Research Article

Orthographic and Morphemic Effects in the Written Syllable Counting Task

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Abstract. According to a recent hypothesis, the organization of letters into groups of successive consonants and vowels (i.e., CV pattern) constrains the orthographic structure of words. Here, we examined to what extent the morphological structure of words modifies the influence of the CV pattern in a syllable counting task. Participants were presented with written words matched for the number of syllables and comprising either one vowel cluster less than the number of syllables (hiatus words, e.g., *création*) or the same number of vowel clusters (control words, e.g., *crépiter*). Participants were slower and less accurate for hiatus than control stimuli, be it words (Experiments 1, 3) or pseudowords (Experiment 2). More importantly, this hiatus effect was present even when the stimuli had a morphemic boundary falling within the hiatus (e.g., *ré-agir*). The results suggest that the CV pattern of items more strongly influences performance in the syllable counting task than the morphological structure.

Keywords: CV pattern, morphemes, prefix, hiatus, written word processing

The issue of polysyllabic word reading has been of high interest in the last decades, and there is now converging evidence that large units such as morphemes or syllables are activated during visual word recognition (see Amenta & Crepaldi, 2012; Chetail, 2012, for reviews on morphemic and syllabic effects respectively). However, little is known about how these units interact during word processing, the role of each unit being usually investigated separately. In the present study, we examined the interactions between the syllabic, orthographic, and morphemic structure of letter strings during written processing.

A large number of studies have demonstrated that syllabic units are activated during written word processing. For example, words with syllables of high frequency are processed more slowly than words with syllables of low frequency (e.g., Carreiras, Alvarez, & de Vega, 1993, in Spanish; Conrad & Jacobs, 2004, in German). The effect has been accounted for in terms of competition between words sharing the initial phonological syllable (referred to as syllabic neighbors). During lexical access, syllabic neighbors are activated and compete with the target, thus delaying its processing. Competition would be stronger when there are numerous syllabic neighbors, that is, when the target contains a high-frequency syllable rather than a low-frequency one (Carreiras et al., 1993). Inhibitory effects of syllabic neighborhood have also been confirmed in masked priming experiments (e.g., Carreiras & Perea, 2002; Domínguez, de Vega, & de Cuetos, 1997; in Spanish; Mathey, Doignon-Camus, & Chetail, 2013, in French). For example, Mathey et al. (2013) showed that a French word like *rocher* (/ʀɔ.ʃe/) which has a first syllable of low frequency was recognized more slowly when it was preceded by a pseudoword prime sharing the first syllable (e.g., *robane*, /ʀɔban/) rather than the first letters (e.g., *roisie*, /ʀwasi/).

The proposition that polysyllabic words are parsed into letter clusters corresponding to phonological syllables contrasts with the recent work of Chetail and Content (2012, 2013, 2014, in French; Chetail, Scaltritti, & Content, 2014, in Italian) suggesting that the segmentation of words into small units is primarily driven by orthographic cues. According to this hypothesis, the organization of consonant and vowel letters within words (i.e., the CV pattern) constrains the perceptual structure of letter strings, with each vowel or vowel cluster underlying one orthographic unit. Hence, a word like *feeling* would be structured into two units during visual word processing not because it entails two phonological syllables but because it has two vowel clusters (e.g., *ee* and *i*). The first evidence for this hypothesis was reported in French using written words in a forced-choice syllable counting task. Some words – referred to as hiatus words – had a number of vowel clusters that mismatched for the number of phonological syllables due to the presence of adjacent vowels that are pronounced

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separately (e.g., *client*, /kli.jɑ̃/, two syllables but one vowel cluster) while control words had the same number of syllables and vowel clusters (e.g., *flacon*, /fla.kõ/, two syllables, two vowel clusters). Participants were slower and less accurate to count the number of syllables in hiatus words than in control words, and erroneous responses for hiatus words most often corresponded to the number of vowel clusters (i.e., responses "1 syllable" for *client*), while control words led to random errors (e.g., similar rate of errors "1 syllable" and "3 syllables" for *flacon*). The effect was interpreted as a conflict between the perceptual orthographic structure derived from the distribution of vowel and consonant letters (e.g., *client*, one unit), and the phonological syllabic structure activated later on (e.g., /kli-jɑ̃/, two units), especially through subvocal pronunciation. The mismatch between the two structures leads either to errors in favor of vowel-centerd units, or to longer processing, necessary to solve the conflict. Accordingly, Chetail and Content (2012) showed that when the intentional resort to phonology was reduced (concurrent articulation), the influence of orthographic information increased, leading to a stronger hiatus effect.

Hiatus words are particularly appropriate to disentangle orthographic and phonological activation during visual word recognition, due to the mismatch between orthographic vowel-centerd units and phonological syllables. However, many hiatus words entail a prefix that precisely creates the hiatus pattern (e.g., *réagir*, *proactif*, *triathlon*, in French), so hiatus effects could ensue from affixation. Two units would be perceived in *réagir* (*react* in English) not because the word entails two vowel clusters, but because a segmentation based on the prefix leads to two units (e.g., *ré-agir*). The plausibility of this hypothesis is supported by the numerous studies showing that polysyllabic words are decomposed into morphological units during visual word recognition. For example, the processing of a prefixed word (e.g., *REVIVE*) is facilitated by a prefixed prime sharing its root (e.g., *survive*) compared to a control prime, both with visible and non-visible primes (e.g., Forster & Azuma, 2000; Marslen-Wilson, Tyler, Waksler, & Older, 1994, in English; but see Feldman, Bara-Cikoja, & Kostic, 2002, in Serbian). Moreover, morphological units are activated early during the time course of word processing, and constrain the access to orthographic word representations independently of their meaning (e.g., Duñabeitia, Perea, & Carreiras, 2007 in Spanish; Longtin, Segui, & Hallé, 2003, in French; Rastle, Davis, & New, 2004 in English, but see Feldman, O'Connor, & Martín, 2009, for alternative results in English). For example, Rastle et al. (2004) found a priming effect both when primes and targets shared a semantically transparent morphological relationship (e.g., *cleaner – CLEAN*) and when they shared an apparent morphological relationship with no semantic overlap (e.g., *corner – CORN*) but not when they had an orthographic relationship without semantic or apparent morphological relationship (e.g., *brothel – BROTH*). According to the authors, this suggests that words entailing a morphological surface structure (e.g., *cleaner*, *corner*) are early segmented into morphemic units, and morphemic units activate in turn lexical representations in the orthographic lexicon.

