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Effect of consonant/vowel letter organisation on the syllable counting task: evidence from English

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ABSTRACT

Recent studies in alphabetic writing systems have investigated whether the status of letters as consonants or vowels influences the perception and processing of written words. Here, we examined to what extent the organisation of consonants and vowels within words affects performance in a syllable counting task in English. Participants were asked to judge the number of syllables in written words that were matched for the number of spoken syllables but comprised either 1 orthographic vowel cluster less than the number of syllables (hiatus words, e.g., *triumph*) or as many vowel clusters as syllables (e.g., *pudding*). In 3 experiments, we found that readers were slower and less accurate on hiatus than control words, even when phonological complexity (Experiment 1), number of reduced vowels (Experiment 2), and number of letters (Experiment 3) were taken into account. Interestingly, for words with or without the same number of vowel clusters and syllables, participants' errors were more likely to underestimate the number of syllables than to overestimate it. Results are discussed in a cross-linguistic perspective.

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A contrasting feature of alphabetic writing systems is the regularity with which a given character is associated with a spoken counterpart. In Vietnamese, for example, the character *ǎ* is systematically associated with the sound /a/ and vice versa, and almost all other characters have simple mappings of this sort. In other writing systems, including French and English, a letter may be associated with more than one phoneme. Such differences have led some researchers to rank languages according to the transparency of their print-to-sound relations (see Van den Bosch, Content, Daelemans, & de Gelder, 1994).

Another major difference among languages concerns the size of functional orthographic units. Because alphabetic writing systems code phonology, it is expected that the perceived structure of letter strings is one that favours the mapping between the orthographic and phonological forms. Due to the clarity of grapheme-to-phoneme correspondences in transparent writing systems, readers of these systems may rely more on small units, such as single letters or graphemes, although larger units may be used as well (e.g., Brown & Deavers, 1999; Carreiras, Alvarez, & de Vega 1993). In more opaque orthographies, where inconsistencies at the graphemic level can sometimes be resolved by taking higher-order correspondences into account, larger units may be predominant. Consistent with this idea, units like rimes and onsets (e.g., *on* and *tr* in *patron* respectively) seem to be important reading units in English (see Treiman, Mullennix, Bijeljac-Babic, & Richmond-Welty, 1995; Ziegler & Goswami, 2005 for reviews). Moreover, evidence for syllabic activation has been repeatedly reported in French (see Chetail, 2012, for a review), but results have been less consistent in English (e.g., Ferrand, Segui, & Humphreys, 1997; Macizo & van Petten, 2006). One possible explanation is that syllabic segmentation is more ambiguous and less useful in English. Romance languages such as French or Italian, are considered syllable-timed languages. In contrast, English is often said to be a stress-timed language, as it is perceived as assigning similar durations to feet, that is, large phonological units comprising one strong syllable and one or several unstressed weak syllables (McMahon, 2002).

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Many current proposals investigating perceptual units in visual word recognition consider them to be direct counterparts of phonological units (e.g., Conrad, Carreiras, Tamm, & Jacobs, 2009; Mathey, Zagar, Doignon, & Seigneuric, 2006; Patterson & Morton, 1985; Shallice & McCarthy, 1985). According to a recent hypothesis, however, perceptual units may be defined from orthographic cues—namely, the arrangement of consonant and vowel letters—rather than from phonological properties. Thus, the overall organisation of consonant and vowels letters, hereafter labelled the *CV pattern*, determines the structure of printed words (e.g., Chetail & Content, 2012, 2014). The aim of the present study is to examine this hypothesis in English.

