to account for the way orthographic strings of letters are structured into functional units. The aim of the present study was to assess the contribution of phonological and orthographic factors to orthographic segmentation. In the first experiment, we used a metalinguistic task to directly probe readers' explicit intuitions concerning the structure of printed words. In the second experiment, we assessed word segmentation processes indirectly by means of an on-line letter detection task.

2 Experiment 1

Listeners' segmentation preferences have been widely used to study spoken syllabification (e.g., Content et al., 2001; Goslin & Floccia, 2007; Goslin & Frauenfelder, 2001; Treiman et al., 2002; Treiman & Danis, 1988; Treiman & Zukowski, 1990), and the resulting findings have helped constrain syllabification theories (Treiman & Zukowski, 1990). In contrast, this very simple technique has hardly been used with print. Treiman and colleagues (Treiman & Danis, 1988; Treiman & Zukowski, 1990) had participants choose between two segmented written forms (e.g., *le-mon* vs. *lem-on*) and reported that preference patterns mirrored those observed in the spoken modality. However, they used a constrained forced-choice method and did not systematically explore cases in which spelling and sound diverge. Here, we examined to what extent the orthographic structure drawn by readers follows spoken syllabification by presenting written words including consonantal clusters with different oral segmentation patterns. For instance, words with Fricative-Liquid clusters (e.g., *avril*) and words with Liquid-Fricative clusters (e.g., *berger*) respectively elicit C.VVC and CV.VC segmentations according to previous linguistic and psycholinguistic studies in the spoken modality (Dell, 1995; Goslin & Floccia, 2007; Goslin & Frauenfelder, 2001; Laporte, 1992; Pulgram, 1970). Hence, if written segmentation is based on phonological structure, an analogous pattern should be found with written stimuli in the present study. Furthermore, we included two series of words aimed at assessing the influence of orthographic properties. One set of words was deemed as a direct test of Hansen and Rodgers' (1965) proposal. We capitalized on one specificity of the French language, the so-called "silent schwa". French includes many words with an internal or final *e* letter, which is not pronounced in the standard pronunciation (e.g., *pu-re-té* – /pyʀ.te/; *pa-la-ce* – /pa.las/), so that such words systematically entail one more VCG than the number of (phonological) syllables. The other set included words with a silent letter (e.g., *trahir*, /tʀaiʀ/) or a letter string disrupting the grapheme/phoneme alignment. In that case, words exhibited an ambiguous letter at the boundary between two syllables, which enables us to assess to which unit (the preceding or following one) the critical letter is attached.

2.1 Method

2.1.1 Participants. One hundred and four volunteer students participated in this experiment. They were all native French speakers.

2.1.2 Materials. One hundred and fifty-five common words (overall word frequency: 10.32 Occurrences per million) were selected from the Lexique database (New et al., 2004). These 155 words were divided into four sets (see Table 1). In each set, half of the words were considered bisyllabic and half trisyllabic according to current psycholinguistic lexical databases (Content, Mousty, & Radeau, 1990; New et al., 2004). Words were controlled for their lexical frequency, number of syllables and number of letters (see Appendix 1 for the complete list of stimuli).

In the first set (base set), we selected 40 words with simple and direct mappings between phonological and orthographic forms (e.g., *douloureux*, /duluʀø/; *pencher*, /pɑ̃ʃe/) in which either phonological or orthographic parsing would converge on the same responses. From a phonological viewpoint these items were deemed to be easy to segment because their phonological representation included only singleton intervocalic consonants (VCV) unanimously syllabified as V.CV both in linguistic descriptions of French and in native speaker judgments (e.g., Goslin & Frauenfelder, 2001; Hooper, 1972; Laporte, 1992; Pulgram, 1970).

Table 1. Distribution of the words across the different sets, word characteristics, and results for four dependent variables.

	Sets											
	Base	Schwa			Mismatch			Cluster				
	–	Internal	Final	*Total*	Silent letter (*h*, *p*, e)	Multiphonemic correspondences (*ll*, *y*)	*Total*	FL	FP	LF	PF	*Total*
Number of items	*40*	20	20	*40*	19	17	*36*	9	10	10	10	*39*
Example	*pencher*	samedi	avantage	–	envahir, baptiser, gaiement	griller, bruyant	–	avril	poster	berger	lapsus	–
Lexical frequency	*10.42*	13.13	9.72	*11.42*	7.04	10.78	*8.81*	11.9	12.84	10.33	7.91	*10.71*
Mean number of letters	*7.58*	8.05	7.90	*7.98*	7.93	7.59	*7.78*	7.33	7.7	7.6	7.3	*7.49*
Mean number of syllables (databases)	*2.50*	2.50	2.50	*2.50*	2.53	2.47	*2.50*	2.44	2.50	2.50	2.50	*2.49*
Mean mode of number of syllables (participants)	*2.50*	3.50	3.45	*3.48*	2.53	2.47	*2.50*	2.44	2.50	2.50	2.50	*2.49*
Database agreement	*.95*	.05	.33	*.19*	.95	.95	*.95*	.98	.94	.94	.95	*.95*
Response strength (number of syllables)	*.95*	.94	.66	*.80*	.95	.95	*.95*	.98	.94	.94	.95	*.95*
Segmentation agreement	*.93*	.90	.97	*.93*	.83	.54	*.70*	.95	.80	.91	.75	*.85*

Notes. FL: words with a Fricative-Liquid consonant cluster. FP: words with a Fricative-Plosive consonant cluster. LF: words with a Liquid-Fricative consonant cluster. PF: words with a Plosive-Fricative consonant cluster.

The second set (cluster set) aimed at testing whether written segmentation directly matches spoken segmentation. We selected words exhibiting a VCCV sequence, using consonant clusters that have been examined in spoken syllabification studies. The consonant cluster was either a fricative consonant followed by a liquid consonant (e.g., *avril*), a liquid followed by a fricative (e.g., *berger*), a plosive followed by a fricative (e.g., *lapsus*), or a fricative followed by a plosive (e.g., *poster*) for one fourth of the set.