Given the potential confound between hiatus pattern and affixation, the aim of the present study was to examine whether the impact of the orthographic CV structure of letter strings is influenced by morphemes units or not. There is some evidence that morphological effects are independent of syllabic effects during word processing in Spanish (e.g., Alvarez, Carreiras, & Taft, 2001; Domínguez, Alija, Cuetos, & de Vega, 2006). For example, capitalizing on the fact that the first bigram *RE* in words corresponds either to a syllabic unit only (e.g., *regallo*) or also to a prefix (e.g., *reaccion*), Domínguez et al. (2006) showed that the processing of a prefixed target word like *REFORMA* was delayed in the lexical decision task when it was preceded by a syllabic prime (e.g., *regallo*) but facilitated when it was preceded by a morphemic prime (e.g., *reaccion*), thus suggesting that the effects occur through two different pathways. However, no study has tried to disentangle the role of vowel-centerd units and morphemes so far, and given that both the CV structure and the morphemic structure of words are assumed to be activated at an orthographic level of processing, it is not clear whether and how these two levels of processing interact.

To disentangle the putative role of morphemes and vowel-centerd orthographic units during visual word recognition, we capitalized on the fact that some hiatus words are prefixed (e.g., *réagir*) whereas others are not (e.g., *création*). Hiatus words were compared to control words in a syllable counting task, and half of the hiatus words had a prefix (e.g., *ré* in *réagir*) so that the morphemic boundary fall within the hiatus cluster (e.g., *ré-agir*), while the other half included hiatus words for which the hiatus was not morphologically constructed (e.g., *création*, *cré* is not a prefix). We expected hiatus words to be processed more slowly, less accurately, and to lead to more underestimation errors than control words (Chetail & Content, 2012). If this effect genuinely stems from the CV pattern of words, it should be present for both prefixed and non-prefixed items. If the effect is confounded with a morphemic effect, only prefixed items should present a bias (e.g., only words like *réagir* should tend to be responded two units because morphological decomposition leads to two salient morphemic units, *ré-agir*). If morphological and orthographic information are jointly activated, the salient morphemic structure should help to accurately decompose words into syllables, leading to a weaker hiatus effect for prefixed hiatus words than for non-prefixed hiatus words. Indeed, since the morphemic boundary falls within the hiatus cluster, prefix processing should help to break the hiatus cluster into two distinct units (e.g., extracting *ré* in *agir* helps to process separately *ré* and *agir*), thereby breaking the vowel cluster and leading to a structure with the same number of vowel clusters (e.g., *é*, *a*, and *i*) than the number of syllables.

Experiment 1

Method

Participants

Twenty-one native French speakers with normal or corrected-to-normal vision participated in the experiment for course credits.

Stimuli

Twenty-eight triplets of words were selected from the Lexique database (New, Pallier, Brysbaert, & Ferrand, 2004), half being three-syllables words, the other half being four-syllable words.[1] Two words in each triplet had an orthographic hiatus, that is a sequence of two adjacent vowel letters mapping onto two phonemes. In one word, the hiatus was created by the addition of the prefixes *co*, *pré*, *pro* or *ré* to a base word (prefixed hiatus words: e.g., *réaction*) whereas the other word began by a similar bigram or trigram which was not a prefix (non-prefixed hiatus word: e.g., *création*). The two hiatus words had one vowel cluster less than the number of syllables (e.g., *réaction*, *création*: three syllables but two vowel clusters). In contrast, the number of syllables of the third word in the triplet was identical to its number of vowel clusters (control words, e.g., *crépiter*: three syllables, three vowel clusters). Words were matched on word frequency, number of letters, number of syllables, density of orthographic neighborhood (OLD20), and summed bigram frequency (all *p*s > .28). Twenty-eight three- or four-syllable fillers were added so that there was the same number of hiatus and control words, and 56 bisyllabic fillers were added so that the same number of "2," "3," and "4" responses could be elicited. To sum up, the whole set of items contained 168 stimuli, with 84 experimental items (56 hiatus words and 28 control words), and 84 fillers (see Appendix A).

Procedure

Participants performed a syllable counting task programmed with the Psychtoolbox extension (Brainard, 1997). Each trial started by a fixation cross for 500 ms in the center of the screen, followed by a lowercase word which remained on the screen until the participants responded. Words were displayed in Courier New font. Participants had to decide as quickly and as accurately as possible whether the target word had two, three, or four syllables. To give their responses, they had to press one of three contiguous keys on the keyboard with the three central fingers of their dominant hand. The leftmost finger was used to respond two syllables, the forefinger to respond three syllables, and the rightmost finger to respond four syllables. Response times were measured from target onset. Participants performed nine practice trials before receiving the 168 trials in a variable random order.

Table 1. Mean reaction times and error rates in Experiment 1 (examples in brackets)

	RTs (Error rates)	Difference
Control words (*crépiter*)	1,451 (9.7)	
Non-prefixed hiatus words (*création*)	1,551 (20.2)	100 (10.5)
Prefixed hiatus words (*réunion*)	1,563 (19.6)	112 (9.9)

Note. Differences are computed against the condition of control words.

Results

The mean correct reaction times and mean error rates averaged over participants are presented in Table 1. The data were submitted to separate analyses of variance on the participant means (*F*1) and on the item means (*F*2) with word type (prefixed hiatus, non-prefixed hiatus, control) as main factor.

Reaction Times

There was a main effect of word type, $F1(2, 40) = 4.81$, $p = .01$, $F2(2, 81) = 4.87$, $p = .01$. Planned comparisons showed that hiatus words (prefixed and non-prefixed) were processed more slowly than control words, $F1(1, 20) = 8.17$, $p = .01$, $F2(1, 81) = 9.53$, $p = .003$, while there was no difference between prefixed and non-prefixed hiatus words, $F < 1$.