According to the CV pattern hypothesis, written words are structured into letter groups centred on vowel letters, or clusters of vowel letters, separated by consonants. The influence of these vowel-centred units was initially demonstrated by Chetail and Content (2012), who asked skilled readers of French to decide whether words had one, two, or three syllables. The words used in this forced-choice syllable counting task had either the same number of vowel-centred units and syllables, as with *evasion* (three of each) or one vowel-centred unit less than the number of syllables, as with *réunion* (two vowel-centred units but three syllables). The latter—hiatus words—include two contiguous vowel letters that are pronounced separately. Chetail and Content reasoned that, if the CV pattern was involved in word processing, vowel-centred units should interfere with judgements about syllabic units when the two do not match. Consistent with this prediction, readers were slower and less accurate at counting the number of syllables in hiatus words than in control words, an effect that was called the vowel effect. Additionally, erroneous responses for hiatus words most often corresponded to the number of vowel clusters (e.g., more "one syllable" than "three syllable" errors for *client*). To ensure that these effects stemmed from the arrangement of consonant and vowel letters, a follow-up experiment used two kinds of hiatus words, both with two contiguous phonological vowels. In phonological-only hiatus words (P hiatus words), the phonological hiatus corresponded to two vowel letters separated either by consonants that did not modify the pronunciation (e.g., *ll* in *briller*, /bʀi.je/, which has the same hiatus pattern as the hiatus word *crier*, /kʀi.je/) or by silent consonants (e.g., *bahut*, /ba.y/, *h* being silent in French). In orthographic-and-phonological hiatus words (OP hiatus words) like *chaos* (/ka.o/), the phonological hiatus corresponded to adjacent vowel letters. In both cases, the additional letters lead to two disjoint orthographic vowel clusters. Hence, although the phonological form of *briller* contains two contiguous vowels, the alternation of consonant and vowel letters determines an orthographic segmentation that is consistent with the phonological syllabification. The results showed that OP hiatus words like *chaos* but not P hiatus words like *briller* produced longer reaction times and higher error rates than control words in the syllable counting task.

The results are compatible with an interactive-activation model of visual word recognition that includes an intermediate level of vowel-centred units between letters and orthographic word forms (Chetail, Drabs, & Content, 2014). In this framework, written words are perceptually structured into letter groups corresponding to vowel clusters, each corresponding to a distinct node at the intermediate layer. The number of active vowel-centred nodes or the summed activity in this layer may provide a cue to string length and structure. Indeed studies using online tasks (e.g., Chetail, Balota, Treiman, & Content, 2015; Chetail, Drabs, & Content, 2014) suggest that the processing of the CV pattern arises at a sublexical level. Additionally, in the syllable counting task, the phonological structure would also be activated as participants intentionally evoke the pronunciation. The syllable counting task requires access to phonological forms, and participants often report using subvocal pronunciation. Despite this, responses are less accurate and slower for hiatus words than for control words. The interpretation is that, in control words, the two streams of information (number of nodes activated at the orthographic and phonological levels) induce the same response, whereas in hiatus words the information about length from the two sources is discrepant. The longer reaction times for hiatus words may therefore reflect the time needed to resolve the conflict between the two structures. In other words, the task involves the activation of two codes that compete with one another when they do not yield the same response (the case of hiatus words); one is an orthographic code (CV structure) which is activated during written word perception and processing; and one is a phonological code (syllabic structure), which is required to perform the task.

The aim of the present study was to test the vowel effect in English. So far, evidence has been reported in French and Italian (Chetail & Content, 2012; Chetail, Scaltritti, & Content, 2014), two closely related Romance languages with orthographies more transparent than that of English and with clearer syllabic structure. One could argue that, because syllabic structure is less salient in English, responses could be more influenced by orthographic structure, and thus, a CV pattern effect should be observed. However, English has other properties that make it questionable whether the CV pattern hypothesis would apply. CV pattern effects can only arise if letters are rapidly assigned to the consonant or vowel category. These letter categories may reflect the fact that the two groups of letters code for speech elements differing in nature, namely vowels—stable complex periodic waves—and consonant phonemes—brief friction or explosion noises. In English, the correspondence between C and V letters and C and V phonemes is not as clear as in some other writing systems, such as Italian. Some consonant and vowel phonemes can be coded by groups that include both vowel and consonant letters (e.g., /ai/ in *high*, /o/ in *sew*, /ʃ/, in *social*, /t/ in *paced*; Berndt, Reggia, & Mitchum, 1987). Moreover, there are many cases of disjoint graphemes in English rimes, corresponding to a grapheme combining vowel letters with a silent E separated by a consonant letter (e.g., /ei/ in *save*). Here, the mapping between vowel letters and phonemes depends on the presence of consonants. These properties of English might mean that the distinction between consonant and vowel letters is not clear enough to cause CV pattern effects. It is therefore necessary to test CV pattern effects in English to examine whether the influence of the arrangement of consonant and vowel letters depends on the clarity of the mapping between consonant/vowel letters and consonant/vowel phonemes. If it does not, a CV pattern effect should be found in English as in previous studies in French and Italian.