In the third set (schwa set), the orthographic structure of the words differed from their phonological structure because they included a schwa either internally (e.g., *samedi*, /samdi/, 20 words) or word-finally (e.g., *volume*, /volym/, 20 words). According to the dominant pronunciation, the letter *e* is not pronounced although it is written (e.g., Content et al., 1990; Delattre, 1966; Dufour, Peereman, Pallier, & Radeau, 2002; New et al., 2004). Concerning internal schwas, Racine and Grosjean (2002) argued that the pronunciation of the silent *e* in French is obligatory (e.g., *atelier*, /atəlje/), optional (e.g., *cheval*, /ʃəval/ or /ʃval/), or forbidden (e.g., *avenir*, /avniʀ/). For our third set, all the words with an internal schwa belonged to the last category.

Finally, the fourth set (mismatch set) comprised 36 words the orthographic form of which did not directly match the phonological form, either because the spelling included a silent letter or a silent letter group, or because it contained a letter with multiple phonemic correspondences. Several different cases were sampled: silent *h* (e.g., *envahir*, /ɑ̃vaiʀ/, 8 words), silent *p* (e.g., *baptiser*, /batize/, 4 words), silent *e* (e.g., *gaiement*, /gɛmɑ̃/, 7 words), and *ll* (e.g., *griller*, /gʀije/, 8 words), and *y* (e.g., *crayon*, /kʀɛjõ/, 9 words).[1]

2.1.3 Procedure. Participants were tested in groups. They were given a sheet of paper with written instructions on one side and the words organized in four columns on the other side. They were asked to segment the words into syllables by inserting a vertical mark where they thought a syllable boundary would lie. There was no time limit, but participants were encouraged to respond quickly and spontaneously, without skipping items or going back. They were assigned randomly to one of four different random arrangements of the stimuli.

2.2 Results

For each participant, the number of letter units and the location of the segmentation marks were collected for each word. Altogether, the rate of valid responses was 98%, with 0.41% of abstentions. We considered valid any segmentation response including two parts for bisyllabic words and three parts for trisyllabic words for all except the schwa set, for which one additional unit was admitted.[2]

2.2.1 Number of syllables. We first calculated the number of orthographic syllables for each word as the modal number of syllables attributed across participants. In addition, we used the proportion of participants that produced the modal response as an index of agreement or response strength, and the proportion of participants that produced the number of units indicated in lexical databases as an index of database agreement rate. For example, 89% of the participants stated that the word *avenue* has three syllables, and 11% that it has two syllables. Thus the number of units was 3, the response strength was 0.89, and the database agreement was 0.11 since *avenue* is considered a bisyllabic word (Content et al., 1990; New et al., 2004). For the word *intuition*, 2% of the participants stated that it has 2 syllables, 95% that it has 3 syllables, and 3% that it has 4 syllables. Hence it was categorized as trisyllabic, with 0.95 for the response strength and 0.95 for database agreement.

For the 155 words, the mean number of syllables based on participants' responses was 2.75 and the response strength was 0.91, while the mean number of syllables indicated in lexical databases was 2.50. Thus, overall, participants seem to overestimate the number of syllables in spelling. As can be seen in Table 1, however, this trend was clearly due to the schwa words.

With the schwa words, the participants provided on average one syllable more ($m = 3.48$) than for the baseline set ($m = 2.50$), and the tendency to indicate one supplementary syllable was even more manifest for words with an internal schwa ($m = 3.50$) than for words with a final schwa ($m = 3.45$). The response strength for the schwa set ($m = 0.80$) was significantly lower than for the baseline set ($m = 0.95$), $t(78) = 5.32$, $p < .001$, indicating that agreement was lower for schwa words than for non-ambiguous items. In addition, database agreement was much lower for the schwa words ($m = 0.19$) than for the base set ($m = 0.95$), $t(78) = 27.64$, $p < .001$. Database agreement was also lower for words with an internal schwa ($m = 0.05$) than for words with a final schwa ($m = 0.33$), $t(38) = 12.46$, $p < .001$, whereas response strength was higher for items with an internal schwa ($m = 0.94$) than for items with a final schwa ($m = 0.66$), $t(38) = 12.64$, $p < .001$. This means that participants' responses deviated more and more consistently from the number of syllables indicated in lexical databases for items containing an internal schwa than for items ending with a schwa. This is particularly striking for items such as *javelot* or *biberon* (bisyllabic words with dominant pronunciations /ʒavlo/ and /bibʀõ/) for which 99% of participants attributed three syllables rather than two.

2.2.2 Location of syllable boundaries. We examined the different segmentation solutions for each word set and their distribution across participants. To evaluate the degree of agreement on the segmentation of each word, we computed the proportion of responses corresponding to the dominant solution. Overall the agreement was relatively high, indicating that participants would generally converge on the same parsing ($m = 0.86$). Agreement was particularly high for the base and schwa sets ($m > 0.90$), whereas responses varied more for the two other sets.

For the cluster set, the agreement was significantly lower ($m = 0.85$) than for the base set ($m = 0.93$), $t(77) = 2.31$, $p = .02$ and a one-way ANOVA showed that there were differences among the four types of clusters, $F(3, 35) = 3.94$, $p = .02$. Fricative-Liquid and Liquid-Fricative clusters produced more unanimous parsing (respectively 0.95 and 0.91) than Fricative-Plosive and Plosive-Fricative clusters (respectively 0.80 and 0.75), $F(1, 35) = 11.05$, $p = .002$. Post-hoc tests indicated that neither the difference between Fricative-Liquid and Liquid-Fricative clusters nor the difference between Fricative-Plosive and Plosive-Fricative clusters was significant. Most responses included a segmentation either before the cluster, V.CCV, or within the cluster, VC.CV. The third logical possibility, VCC.V, was extremely rare (less than 0.5%) and was not considered further. As shown in Figure 1, the location of the preferred boundary also varied with regard to the consonant clusters. Chi-squared tests comparing the proportion of V.CCV and VC.CV segmentations indicated that participants preferred parsing Fricative-Liquid words before the consonant cluster, $\chi^2 = 57.76$ ($df = 1$), $p < .001$, whereas they preferred within-cluster segmentation for the three other series, respectively $\chi^2 = 49.00$ ($df = 1$), $p < .001$, $\chi^2 = 92.16$ ($df = 1$), $p < .001$, and $\chi^2 = 24.25$ ($df = 1$), $p < .001$ for Fricative-Plosive, Liquid-Fricative, and Plosive-Fricative words.