Error Rates

The same pattern as in reaction times was found. The effect of word type was significant, $F1(2, 40) = 14.39$, $p < .001$, $F2(2, 81) = 6.84$, $p = .002$. Hiatus words elicited more errors than control words, $F1(1, 20) = 23.63$, $p < .001$, $F2(1, 81) = 13.64$, $p < .001$, but there was no difference between the two conditions of hiatus words, $F < 1$.

Nature of Errors

For trisyllabic words, errors reflect an underestimation or overestimation of the number of syllables (responses "two syllables" and "four syllables" respectively). We examined the effect of error type (two vs. four syllables) as a function of word type (prefixed vs. non-prefixed

[1] Contrary to Chetail and Content (2013), it was not possible to use bi- and tri-syllabic words. This led us to ask the participants to decide whether the items had two, three, or four syllables instead of one, two, or three.

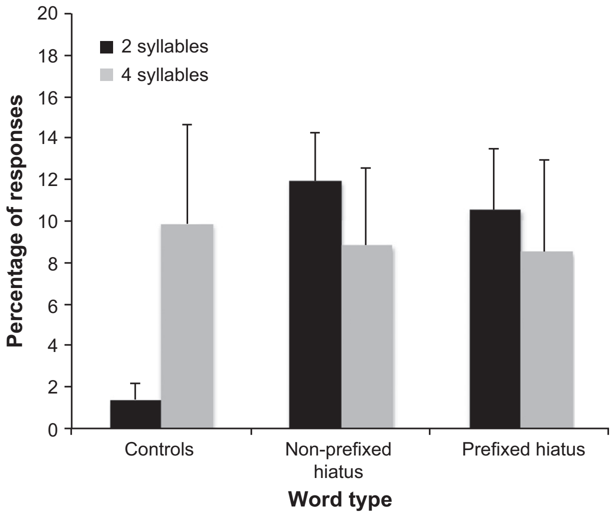

Figure 1. Nature of errors for trisyllabic words in Experiment 1 (with standard errors).

hiatus words). As shown Figure 1, there was an interaction between the variables, $F(2, 40) = 9.01$, $p < .001$, showing that the proportion of overestimation (four syllables responses) was not different across conditions, $F < 1$, whereas the proportion of underestimation (two syllables) was, $F(2, 40) = 10.78$, $p < .001$. Hiatus words led to more underestimation errors than control words, $F(1, 20) = 25.88$, $p < .001$, and there was no difference between prefixed and non-prefixed hiatus words, *F*s < 1.

Discussion

The results show that participants were slower and less accurate to count the number of syllables in hiatus words (e.g., *création*) than in control words (e.g., *crépiter*), and when they failed, they were more prone to underestimate the number of syllables for hiatus than control words. This replicates the findings reported by Chetail and Content (2012) according to which the CV pattern constrains the orthographic structure of letter strings. More importantly, underestimation occurred both in prefixed (e.g., *réunion*) and non-prefixed (e.g., *création*) hiatus words. This suggests that on the one hand the hiatus effect cannot be reduced to a morphemic effect, and on the other hand that the presence of a prefix at word beginning does not significantly help readers to break the hiatus cluster into two units.

The nature of errors (underestimation or overestimation) for hiatus words shows that items were structured into letter clusters organized around vowel groups. However, it is not possible to decide whether this occurs because vowels are used as anchor points to determine the core of two units (e.g., *éa* and *io* in *réaction*), or because intersyllabic consonants (e.g., *ct*) are used as anchor points to perceive a boundary between vowel clusters, leading in the end to two units (e.g., *réac-tion*). The role of vowels as core of units necessarily depends on the presence of consonants at boundaries, and vice versa, the role of consonants as anchor points that help to delimit boundaries between units depends on the presence of vowels. It seems therefore more appropriate to interpret the results in terms of *CV pattern* (i.e., the arrangement of both vowels and consonants) rather than only in terms of vowels or only in terms of consonants.

Before discussing these results in more detail, we wanted to confirm the findings in a second experiment, in which we used pseudowords instead of words. The rationale for using pseudowords is that they cannot be recognized as a whole, thereby increasing the likelihood of activating smaller access units that correspond to morphemes (Burani, Dovetto, Thornton, & Laudanna, 1997). In addition, the use of pseudowords made it possible to run the experiment with a larger set of stimuli than in Experiment 1, with better controls. Pseudowords were devised from extant words, leading to either hiatus pseudowords (e.g., *créouvrir*, *préouvrir*, from the word *ouvrir*, "to open") or control pseudowords (e.g., *créporter*, *préporter*, from *porter*, "to carry") (see Taft & Nillsen, 2013; Taft, Hambly, & Kinoshita, 1986, for the use of similar stimuli in English). Similarly to Experiment 1, half of these pseudowords were constructed by adding a prefix (e.g., *pré* in *préouvrir*, *préporter*) or a control bigram/trigram (e.g., *cré* in *créouvrir*, *créporter*) at the beginning of the extant words (see Laudanna, Burani, & Cermele, 1994, for a similar method). As in Experiment 1, we expected hiatus pseudowords to be processed less efficiently than control pseudowords. Furthermore, given that prefixed pseudowords were built so that their meaning was interpretable from the meaning of their morphemic constituents (e.g., *préouvrir*: to start opening something without fully opening it), this should increase the likelihood of the participants relying on morphological decomposition (Schreuder & Baayen, 1995).

Experiment 2

Method

Participants

A new group of twenty-one native French speakers with normal or corrected-to-normal vision participated in the experiment for course credits.