In order to compare English to French and Italian, we decided to use the syllable counting task. This task can be considered a metalinguistic judgement task, but the thrust of our study does not lie in metalinguistic performance per se but rather in the indirect effect of a putative perceptual property of written words—the organisation of letter strings into units according to vowel clusters—on those judgements. In past studies, the general pattern of results obtained with the syllable counting task (i.e., longer and less accurate responses for hiatus words) has been consistent with that found in word recognition and perceptual tasks (see Chetail & Content, 2014; Chetail, Drabs, & Content, 2014).

Experiment 1

In this experiment, we compared hiatus words and controls in a forced-choice syllable counting task. The experiment included OP hiatus words such as *triumph* in which a hiatus is present both phonologically and orthographically. P hiatus words were also included to ensure that the vowel effect is driven by the arrangement of vowel and consonant letters and not by phonology. For P hiatus words, we relied mostly on the letter *y*. This letter can be considered to act as a consonant between two vowels, as in *buyer*. In such words, the fact that the hiatus pattern coincides with two vowel letters separated by a consonant leads to two vowel clusters. Phonologically, however, the hiatus pattern in *prior* is similar to that in *buyer*. If the putative vowel effect in English stems from the arrangement of consonant and vowel letters, only OP hiatus words should be processed more slowly and less accurately than control words.

Participants. Twenty-two graduate or undergraduate students from Washington University in Saint Louis were paid to participate (mean age 21.6 years, 12 females). They were native speakers of American English and had normal or corrected-to-normal vision.

Materials. Twenty-one triplets of bisyllabic or trisyllabic English words were selected from the Celex database (Baayen, Piependrock, & van Rijn, 1993). In each triplet, two words exhibited a phonological hiatus pattern. In the OP hiatus words, the two adjacent vowels coincided with two contiguous vowel letters (e.g., *prior* /ˈpraɪər/) so that the hiatus was present both in written and spoken form. In the P hiatus words, the two vowels producing the hiatus pattern were separated by the letters *y* or *w* (e.g., *buyer* /ˈbaɪər/) so that the hiatus pattern is present phonologically but not orthographically. The third word of the triplet was a control word (e.g., *villa*, /ˈvilə/) exhibiting no hiatus and matched with the two hiatus words on a number of dimensions, including lexical frequency (written word frequency in Celex, in number of occurrences per million; Baayen et al., 1993), number of letters and syllables, summed bigram frequency, and morphemic complexity (see Appendix A). Monosyllabic (33 words) and bisyllabic (3 words) fillers were added so that the same number of mono-, bi- and trisyllabic words would be presented overall.

Procedure. Participants performed a syllable counting task programmed with Octave software (http://www.gnu.org/software/octave/) and PsychToolbox (Brainard, 1997). Each trial started with a fixation cross for 500 ms in the centre of the screen, followed by a lowercase word written in Courier New font which remained on the screen until the participant responded or 3,000 ms had elapsed. Participants were asked to decide as quickly and as accurately as possible whether the target word had one, two, or three syllables. They responded by pressing one of three contiguous keys on the keyboard with the three central fingers of their dominant hand. Response times were measured from target onset. Participants performed 14 practice trials before receiving the 99 trials in a random order. To ensure that the items were pronounced with the expected number of syllables, participants were asked to read all items aloud after the syllable counting task, and their responses were recorded.

Results and discussion

The results are presented Table 1. Outlier trials (RTs below 300 ms or reaching the 3,000 ms deadline) were excluded from analyses (0.83%). One participant was excluded due to a very high error rate (more than three standard deviations above the group mean).

The data were then submitted to separate analyses of variance on the participant and item means with word type (OP hiatus, P hiatus, control) as the only factor. For reaction times, there was a significant effect of word type, $F1(2, 40) = 15.02$, $p < .001$, $\eta^2 = .43$, $F2(2, 60) = 8.72$, $p < .001$, $\eta^2 = .23$. OP hiatus words were responded to more slowly than control words, $F1(1, 20) = 29.10$, $p < .001$, $\eta^2 = .59$, $F2(1, 60) = 17.41$, $p < .001$, $\eta^2 = .22$, whereas there was no significant difference between P hiatus and control words, *F*s < 1. In the error rate analysis, there was a significant effect of word type, $F1(2, 40) = 12.65$, $p < .001$, $\eta^2 = .39$, $F2(2, 60) = 6.40$, $p = .003$, $\eta^2 = .18$. OP hiatus words produced more errors than control words, $F1(1, 20) = 14.23$, $p = .001$, $\eta^2 = .42$, $F2(1, 60) = 12.68$, $p < .001$, $\eta^2 = .17$, whereas there was no significant difference between P hiatus and control words, *F*s < 1.