For the mismatch set, the segmentation agreement ($m = 0.70$) was lower than for the base set, $t(74) = 6.16$, $p < .001$ and varied for the different subsets. Agreement was lower for words with letters having multiphonemic correspondences ($m = 0.54$ and 0.55 for *LL* and *Y* words respectively) than for words with a silent letter ($m = 0.96$, 0.81, 0.62 for *H, E*, and *P* words respectively), $t(34) = 7.14$, $p < .001$. Regarding the boundary location, clear differences were observed across the different cases examined. Items with a silent *H* were preferentially segmented before the *H*,

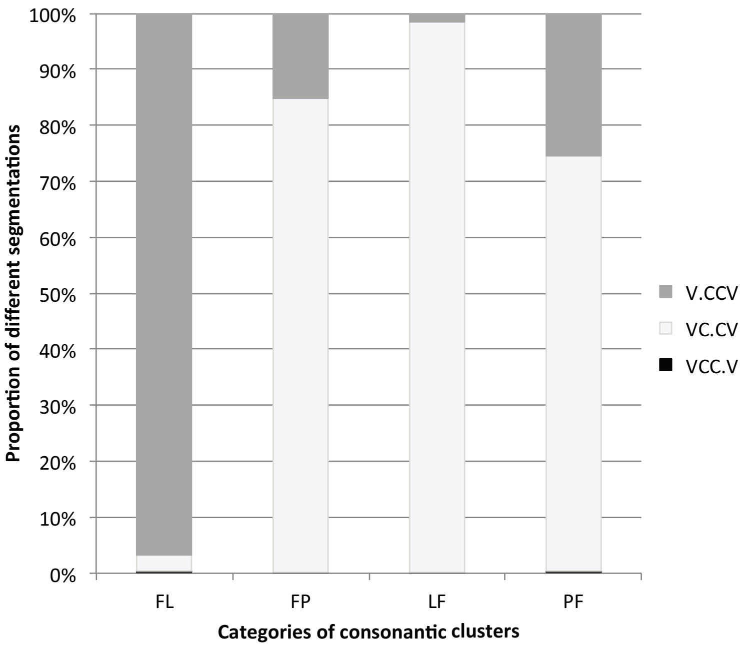

Figure 1. Proportion of different segmentations for words of the cluster set as a function of categories (FL: Fricative-Liquid, PF: Plosive-Fricative, FP: Fricative-Plosive, LF: Liquid-Fricative).

$\chi^2 = 92.16$ ($df = 1$), $p < .001$. Items with a silent *P* were preferentially segmented after the *P*, $\chi^2 = 11.56$ ($df = 1$), $p < .001$. Items with a silent *E* were also mostly segmented after the silent letter rather than before, $\chi^2 = 52.13$ ($df = 1$), $p < .001$, although a small percentage of participants gave responses involving two syllabic boundaries, namely both before and after the critical letter (e.g., *pai-e-ment*) (Figure 2). For the words with *LL*, participants' preferred segmentations were equally distributed among before and within the cluster, $\chi^2 = 2.37$ ($df = 1$), $p = .12$, these two types of segmentation being preferred to segmentation after the cluster, $\chi^2 = 39.50$ ($df = 2$), $p < .001$ (Figure 3A). For items with the letter *Y*, the participants preferentially parsed words before the letter *Y* rather than after, $\chi^2 = 8.17$ ($df = 1$), $p = .004$. Interestingly, a few of the responses (3%) had the mark intentionally put on the letter *y*, suggesting that participants were sensitive to the multiphonemic status of the letter (Figure 3B).

2.3 Discussion

To assess whether the explicit segmentation of written words was consistent with syllabification patterns for spoken words, we first used a set of VCV items with simple and direct mappings to the corresponding orthographic forms (e.g., *plumer*, /plyme/). In that case, participants showed a clear and consistent preference to locate syllabic boundaries before the singleton consonant (e.g., *plu-mer*). Thus, the orthographic segmentation of VCV structures corresponds to the dominant pattern obtained in spoken syllabification in French (e.g., Goslin & Frauenfelder, 2001) and does not fit with the BOSS proposal (Taft, 1979), which predicts that words should be parsed after the consonant (e.g., *plumer* leading to *plum-er*). The V-CV preference fits with spoken syllabification data