Stimuli

We used 32 quadruplets of pseudowords so that the type of items (hiatus vs. control) and the initial part of items (prefix vs. non-prefix) were orthogonally manipulated. First, we selected pairs of monomorphemic verbs and adjectives in Lexique (New et al., 2004) matched on number of letters,

Table 2. Mean reaction times, error rates (in brackets) and examples (in italics) in Experiment 2

	Control pseudowords	Hiatus pseudowords	Difference
Non-prefixed	*créporter*: 1,964 (6.5)	*créouvrir*: 2,240 (16.5)	276 (10.0)
Prefixed	*préporter*: 1,828 (7.7)	*préouvrir*: 2,150 (14.3)	322 (6.6)

number of syllables, and word frequency. One word began with a consonant and the other with a vowel (e.g., *porter* and *ouvrir* respectively). Then, we selected a set of monosyllabic prefixes ending with a vowel (*pré*, *co*, *dé*, *tri*, *pré*) and matched with a set of non-prefix bigrams and trigrams (*cré*, *bo*, *gé*, *fri*, *cri*, *pri*, *lé*, *fé*, *po*, *sé*) which were as close as possible to the prefixes in terms of structure and frequency (token bigram and trigram frequencies were computed on Lexique). Finally, we combined the two types of bigrams/trigrams with the pair of words, leading to two prefixed pseudowords (e.g., *préouvrir*, *préporter*) and two non-prefixed pseudowords (e.g., *créouvrir*, *créporter*), one in each pair being a hiatus item (e.g., *préouvrir*, *créouvrir*) and the other one being a control item (e.g., *préporter*, *créporter*). Initially, we created 60 quadruplets. To ensure that the meaning of the prefixed pseudowords was transparent, we conducted a pre-test with 16 new participants who had to decide on a 5-point Likert scale how easy it was to give a meaning to the pseudowords. For the experiment, we selected 32 of the quadruplets that included prefixed pseudowords highly transparent in meaning and which were matched with the non-prefixed items on number of letters, OLD20, and summed bigram frequency ($ps < .001$).[2] Sixty-four bisyllabic fillers – created from an extant word – were added so that the same number of "2," "3," and "4" responses could be elicited. In total, the experiment included 192 pseudowords, with 128 experimental pseudowords and 64 fillers (see Appendix B).

Procedure

The procedure was identical to that of Experiment 1 except that the participants were told that items were pseudowords, some of them looking like words.

Results

The mean correct reaction times and mean error rates averaged over participants are presented in Table 2. Reaction times above 7,000 ms were excluded (0.55% of the data). A posteriori, we noticed that three of the base words used to create the pseudowords were ambiguous concerning their number of syllables, especially in the Belgian dialect (*avouer*, *échouer*, and *diminuer*, often segmented in /a.vu.e/, /e.ʃu.e/, and /di.mi.ny.e/ respectively). The six pseudowords created from these items were removed from the analyses. The data were submitted to separate analyses of variance on the participant means ($F1$) and on the item means ($F2$) with pseudoword type (hiatus, control) and initial part of item (prefix, non-prefix) as main factors.

Reaction Times

Hiatus pseudowords were processed more slowly than control pseudowords, $F1(1, 20) = 25.82$, $p < .001$, $F2(1, 59) = 24.42$, $p < .001$, and prefixed items were processed more rapidly than non-prefixed items, $F1(1, 20) = 6.74$, $p = .017$, $F2(1, 59) = 10.28$, $p = .002$. Pseudoword type and initial part of item did not interact, $Fs < 1$.

Error Rates

Hiatus pseudowords elicited more errors than control pseudowords, $F1(1, 20) = 7.74$, $p = .011$, $F2(1, 59) = 16.43$, $p < .001$. The effect of initial part of item was not significant, $Fs < 1$, and did not interact significantly with pseudoword type, $F1(1, 20) = 2.16$, $p = .16$, $F2(1, 59) = 2.35$, $p = .13$.

Nature of Errors

The examination of underestimation (two syllables) and overestimation (four syllables) responses for trisyllabic words showed an interaction between the type of pseudowords and the type of errors, $F(1, 20) = 4.96$, $p = .038$. The number of overestimations (four syllables responses) was not different for hiatus and controls, $F < 1$, but there was more underestimation errors (two syllables) for hiatus pseudowords, $F(1, 20) = 5.55$, $p = .029$. As presented in Figure 2, the difference of underestimation errors between control and hiatus pseudowords was present both in the non-prefixed, $F(1, 20) = 5.49$, $p = .03$ and in the prefixed, $F(1, 20) = 5.03$, $p = .04$, conditions (no effect on overestimation errors in both conditions, $ps > .16$).

Discussion

Experiment 2 confirms the findings of Experiment 1 with a larger set of items. The hiatus effect is present for both

[2] A posteriori, we found that hiatus and control words were not matched on phonological neighborhood in Experiments 2 and 3 (higher PLD20 for control words), but covariate analyses showed that the hiatus effect remains highly significant when the effect of PLD20 is controlled.

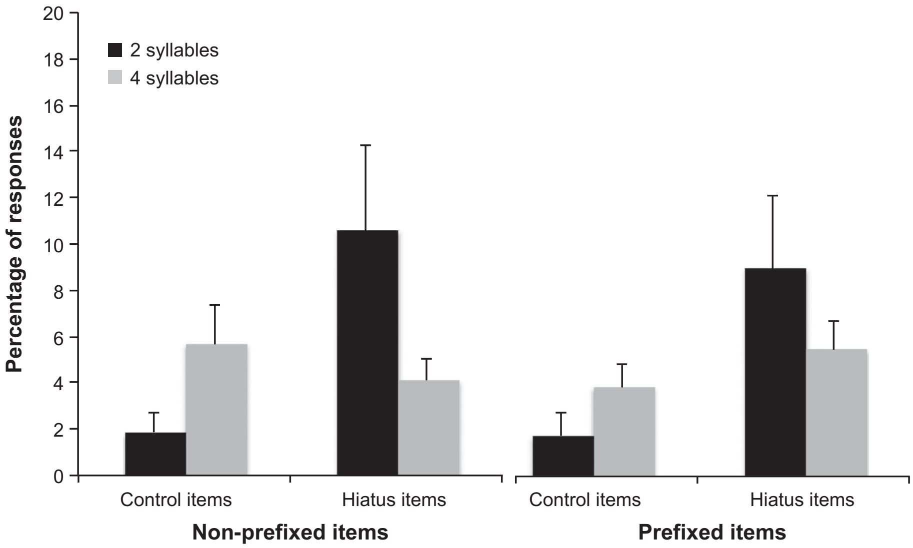

Figure 2. Nature of errors for trisyllabic words in Experiment 2 (with standard errors).

prefixed and non-prefixed hiatus pseudowords, without any difference between the two conditions. This suggests that the CV structure of letter strings influences word processing independently of their morphemic structure.