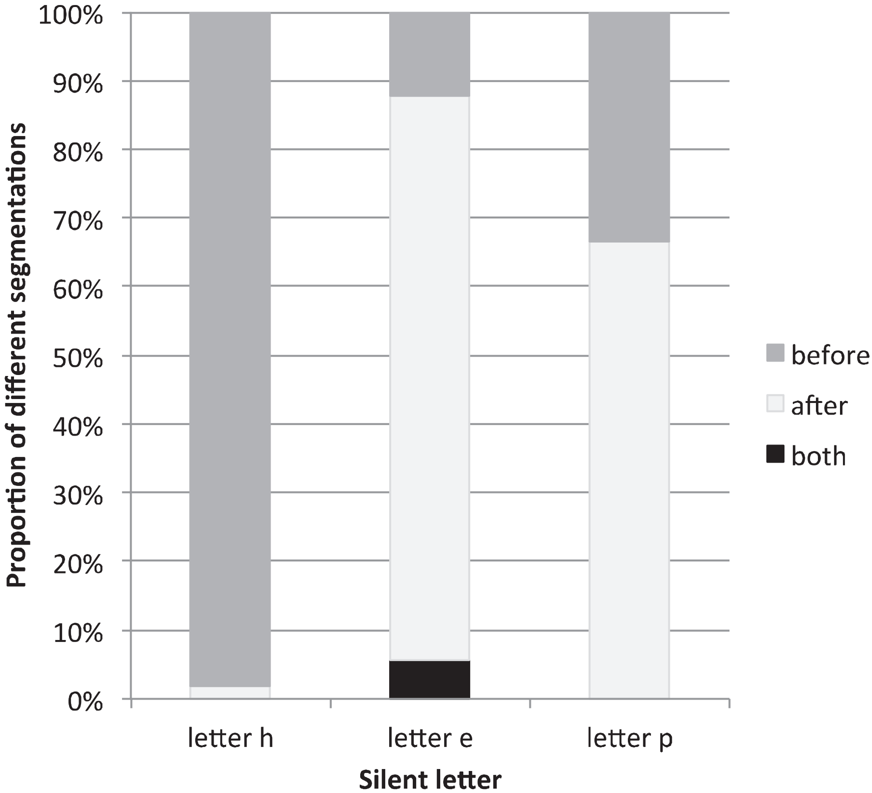

Figure 2. Proportion of different segmentations for words exhibiting a silent letter in the mismatch set as a function of the nature of the silent letter (*h*, *e*, or *p*).

(Content et al., 2001) and is in agreement with general linguistic principles such as the Obligatory Onset Principle (Hooper, 1972) or the Maximal Onset Principle (e.g., Pulgram, 1970).

The segmentation pattern obtained for the cluster set was also quite similar to that found in spoken segmentation studies (e.g., Goslin & Floccia, 2007; Goslin & Frauenfelder, 2001). Consonant clusters were consistently segmented as V.CCV for Fricative-Liquid words (e.g., *a-vril*), and as VC.CV for Liquid-Fricative words (e.g., *ber-ger*). On the contrary, words including clusters with plosive and fricative consonants (Plosive-Fricative and Fricative-Plosive words) produced less consistent responses although VC.CV segmentation was mostly preferred (e.g., *lap-sus, pos-ter*). Overall, the pattern is coherent with onset maximization (Pulgram, 1970), legality (Selkirk, 1982), and sonority sequencing (Clements, 1990) principles. As argued by Goslin and Frauenfelder (2001), the inconsistent responses for FP and PF clusters can be related to legality, as consistency is lower when various segmentations yield legal onsets. Actually, both FP and PF items in our experiment had multiple legal onsets (e.g., PF words: *pos-ter* is legal, but also *po-ster*, given the existence of words such as st*ylo*; FP words: *lap-sus* is legal, but also *la-psus*, given the existence of words such as ps*aume*). When the first consonant of the cluster is a liquid (LF words), the preferred parsing lies between the two consonants both because of legality (*be-rger* is not legal given that no French word begins with the cluster *rg*) and because of sonority, since the liquid is more sonorant than the occlusive. Conversely, if the liquid is the second consonant (FL words), the cluster is

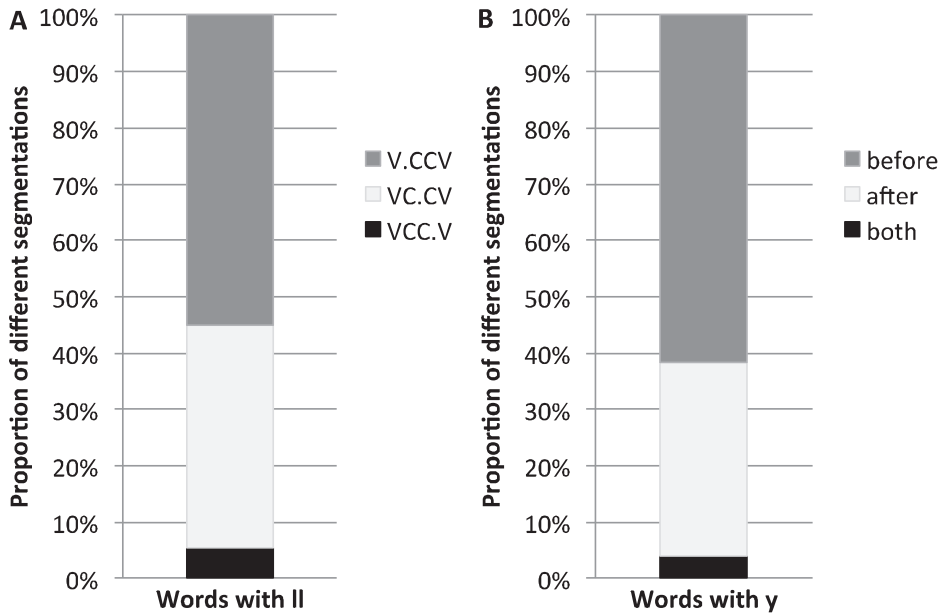

Figure 3. Proportion of different segmentations for words exhibiting letters with multiphonemic correspondences in the mismatch set. Figure 3A: words including the letters *ll*, Figure 3B: words including the letter *y*.

treated as a single inseparable onset, since it is both legal and increasing in sonority from the fricative to the vowel (Clements, 1990; see also Dell, 1995; Goslin & Frauenfelder, 2001).

Whereas printed and spoken word segmentation closely corresponded for the first two series, this was not the case for the schwa set. With words exhibiting an internal schwa (e.g., *samedi*, /samdi/) or a final schwa (e.g., *avantage*, /avãtaʒ/) participants systematically took the silent *e* of such items into account (i.e., *sa*-me-*di, a-van-ta*-ge). Therefore, their dominant segmentation differed from the syllabification based on pronunciation because it almost systematically entailed one more unit.

The latter finding suggests that orthographic and phonological segmentation do not always match and that readers rely on purely orthographic cues to parse printed strings of letters. However, the strength of that conclusion is limited by the metalinguistic nature of the task used, and one could argue that the performance reflects task-specific segmentation strategies rather than structural features of perceptual representations. Hence, in Experiment 2, we examined further the influence of schwa on written word structure by means of an on-line letter detection task.

3 Experiment 2

A striking result in Experiment 1 was that participants attributed one more unit than the number of syllables to words including a schwa. However, one could argue that this phenomenon is due to the metalinguistic nature of the task, and that participants have applied explicitly learned spelling segmentation rules to perform the task. To rule out this possibility, we used a letter detection task and contrasted words containing an obstruent-liquid cluster, spelled either with or without an interposed schwa (e.g., *biberon*, /bi-bʀõ/ vs. *nombril*, /nõ-bʀil/). We relied on a study conducted by

Brand, Giroux, Puijalon, and Rey (2007), who showed that it was harder to detect a letter at the second position of a syllable onset (e.g., *L* in *TA-BLIER*: multi-letter syllable onset) than a letter at the first position of the onset (e.g., *E-CO-LIER*: single-letter syllable onset). We reasoned that if the written functional units are based on the phonological form, the letter *R* should be as hard to detect in *nombril* as in *biberon* because both words have their second syllable beginning with a multi-letter syllable onset (/bi-bʀõ/, *bi-beron*, and /nõ-bʀil/, *nom-bril*). On the contrary, if readers rely on orthographic vowels to extract units, the letter *R* should be detected faster in schwa words than in control words, because it appears at the first position of an onset in the former (*bi-be-ron*) but not in the latter (*nom-bril*).

3.1 Method

3.1.1 Participants. Thirty-five students participated in the experiment for course credits. They were all native French speakers and reported normal or corrected-to-normal vision. None of them participated in the previous experiment.

3.1.2 Materials. We used 60 target-present trials, for which the letter to be detected was present in the word, and 60 target-absent trials. Words were selected from the Lexique database (New et al., 2004). The target-present trials included 20 pairs of experimental words and 20 fillers, with either an *L* or *R* letter to detect. Each pair was composed of a control word and a schwa word. All the schwa words contained an internal silent *e*, not pronounced in French (Racine & Grosjean, 2002). Both control and schwa words had an obstruent-liquid intervocalic consonant cluster including a plosive or fricative consonant (*p, b, v, t, d*) followed by a liquid one (*l, r*). In each pair, the target letter was at the same position within words (m = 5.4), but for control words, the letter followed a consonant (e.g., *nom.bril*), while it followed a vowel (the silent *e*) for schwa words (e.g., *bi.beron*). Control and schwa words were matched for number of letters (m = 7.95 in both sets), lexical frequency (5.27 and 3.20 occurrences per million respectively), orthographic neighborhood (0.37 and 0.25 orthographic neighbors respectively), and summed bigram frequency (21,082 and 20,953 occurrences per million respectively). See Appendix 2 for the list of stimuli. For the remaining 20 target-present fillers, the letter to be detected was also either *R* or *L* but located at various positions within the words (m = 3.5).

3.1.3 Procedure. Participants performed a letter detection task. For each trial, a letter (*R* or *L*) was presented in uppercase for 700 ms in the center of the screen. Then, a fixation cross was displayed for 500 ms, and immediately followed by the word stimulus in lowercase for a duration of 50 ms. After a blank of 67 ms, a post-mask (a row of 12 hash marks) was displayed until the participants responded. Participants had to decide as quickly and as accurately as possible whether the letter initially presented was included in the word by pressing one of two buttons on the keyboard. Feedback was provided when they failed to respond. All participants performed 10 practice trials before receiving the 120 trials in a different random order.

3.2 Results

The mean correct reaction times and mean error rates averaged over participants for experimental words are presented in Table 2. Two extreme reaction times were excluded from data analyses. The data were submitted to ANOVAs on the participant ($F1$) and item ($F2$) means with word type (control, schwa) as main factor.

Table 2. Mean reaction times (ms) and error rates (%) for control and schwa words in Experiment 2.

	Word type	
	Control	Schwa
Reaction times	724	682
Error rates	10.3	7.7

In the reaction time analyses, there was a significant effect of word type, $F1(1, 34) = 12.43$, $p = .001$, $F2(1, 38) = 4.39$, $p = .04$, target letters being detected more rapidly in schwa words than in control words (-42 ms). Consistently, target letters were more accurately detected in schwa words than in control ones, but the effect reached significance only in the participant analysis, $F1(1, 34) = 4.00$, $p = .05$, $F2(1, 38) = 1.20$, $p = .28$.

3.3 Discussion

Although schwa words and control words were matched on phonological structure and included the same obstruent-liquid intervocalic consonant cluster, the detection of the *L* or *R* was faster in schwa words than in control words. Given that letters are recognized more rapidly at the first position of the onset than at other positions of multi-letter onsets (Brand et al., 2007), the present finding suggests that the liquid letter of schwa words constitutes the onset of an orthographic unit. This is consistent with the data of Experiment 1 showing that readers consider that the silent *e* delimits an orthographic unit, thus positing the following consonant as an onset (e.g., *bi-be-ron, ja-ve-lot, pa-pe-te-rie*). This experiment therefore confirms the hypothesis that written word segmentation is driven by vocalic groups defined at an orthographic level, even if these vowels do not have a phonological counterpart.

4 General discussion

The aim of the present study was twofold. First, given that the internal orthographic structure of letter strings has generally been derived from spoken syllabification, we examined to what extent the explicit segmentation of written words is consistent with syllabification patterns for spoken words (e.g., Content et al., 2001; Goslin & Floccia, 2007; Goslin & Frauenfelder, 2001; Treiman & Danis, 1988; Treiman & Zukowski, 1990). Second, we capitalized on words with grapheme/phoneme misalignments, such as words with silent letters or letters with multiple phonemic correspondences to determine whether printed word segmentation is driven by orthographic or phonological structure.

Experiment 1 showed that written words with clear one-to-one mappings between orthography and phonology were segmented without ambiguity as the corresponding spoken forms. In the same vein, words with consonant clusters produced segmentation patterns similar to those reported in the spoken modality. Based on these results, one could claim that functional units in printed words correspond to spoken syllables but it remains possible that the segmentation is based on either orthographic or phonological cues. One way to settle this issue is to use words eliciting different parsing when either orthographic or phonological cues are used.