Interestingly, we found a prefix effect, responses for prefixed pseudowords (e.g., *préporter, préouvrir*) being faster than non-prefixed ones (e.g., *créporter, créouvrir*). This facilitation may result from a morphemic decomposition of the target items, leading to the co-activation of the prefix and base word representations. Prior studies reported that it is more difficult to make a lexical decision and easier to name pseudowords that entail a base word plus a prefix than matched pseudowords not made up of such morphemes (Burani & Laudanna, 2003 in naming; Laudanna et al., 1994; Taft et al., 1986 in lexical decision). In both cases, processing is modified by the greater word-likeness of prefixed pseudowords. Hence, given that our participants declared that they resorted to subvocal pronunciation to perform the task (in both experiments), one hypothesis is that the morphemic structure of pseudowords, especially those with the clearest structure (prefixed pseudowords) could have helped them to perform subvocalization, leading to faster responses overall. This explanation is detailed in the General Discussion.

The failure to observe an interaction between word type and prefixation in Experiments 1 and 2 might, nonetheless, result from potential confounds. Many hiatus words had an accent on the hiatus pattern, and this salient visual clue toward hiatus could have prevented the perception and processing of prefixes. Second, most of the control stimuli (especially in Experiment 1) contained only singleton vowels (e.g., *cognitive*, *cotiser*) while some of the hiatus words contain several complex vowel clusters (e.g., *coauteur*, *laotien*) which could explain that syllable counting was particularly difficult for hiatus words, independently of the hiatus pattern. We therefore conducted a third experiment to ensure that the absence of interaction between the morphemic structure and the CV pattern was not due to these confounds (words presented in uppercase without diacritic marks, and matched with control words on the number of complex vowel clusters).

Experiment 3

Method

Participants

Twenty-three new native French speakers with normal or corrected-to-normal vision participated in the experiment for course credits.

Stimuli

Twenty triplets of words of three or four syllables were selected similarly to Experiment 1 and controlled for the same variables, except that there were also matched on number of vowels. Twenty-eight three- or four-syllables fillers were added so that there was the same number of hiatus and control words, and 44 bisyllabic fillers were added so that the same number of "2," "3," and "4" responses could be elicited. The whole set of items contained 132 stimuli, with 60 experimental items (40 hiatus words and 20 control words) and 72 fillers (see Appendix C).

Procedure

The procedure was identical to that of Experiment 1 except that items were displayed in uppercase, without accent, since diacritics are omitted most of the time in upper-case French script.

Table 3. Mean reaction times and error rates in Experiment 3 (examples in brackets)

	RTs (Error rates)	Difference
Control words (*BOULIMIE*)	1,551 (11.1)	
Non-prefixed hiatus words (*TRUANDER*)	1,734 (16.3)	183 (5.2)
Prefixed hiatus words (*COAUTEUR*)	1,761 (19.6)	210 (8.5)

Note. Differences are computed against the condition of control words.

Results

The mean correct reaction times and mean error rates averaged over participants are presented in Table 3. A posteriori, we noticed that two control words eliciting a high error rate were ambiguous concerning their number of syllables in the Belgian dialect (*biologie* and *aviation*, often segmented in /bi.jɔ.lɔ.ʒi/ and a.vi.ja.sjɔ̃ respectively), and were therefore removed from the analyses. The data were submitted to separate analyses of variance on the participant means (*F*1) and on the item means (*F*2) with word type (prefixed hiatus, non-prefixed hiatus, control) as main factor.

Reaction Times

There was a main effect of word type, $F1(2, 44) = 8.68$, $p < .001$, $F2(2, 55) = 6.24$, $p = .004$. Planned comparisons showed that hiatus words (prefixed and non-prefixed) were processed more slowly than control words, $F1(1, 22) = 14.01$, $p = .001$, $F2(1, 55) = 12.43$, $p < .001$, while there was no difference between prefixed and non-prefixed hiatus words, *F*s < 1.

Error Rates

The effect of word type was also significant, $F1(2, 44) = 5.93$, $p = .005$, $F2(2, 55) = 3.93$, $p = .03$. Hiatus words elicited more errors than control words, $F1(1, 22) = 10.06$, $p = .004$, $F2(1, 55) = 6.64$, $p = .01$, but there was no difference between the two conditions of hiatus words, $F1(1, 22) = 1.75$, $p = .20$, $F2(1, 55) = 1.22$, $p = .27$.

Nature of Errors

As in Experiment 1, we examined the effect of error type (two vs. four syllables) as a function of word type. As shown in Figure 3, there was a significant interaction, $F(2, 44) = 7.87$, $p = .001$, showing that the proportion of overestimation ("four syllables" responses) was not different across conditions, $F(2, 44) = 2.26$, $p = .12$, whereas the proportion of underestimation ("two syllables" responses)

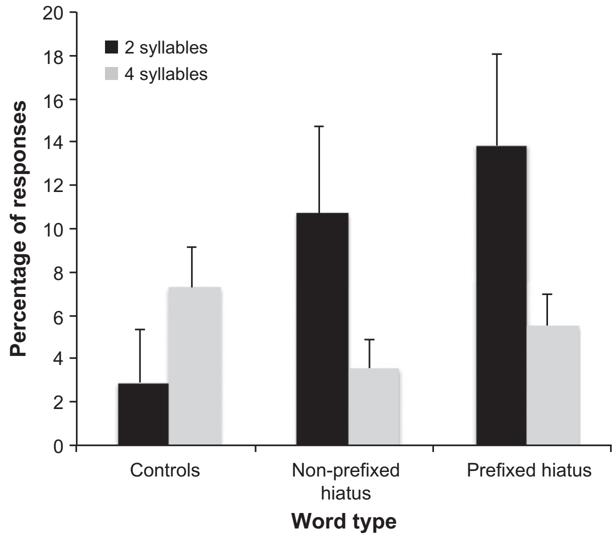

Figure 3. Nature of errors for trisyllabic words in Experiment 3 (with standard errors).

was, $F(2, 44) = 6.62$, $p = .003$. Hiatus words led to more underestimation errors than control words, $F(1, 22) = 10.22$, $p = .004$, and there was no difference between prefixed and non-prefixed hiatus words, $F(1, 22) = 1.30$, $p = .27$.