The most interesting class of words in the present study to assess an orthographic influence on word parsing was that of schwa words, because they include a silent *e* in the written form that has no counterpart in phonology (e.g., biberon, /bibʀõ/). In the metalinguistic task (Experiment 1), readers relied in a straightforward way on the silent *e* (especially on internal *e*) to parse words, and therefore reported one additional unit (e.g., *bi-be-ron*) compared to what would be predicted by a phonological parsing (e.g., *bi-beron*). The evidence of an influence of orthographic information on letter string parsing is further supported by the observation that participants did not respond haphazardly with words including silent letters in the mismatch set. They displayed clear segmentation preferences even though the absence of relevant phonological information should lead to random attachment of the silent letters to either the preceding or following unit. Furthermore, the results for schwa words were confirmed in Experiment 2 with a letter detection task. The faster detection of *L* and *R* following the silent *e* in schwa words supports the view that the target letters correspond to the first letter of a unit onset, thus ruling out the possibility that the previous results merely ensued from explicit parsing strategies.

Taken together, the present findings provide clear and unambiguous evidence for an orthographic level of structure which is not directly related to phonology. One interesting possibility is that the extraction of this structure is driven by the distinction between vowel and consonant letters as suggested by Hansen and Rodgers (1965), even when the letters have no spoken counterpart. The notion that consonant/vowel alternation may be an important cue to orthographic structure can account not only for schwa word segmentation but also for the performance with the other word sets. Because of the quasi-systematic mapping between orthographic and phonological forms, an algorithm similar to Hansen and Rodgers' based on the repartition of vowel and consonant letters as well as orthotactic regularities might account for the segmentation responses.

Interestingly, this hypothesis fits quite well with the orthographic parsing procedure implemented in the CDP++ model of polysyllabic word reading (Perry, Ziegler, & Zorzi, 2010). In this model, letter strings are parsed into graphemes and graphemes are assigned to onset, nucleus and coda constituent slots, based on the distinction between consonants and vowels, much like we proposed here. To assign consonants between the nuclei of bisyllabic words to the coda of the first syllable or to the onset of the second one, the model relies on the onset maximization (e.g., Pulgram, 1970) and legality principles. Consonant graphemes are assigned to onset positions provided the resulting orthographic string has been attested in the given position during learning. Otherwise the assignment is revised by shifting the leftmost consonant back into the coda of the first graphosyllable (e.g., *be-rger* → *ber-ger*). Such a process would account for most of the segmentation performance in Experiment 1. One difference, however, arises with the treatment of the *-e* letter at the end of words. Because in English, the final *-e* most often serves to distinguish between the short and long pronunciation of the preceding vowel (e.g., *hat* vs. *hate*), it has generally been treated as part of the coda. The CDP++ model successfully treats it as a coda element in monosyllabic words (e.g., *fines*) and as the vowel grapheme of the second graphosyllable in bisyllabic ones (e.g., *finest*), whereas our results suggest that in both cases, French readers perceive the *-e* letter as the vowel center of an additional graphosyllable. Whether this is true also in English or whether the different function of the *-e* in French and English induces different orthographic segmentation preferences remains to be investigated.

It is worth noting that the present conclusions are compatible with extant results with perceptual as well as with production tasks. In the perceptual domain, the illusory conjunction task constitutes one major paradigm used to investigate reading units (Prinzmetal et al., 1986). In this task, participants have to report the color of the central letter in briefly presented letter strings and they tend to make more errors when the repartition of the colors does not correspond to the internal structure of the item (e.g., *co-bra* with *cob* and *ra* in different colors). In a recent study, Doignon-Camus, Zagar, and Mathey (2009) observed illusory conjunctions for written words such as *niche* (/niʃ/, monosyllabic word with a final schwa). This effect could be accounted for by the fact that these words were orthographically treated as composed of two orthographic chunks (i.e., *ni-che*) rather than only one phonological syllabic unit as stated by the authors. Regarding production, Kandel, Hérault, Grosjacques, Lambert, and Fayol (2009) recently analyzed children's handwriting dynamics for monosyllabic words with a final schwa (e.g., *barque*, /baʀk/) and bisyllabic words (e.g., *balcon*, /bal-kõ/). Both types of words were processed rather similarly, with writing speeds and pause durations indicative of a two-part structure. Although the latter studies were also conducted in French, one should not infer that the influence of consonant/vowel alternation on letter string segmentation is restricted to this language. Indeed, the initial proposal was formulated by Hansen and Rodgers (1965) for English. Yet, further studies in other languages would be useful to assess whether the hypothesis holds cross-linguistically.

In sum, the present findings point to the lack of a full isomorphism between (spoken) syllabic and orthographic structure. It would thus be cautious to adopt different terms to address perceptual and production units in speech – the traditional notion of syllable – and in writing. Accordingly, Caramazza and Miceli (1990) introduced the term 'graphosyllable' to refer to syllable-sized units in the visual modality. Empirically, it would be useful to examine the implications of such a distinction for quantitative measures of lexical properties such as number of units for complex words or neighborhood and similarity characteristics. At the theoretical level, the present data point to the need for more systematic studies of the orthographic structuration of long and complex words, in order to disentangle visuo-orthographic from phonological influences and to understand the time course and locus of this structuration process.

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Notes

1. In the schwa set, the fact that the silent letter is included *within* a syllable enabled us to assess whether participants parsed the corresponding unit into two smaller units based on this silent letter. In the mismatch set, the words exhibited an ambiguous letter *at the boundary* of two syllables, which made it possible to assess to which unit (the preceding or following one) the critical letter was attached.
2. An additional segmentation was also allowed for a few items in the four sets with *i* + vowel because in such words the letter *i* could be realized either as a semi-vowel (/j/) or as a full vowel.

References

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

Brand, M., Giroux, I., Puijalon, C., & Rey, A. (2007). Syllable onsets are perceptual reading units. *Memory & Cognition*, *35*, 966–973.

Caramazza, A., & Miceli, G. (1990). The structure of graphemic representations. *Cognition*, *37*, 243–297.

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.

Chetail, F., & Mathey, S. (2009a). Syllabic priming in lexical decision and naming tasks: The syllable congruency effect re-examined in French. *Canadian Journal of Experimental Psychology*, *63*, 40–48.

Chetail, F., & Mathey, S. (2009b). The syllable frequency effect in visual recognition of French words: A study in skilled and beginning readers. *Reading and Writing*, *22*, 955–973.

Chetail, F., & Mathey, S. (2010). InfoSyll: A syllabary providing statistical information on phonological and orthographic syllables. *Journal of Psycholinguistic Research*, *39*, 485–504.

Clements, G. N. (1990). The role of the sonority cycle in core syllabification. In J. Kingston and M. Beckman (Eds.), *Laboratory Phonology 1* (pp. 283–333). Cambridge: Cambridge University Press.

Coltheart, M. (1978). Lexical access in simple reading tasks. In G. Underwood (Ed.), *Strategies of information processing* (pp. 151–216). San Diego, CA: Academic Press.

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.

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.

Content, A., Kearns, R. K., & Frauenfelder, U. H. (2001). Boundaries versus onsets in syllabic segmentation. *Journal of Memory and Language*, *45*, 177–199.

Content, A., Mousty, P., & Radeau, M. (1990). BRULEX : une base de données lexicale informatisée pour le français écrit et parlé. *L'année Psychologique*, *90*, 551–566.

Delattre, P. (1966). *Studies in French and comparative phonetics: Selected papers in French and English*. La Haye: Mouton.

Dell, F. (1995). Consonant clusters and phonological syllables in French. *Lingua*, *95*, 5–26.

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.

Doignon-Camus, N., Zagar, D., & Mathey, S. (2009). Can we see syllables in monosyllabic words? A study with illusory conjunctions. *European Journal of Cognitive Psychology*, *21*, 599–614.

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

Erdmann, B., & Dodge, R. B. (1898). *Psychologische Untersuchungen fiber das Lesen auf experimenteller Grundlage*. Halle: Niemeyer.

Ferrand, L., & New, B. (2003). Syllabic length effects in visual word recognition and naming. *Acta Psychologica*, *113*, 167–183.

Goslin, J., & Floccia, C. (2007). Comparing French syllabification in preliterate children and adults. *Applied Psycholinguistics*, *28*, 341–367.

Goslin, J., & Frauenfelder, U. H. (2001). A comparison of theoretical and human syllabification. *Language and Speech, 44*, 409–436.

Goslin, J., Content, A., & Frauenfelder, U. (1999). *Syllable segmentation: Are humans consistent?* Proceedings of EuroSpeech99, *4*, 1683–1686. Budapest, Hungary: ESCA.

Hansen, D., & Rodgers, T. (1965). An exploration of psycholinguistic units in initial reading. In *Proceedings of the Symposium on the Psycholinguistic Nature of the Reading Process*. Detroit: Wayne State University Press.

Hooper, J. B. (1972). The syllable in phonological theory. *Language*, *48*, 525–540.

Kandel, S., Hérault, L., Grosjacques, G., Lambert, E., & Fayol, M. (2009). Orthographic vs. phonologic syllables in handwriting production. *Cognition*, *110*, 440–444.

Laporte, E. (1992). Phonetic syllables in French: Combinatorics, structure and formal definitions. *Acta Linguistica Hungarica, 41*, 175–189.

New, B., Pallier, C., Brysbaert, M., & Ferrand, L. (2004). Lexique 2: A new French lexical database. *Behavior Research Methods, Instruments, & Computers*, *36*, 516–524.

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.

Perry, C., Ziegler, J. C., & Zorzi, M. (2010). Beyond single syllables: Large-scale modeling of reading aloud with the Connectionist Dual Process (CDP++) model. *Cognitive Psychology*, *61*, 106–151.

Prinzmetal, W., Hoffman, H., & Vest, K. (1991). Automatic processes in word perception: An analysis from illusory conjunctions. *Journal of Experimental Psychology: Human Perception and Performance*, *17*, 902–923.

Prinzmetal, W., Treiman, R., & Rho, S. H. (1986). How to see a reading unit. *Journal of Memory and Language*, *25*, 461–475.

Pulgram, E. (1970). *Syllable, word, nexus*, *cursus*. The Hague: Mouton & Co.

Racine, I., & Grosjean, F. (2002). La production du E caduc facultative est-elle prévisible? Un début de réponse. *Journal of French Language Studies*, *12*, 307–326.

Rapp, B. C. (1992). The nature of sublexical orthographic organization: The bigram trough hypothesis examined. *Journal of Memory and Language*, *31*, 33–53.

Rouibah, A., & Taft, M. (2001). The role of syllabic structure in French word recognition. *Memory & Cognition*, *29*, 373–381.

Schiller, N. O., Meyer, A. S., & Levelt, W. J. M. (1997). The syllabic structure of spoken words: Evidence from the syllabification of intervocalic consonants. *Language and Speech*, *40*, 103–140.

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* (pp. 245–263). Hillsdale: Lawrence Erlbaum Associates.

Selkirk, E. O. ([1982] 1999). The syllable. In J. A. Goldsmith (Ed.), *Phonological theory: The essential readings* (pp. 328–350). Malden: Blackwell Publishers.

Spoehr, K. T., & Smith, E. E. (1973). The role of syllables in perceptual processing. *Cognitive Psychology, 5*, 71–89.

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

Taft, M. (1979). Lexical access via an orthographic code: The basic orthographic syllabic structure (BOSS). *Journal of Verbal Learning and Verbal Behavior*, *18*, 21–39.

Taft, M. (2001). Processing of orthographic structure by adults of different reading ability. *Language and Speech*, *44*, 351–376.

Taft, M., & Radeau, M. (1995). The influence of the phonological characteristics of a language on the functional units of reading: A study in French. *Canadian Journal of Experimental Psychology*, *49*, 330–346.

Treiman, R., & Danis, C. (1988). Syllabification of intervocalic consonants. *Journal of Memory and Language*, *27*, 87–104.