Discussion

Experiment 3 fully replicated the results of the previous experiments. Hiatus words were processed more slowly and less accurately than control words, leading to more underestimation errors. This effect was not modulated by the presence of prefix at word beginning, indicating that prefixes do not help to access syllabic structure of items when performing the task. The whole pattern of results cannot therefore be explained by confounds with diacritic marks or number of vowels.

Additional Analyses: Testing Evidence for the Null Hypothesis

The aim of the study was to examine whether the hiatus effect observed in the syllable counting task is influenced by the morphemic structure of words, and we predicted that if the effect genuinely stems from the orthographic CV pattern of letter strings, it should be present for both prefixed and non-prefixed items. In other words, the hiatus effect (i.e., difference of performance between controls and prefixed hiatus items) was expected to be not different between the two types of hiatus words. To test this prediction, we relied on inferential statistics and on the null-hypothesis significance testing (NHST), as typically done with this type of experimental designs. As detailed by Masson (2011), the NHST gives a *p* value that represents the conditional probability of the likelihood of an observed results (D), given that the null hypothesis (H_0) is correct (i.e., $p(D|H_0)$), but importantly, it does not provide any evidence for H_0. In the present study, the finding of no significant difference of hiatus effect according to the morphemic structure of items in the three experiments led us to conclude that the hiatus effect was similar for prefixed and non-prefixed items. However, support for this interpretation requires an evaluation the probability of the null hypothesis to be true, given the obtained results (i.e., $p(H_0|D)$). Importantly, the magnitude of $p(H_0|D)$ cannot be directly inferred from $p(D|H_0)$, but the Bayesian approach developed by Wagenmakers (2007) and exemplified by Masson (2011) makes it possible to compute $p(H_0|D)$. This requires a reliance on the Bayes theorem, which can be expressed by the following equation:

$$\frac{p(H_0|D)}{p(H_1|D)} = \frac{p(D|H_0)}{p(D|H_1)} \cdot \frac{p(H_0)}{p(H_1)} \quad (1)$$

This equation enables one to estimate the relative evidential support for the null and the alternative hypotheses (left side of the equation). The prior odds (right side) is usually assumed to equal 1, leading to favor neither H_0 nor H_1 (Rouder, Speckman, Sun, Morey, & Iverson, 2009). The Bayes factor (BF, in the middle) is therefore critical to determine the posterior odds (left side), which is of interest here.

Recently, Wagenmakers (2007) proposed a method to generate an estimate of BF using the Bayesian information criterion (BIC). We adopted this approach to estimate $p(H_0|D)$ following the tutorial provided by Masson (2011) to compute the intermediate values of ΔBIC and BF. To gain more support for one of the hypotheses, we aggregated the data across the three experiments (see Masson, 2011). Given that the designs were not the same, we first computed the word type effect for prefixed hiatus items (ΔHP, corresponding to $RT_{PrefixedHiatus} - RT_{Controls}$ in Experiments 1 and 3, and to $RT_{PrefixedHiatus} - RT_{PrefixedControls}$ in Experiment 2) and the hiatus effect for non-prefixed hiatus items (ΔHNP, corresponding to $RT_{Non\text{-}PrefixedHiatus} - RT_{Controls}$ in Experiments 1 and 3, and to $RT_{NonPrefixedHiatus} - RT_{NonPrefixedControls}$ in Experiment 2). At this point, remember that we found no difference between ΔHP and ΔHNP in the three experiments, and that we therefore expected to gain evidence in favor of the null hypothesis in the Bayesian analysis. To perform the analysis, we first ran a repeated-measure ANOVA with two conditions (ΔHP and ΔHNP) so that it was possible to extract the sum of squares for the error terms in the alternative and the null hypothesis models and to compute the Bayes factor. Second, we converted the Bayes factor into posterior probabilities. In the reaction times analyses, we found $p_{BIC}(H_0|D) = .82$ on participants data and $p_{BIC}(H_0|D) = .82$ on item data. In the error rate analyses, $p_{BIC}(H_0|D) = .89$ on participants data and $p_{BIC}(H_0|D) = .86$ on item data. Following the descriptive terms for strength of evidence proposed by Raftery in 1995 (*p* between .50–.75: weak evidence, between .75–.95: positive evidence, between .95–.99: strong evidence, and > .99: very strong evidence), we can conclude that in both cases, we found *positive* evidence in favor of the null hypothesis, thus supporting the conclusion that the hiatus effect did not differ according to the morphological structure of items.

General Discussion

The respective role of consonants and vowels in visual word recognition has been an issue of major interest over the last decades, and it has been approached from different perspectives. First, Berent and Perfetti (1995) proposed the two-cycles hypothesis, according to which phonological conversion of consonants occurs faster than that of vowels. This hypothesis was supported by evidence from English, but it has not been confirmed in more transparent orthographies (e.g., Colombo, Zorzi, Cubelli, & Brivio, 2003), suggesting that it may be dependent on the differential consistency of vowels and consonants in a given language. Second, studies disturbing consonant or vowel information by selective transposition or deletion suggest that consonants provide stronger constraints on lexical selection than vowels (e.g., Duñabeitia & Carreiras, 2011; Lupker, Perea, & Davis, 2008; Perea & Acha, 2009). Third, the present findings, together with other recent, support the psychological reality of large orthographic units determined by the arrangement of consonant and vowel letters (i.e., the CV pattern).