Treiman, R., & Zukowski, A. (1990). Towards an understanding of English syllabification. *Journal of Memory and Language*, *29*, 66–85.

Treiman, R., Bowey, J. A., & Bourassa, D. (2002). Segmentation of spoken words into syllables by English-speaking children as compared to adults. *Journal of Experimental Child Psychology*, *83*, 213–238.

Venezky, R. L., & Suraj, M. (1993). Automatic syllabication for on-line reading tutor. *Behavior Research Methods*, *Instruments*, *& Computers*, *25*, 67–75.

Appendix 1

Words used in Experiment 1 according to the different sets and subsets, along with the relevant results.

Words in the base, mismatch, and cluster sets are presented with their dominant segmentation. Segmentation agreement is indicated in parentheses.

Base set

ca-ché (0.98), plu-mer (1.00), choi-si (0.99), pen-ché (0.99), pom-per (0.99), ca-fard (0.96), la-bour (0.97), fa-cial (0.94), mu-guet (0.98), pi-quer (0.97), ba-veux (0.92), pla-teau (0.98), traî-ner (0.97), chau-vin (0.99), pen-cher (0.99), fon-ceur (0.99), po-choir (0.93), mi-ssion (0.65), ba-bouin (0.72), fu-gueur (0.93), li-bé-ral (0.95), ca-bi-net (0.98), dé-ca-ler (0.95), dé-ci-der (0.95), a-mu-sant (0.88), ba-lan-cer (0.99), sin-gu-lier (0.96), sen-sa-tion (0.99), no-ta-mment (0.52), di-men-sion (0.98), cou-tu-mier (0.97), in-ven-tion (1.00), in-fé-rieur (0.93), in-tui-tion (0.97), plai-san-ter (0.96), dé-pou-iller (0.34), quan-ti-fier (0.95), rou-cou-lant (1.00), dou-lou-reux (0.99), in-sou-cieux (0.98).

Mismatch set

H: ba-hut (0.98), tra-hir (0.97), cha-hut (0.98), ca-hier (0.90), en-va-hir (0.94), co-hé-rent (0.97), co-hé-sion (0.98), pro-hi-ber (0.96). **E**: gaie-ment (0.87), paie-ment (0.82), a-boie-ment (0.79), bé-gaie-ment (0.81), dé-noue-ment (0.80), tu-toie-ment (0.77), en-goue-ment (0.84). **P**: bap-ti-ser (0.60), comp-teur (0.63), comp-tant (0.61), comp-toir (0.63). **LL**: bi-llet (0.47), bri-ller (0.58), gri-ller (0.55), til-leul (0.45), ha-bi-ller (0.54), pa-pi-llon (0.64), ma-qui-ller (0.58), poin-ti-llé (0.53). **Y**: cra-yon (0.63), jo-yeux (0.56), bru-yant (0.64), cro-yant (0.64), fra-yeur (0.59), vo-ya-geur (0.66), plai-do-yer (0.53), ne-tto-yeur (0.31), ra-yo-nnant (0.36).

Cluster set

FL: a-vril (0.74), li-vret (0.94), ron-fler (0.99), con-flit (0.99), poi-vron (0.99), né-vro-sé (0.98), dé-gon-flé (0.98), dé-cou-vrir (0.93), con-fron-ter (0.99). **FP**: pos-ter (0.88), as-pect (0.90), cris-tal (0.71), caf-teur (0.83), cris-pant (0.87), dis-pa-ru (0.87), dis-pu-ter (0.90), dé-ses-poir (0.89), mous-ta-chu (0.73), cons-ti-tuer (0.39). **LF**: ber-ger (0.98), val-ser (0.95), ser-gent (0.99), cal-cium (0.96), bour-geon (0.94), par-fu-mé (0.91), mar-gi-nal (0.95), pré-ser-ver (1.00), per-so-nnel (0.48), re-mer-cier (0.96). **PF**: fa-xer (0.93), bud-get (0.79), bo-xeur (0.85), lap-sus (0.76), soup-çon (0.72), ma-xi-mum (0.82), fi-xa-tion (0.93), é-rup-tion (0.55), con-cep-tion (0.79), soup-ço-nner (0.38).

For words in the schwa set, mode and response strength (in terms of number of syllables) are presented in parentheses respectively.

Schwa set

Internal schwa: samedi (3, 0.97), ennemi (3, 0.88), achevé (3, 0.94), avenue (3, 0.88), biberon (3, 0.99), médecin (3, 0.98), caleçon (3, 0.91), matelot (3, 0.98), javelot (3, 0.99), loterie (3, 0.95), matelassé (4, 0.90), papeterie (4, 0.91), confiserie (4, 0.94), démanteler (4, 0.96), étiqueter (4, 0.88), déchiqueter (4, 0.97), pâtisserie (4, 0.96), enseveli (4, 0.96), développé (4, 0.95), renouveler (4, 0.93). Final schwa: virage (3, 0.68), endive (3, 0.65), futile (3, 0.62), mâchoire (3, 0.73), racine (3, 0.69), volume (3, 0.66), douzaine (3, 0.61), patate (3, 0.88), équipe (3, 0.74), baignade (3, 0.73), avantage (4, 0.61), confidence (4, 0.65), convoitise (4, 0.53), diagonale (4, 0.59), infantile (3, 0.52), volontaire (4, 0.62), limousine (4, 0.57), chromosome (4, 0.65), camarade (4, 0.82), dominante (4, 0.76).

Appendix 2

Experimental words used in Experiment 2, presented by pair according to word type.

Schwa words	Control words
éperon	mépris
appeler	remplir
bibelot	cribler
biberon	nombril
gobelet	doubler
laverie	poivron
loterie	central
poterie	contrée
chapelet	panoplie
couperet	monoprix
penderie	escadron
laideron	chaudron
capeline	peuplier
lapereau	lamproie
banderole	encadrant
chapelure	monoplace
pipelette	simplette
betterave	spectrale
sauterelle	symétrique
banderille	espadrille