Here, more precisely, the aim was to examine the extent to which the effect of orthographic CV structure was independent of the effect of morphemic structure in the syllable counting task. Previous studies have demonstrated that the perceived structure of words is determined by their CV pattern (Chetail & Content, 2012, 2013, 2014), each vowel cluster being the core of an orthographic unit (e.g., *éa* and *io* lead to a potential structure like *créa-tion*). The morphological structure of words also influences written word processing, morphologically complex words being processed faster and more accurately than simple words (Amenta & Crepaldi, 2012). Here, we capitalized on the fact that hiatus words frequently begin with a prefix. In that case, the morphemic boundary falls within a vowel cluster (e.g., *ré-agir*), breaking the orthographic unit and restoring the correspondence with the syllabic structure. We investigated whether the presence of a prefix straddling this boundary facilitates syllable counting judgments by comparing the processing of prefixed and non-prefixed hiatus words (Experiments 1, 3) or pseudowords (Experiment 2).

The results of the three experiments consistently showed that syllable counting judgements were influenced by the CV pattern of letter strings, hiatus items leading to more responses that underestimated the number of syllables than control items, which directly replicates previous studies (Chetail & Content, 2012; Chetail et al., in press).

These findings are consistent with other CV pattern effects showing that two items that do not share the same number of vowel clusters seem less similar than two items matched on the number of vowel clusters. For example, pseudowords like *povirer* (three vowel clusters) are more quickly judged as different from *POIVRER* (two vowel clusters) than pseudowords like *poirver* or *piovrer* (two vowel clusters) in the sequential same/different matching task (Chetail, Drabs, & Content, in press). According to the authors, the fact that this effect was obtained in the same/different task permits the conclusion that the CV pattern of words constrains processing at a sublexical level. More precisely, at the stage of orthographic encoding, letter strings would be automatically parsed into a number of letter groups corresponding to the number of vowel clusters, with each vowel cluster activating a distinct node. Critically, the number of active vowel-centerd nodes or the summed activity in the layer of vowel-centerd units may provide a useful cue to string length and structure, which is consistent with the finding that the number of vowel-centerd units influences the perceived length of words, even with very brief duration of presentation duration (see Chetail & Content, 2014).

One could argue that the results of the present study reflect participants' strategies, because of the metalinguistic nature of the task. Especially, the hiatus effect could be explained by the fact that they intentionally count the number of vowel clusters as a proxy for the number of syllables to perform the task. However, a phonological verification process would still be required to detect items with adjacent vowel graphemes (i.e., hiatus words), and thus counting vowel cluster appears less efficient than simply relying on phonology straightaway. Critically, the thrust of the syllable counting task does not lie in the performance per se, but rather in the indirect effect of the putative structure of letter strings on those judgements. This task requires the processing of items at a phonological level, which can be easily achieved by resorting to the phonological form of words, but although participants reported using subvocal pronunciation to perform phonological syllabification – the strategy that enabled them to give correct responses –, their responses were less accurate and slower for hiatus words. This interference stems from the mismatch between the CV structure (e.g., *réa-gir*, two orthographic vowel-centerd units) and the phonological structure (e.g., /ʀe-a-ʒiʀ/, three syllabic units) of items. Based on previous studies (Chetail & Content, 2014; Chetail et al., in press), we hypothesize that the perception of the CV structure of words arises at a sublexical level, whereas structure retrieved from the phonological form would be strongly activated after participants intentionally evoked the pronunciation of items. The long reaction times observed in the task may therefore reflect the time needed to resolve the conflict between the two activated structures. *Réa-gir* elicits a response "two units" whereas /ʀe-a-ʒiʀ/ elicits a response "three units," so participants need to focus on the latter response despite the perception of two orthographic units.

The evidence that a sublexical level of representations based on the CV structure of words is activated during letter string processing does not discard the possibility that other levels of representations are involved. Here, we examined the interaction between the CV and the morphemic structures. The presence of a similar bias for both prefixed and non-prefixed hiatus items shows that the hiatus effect genuinely stems from a smaller number of vowel clusters, due to the presence of the hiatus. Indeed, if the morphemic structure of words was processed before the orthographic CV structure when performing the syllable counting task, the hiatus effect should have been reduced or even cancelled for prefixed items because the prefix breaks one of the vowel cluster.

Interestingly, although we consistently found no modification of the hiatus effect according to morphemic structure throughout the three experiments, the presence of a prefix effect in Experiment 2, independently of the hiatus pattern, suggests that the participants processed the morphemic structure of items during the task. In the perspective of reading models involving a hierarchy of units more and more complex (e.g., Dehaene, Cohen, Sigman, & Vinckier, 2005; Taft, 1991), a first possibility would be that morphemes and orthographic vowel-centerd units are activated on the same pathway to the lexicon. On this pathway, words would be parsed first into vowel-centerd units (e.g., *réa-gir*) and the activation of two nodes would produce a strong interference with the trisyllabic structure retrieved from the phonological form of items. A morphemic decomposition during which the prefix is stripped off (e.g., *ré-a-gir*) could occur after CV parsing, making possible the activation of the corresponding stem (e.g., *agir*). This level of morphemic decomposition would be more recruited when lexical access is needed to perform the task or when items are not represented in the lexicon (as for the pseudowords, see Burani et al., 1997 for a similar proposition). The fact that lexical access is not central in the syllable counting task could have decreased the likelihood to observe an effect of morphemic structure compared to the strong and earlier effect of CV pattern. When items are pseudowords as in Experiment 2, morphemic decomposition may facilitate the contact with the phonological form (see Burani et al., 1997), leading to an overall facilitatory effect of prefixes (e.g., *préouvir* and *préporter* processed more rapidly than *créouvrir* and *créporter*). The absence of interaction of this effect with the type of items (hiatus vs. control) can be explained by the fact that in both prefixed and non-prefixed pairs, the CV pattern of items is activated before any morphological influence, leading in the end – in both pairs – to a mismatch between the orthographic CV structure and the phonological syllabic structure for one stimulus (hiatus item) but not for the other one (control item).

A second possibility concerning the activation of the morphemic structure of letter string is that word recognition involves independent processing pathways for both units, as already suggested by Alvarez et al. (2001) to account for distinct effects of syllables and morphemes (see also Domínguez et al., 2006; Domínguez, Alija, Rodriguez-Ferreiro, & Cuetos, 2010). On the morphological pathway, letters would quickly activate morphemes, which would in turn activate morphologically related words at the lexical level. Similarly to previous explanations, this pathway would be involved quickly during written word processing (e.g., Domínguez et al., 2007; Duñabeitia et al., 2010; Longtin et al., 2003; Rastle et al., 2004), but may depend on the nature of the task and be more engaged when lexical processing is required, thus explaining that we did not found morphemic effects in words (Experiments 1 and 3). On the orthographic pathway, letters would activate intermediate orthographic units that followed the CV pattern of words (i.e., vowel-centerd units), which in turn activate orthographic word representations. This level of representations could be activated early during the time course of word recognition and may be engaged in tasks tapping both lexical and pre-lexical levels of processing (e.g., syllable counting task, lexical decision task, perceptual tasks, see Chetail & Content, 2012, 2014).

To conclude, the CV pattern of words reliably influences letter string processing, confirming that the orthographic structure of words is based on the arrangement of consonant and vowel letters within words and is distinct from the structure ensuing from a phonological parsing based on syllables. The present study clearly shows that the hiatus effect cannot be explained by the morphemic structure of stimuli and by the presence of prefixes straddling the hiatus pattern. Whether the CV pattern and the morphemic structure of letter strings are processed on the same pathway or on two different pathways cannot be determined from the present data because the syllable counting task is not oriented toward meaning processing (see Taft & Nillsen, 2013, for a discussion on mandatory morphological decomposition pathway for lexical access). However, the absence of modification of the word type effect according to the morphemic structure of letter strings suggests that parsing into vowel-cluster units occurs earlier than morphological decomposition in the syllable counting task.

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Appendix A

Items used in Experiment 1

Word type		
Control hiatus	Prefixed hiatus	Control
truander	coauteur	cognitif
laotien	coopter	cotiser
cruauté	préavis	crudité
croasser	proactif	prosodie
créateur	réacteur	crépiter
goéland	réactif	récurer
création	réaction	réclamer
poésie	réagir	résolu
brioché	réarmer	bricolo
koala	réélu	opéré
béarnais	réemploi	réceptif
croassant	réinscrit	crépitant
léopard	réunion	répéter
paysan	réunir	rigolo
béatifier	réinviter	bénévolat
priorité	coopérer	colonisé
déambuler	réédition	décolorer
caoutchouté	préexistant	cérémonieux
fluorescent	préoccupant	prédominant
géométrie	préoccupé	gémellité
géographie	préoccuper	préparatif
géologie	réanimer	régénéré
poétiser	rééditer	polarité
théologien	réélection	réfrigérer
théoricien	réincarner	rénovateur
géothermie	réinjecter	révocation
néerlandais	réinsertion	négociateur
théoriser	réunifier	tétaniser

Appendix B

Items used in Experiment 2

Pseudoword type			
Control		Hiatus	
Prefixed	Non-prefixed	Prefixed	Non-prefixed
bocoucher	cocoucher	boasseoir	coasseoir
crédouter	prédouter	créavouer	préavouer
gésiéger	désiéger	géancrer	déancrer
potricher	cotricher	poéchouer	coéchouer
poviser	coviser	poépier	coépier
créporter	préporter	créouvrir	préouvrir
gémimer	prémimer	géorner	préorner
crémuter	prémuter	créopter	préopter
crérôti	prérôti	créaigu	préaigu
ponocif	conocif	poéclos	coéclos
popointu	copointu	poéteint	coéteint
prifloral	trifloral	priaqueux	triaqueux
bobranché	cobranché	boanxieux	coanxieux
créconfus	préconfus	créouvert	préouvert
crévilain	prévilain	créodieux	préodieux
crélaineux	prélaineux	créombreux	préombreux
bopréparer	copréparer	boarracher	coarracher
borévéler	corévéler	boavertir	coavertir
boméditer	coméditer	boabriter	coabriter
prigarantir	trigarantir	priassocier	triassocier
crécultiver	précultiver	créafficher	préafficher
gélacérer	délacérer	géamputer	déamputer
fépratiquer	dépratiquer	féenseigner	déenseigner
pomesurer	comesurer	poécarter	coécarter
porésumer	corésumer	poélargir	coélargir
primenacer	trimenacer	priaccuser	triaccuser
créprotéger	préprotéger	créobserver	préobserver
crédiminuer	prédiminuer	créordonner	préordonner
crédélirant	prédélirant	créaffectif	préaffectif
podélavé	codélavé	poétendu	coétendu
créprimitif	préprimitif	créofficiel	préofficiel
crésaccadé	présaccadé	créorageux	préorageux

Appendix C

Items used in Experiment 3

Word type		
Control hiatus	Prefixed hiatus	Control
TRUANDER	COAUTEUR	BOULIMIE
LAOTIEN	COOPTER	CALORIE
CREATEUR	REACTEUR	AVIATION
GOELAND	REACTIF	RAVIOLI
CREATION	REACTION	JALOUSIE
POESIE	REAGIR	RESOLU
KOALA	REELU	OMEGA
BEARNAIS	REEMPLOI	BIOLOGIE
CREANCIER	TRIATHLON	BAROUDEUR
CLOACAL	COAXIAL	BEGONIA
CREATIF	PREAVIS	GALAXIE
PAYSAGER	COOPERER	EVOLUTIF
DEAMBULER	REEDITION	EPILATION
THEOLOGIE	COALITION	AUTONOMIE
FLUORESCENT	PREOCCUPANT	REQUISITION
GEOMETRIE	REECOUTER	TOPOLOGIE
GEOGRAPHIE	PREOCCUPER	DECORATION
GEOLOGIE	REANIMER	INABOUTI
POETISER	REEDITER	ECOLOGIE
THEOLOGIEN	REELECTION	SOCIOLOGIE