Table 1. Mean reaction times and error rates in Experiment 1.

	Control	OP hiatus	P hiatus	Difference (OP hiatus– Control)
Reaction times (ms)	980	1,092	984	112
Error rates (%)	6.4	13.9	5.5	7.5

As in Chetail and Content (2012) and Chetail, Scaltritti, and Content (2014), we also analysed the nature of errors on bisyllabic items, the only ones for which it is possible to observe both underestimation and overestimation errors. We conducted a two-way ANOVA with the factors word type (OP hiatus, P hiatus, control) and error type (one syllable, three syllables) on the percentage of errors made by participants on bisyllabic stimuli. Participants made more underestimation (i.e., one syllable) errors than overestimation (i.e., three syllable) errors for OP hiatus words (11.96% vs. 2.91%), $F(1, 20) = 8.22$, $p = .01$, $\eta^2 = .29$, whereas there was no difference for P hiatus words (2.86% vs. 2.91%), $F < 1$. There were also more underestimation than overestimation errors for control words (8.62% vs. 1.43%), $F(1, 20) = 10.68$, $p = .004$, $\eta^2 = .35$.

The results of this experiment replicate those found in French and Italian (Chetail & Content, 2012; Chetail, Scaltritti, & Content, 2014) in that hiatus words were processed more slowly and less accurately than control words. This difference cannot be ascribed to the presence of the relatively uncommon phonological hiatus pattern because the effect was found for OP but not for P hiatus words. The error analysis also confirmed that participants were sensitive to the CV pattern because most of the errors on OP hiatus words were consistent with the number of vowel cluster units (underestimation), whereas similar proportions of "one syllable" and "three syllable" responses were produced for P hiatus words. Surprisingly, however, control words also showed more underestimation than overestimation errors. One possible explanation for the underestimation for control words appeals to vowel reduction. The presence of many reduced vowels in unstressed syllables could have led participants to sometimes count one syllable less in control words than expected. Indeed, an analysis of the oral reading responses showed that more control words than bisyllabic P hiatus words were pronounced with a reduced vowel (82 vs. 64%, $p < .001$, the percentage for OP hiatus words being 73%). Another difference in the materials was related to bigram frequency. A posteriori *t*-tests showed that P hiatus words were more likely than words in the other two conditions to include a bigram of very low frequency at the syllabic boundary (see Appendix A). Although there is no clear reason why this variable would influence the nature of the errors, taken together, the two analyses show that the stimuli used in Experiment 1 were imperfectly matched on several variables. Moreover, due to the multiple constraints applied in selecting the words, few items were used in each condition ($N = 10$, as compared to 20–40 in previous studies, see Chetail & Content, 2012; Chetail, Scaltritti, & Content, 2014), which implies that the number of errors by participant and condition is very small. We thus conducted additional experiments, first to replicate the overall pattern of results with a new and larger set of words and second to determine whether the pattern of errors in the control condition is replicated.

Experiment 2

This experiment tested the vowel effect with stimuli selected to avoid vowel reduction. In this experiment and in Experiment 3, we used only the control and OP hiatus conditions because it was not possible to find enough matched triplets of OP hiatus, P hiatus, and control words.

Participants. Twenty-four graduate or undergraduate students from Washington University in Saint Louis were paid to participate (mean age 20.0 years, 21 females). All were native speakers of American English and had normal or corrected-to-normal vision.

Materials. Forty-one pairs of bisyllabic or trisyllabic English words were selected. In each pair, one word exhibited an orthographic and phonological hiatus (e.g., *neon* /ˈniɑn/), and the other was a control word with no hiatus pattern and selected to match the hiatus word on a number of dimensions (Appendix B). None of the hiatus or control words had a reduced vowel in their phonological forms. Forty-two monosyllabic and two bisyllabic word fillers were added, so that the same number of mono-, bi- and trisyllabic words were presented overall.

Procedure. The procedure was the same as in Experiment 1.

Results

The results are presented Table 2. Outlier trials, as defined as in Experiment 1, were excluded (0.13%). Analyses of variance with word type (hiatus, control) as factor showed that hiatus words were processed more slowly than control words, $F1(1, 23) = 31.64$, $p < .001$, $\eta^2 = .58$, $F2(1, 80) = 18.72$, $p < .001$, $\eta^2 = .19$. In the error rate analysis, the effect was significant only by participants, $F1(1, 23) = 7.88$, $p = .01$, $\eta^2 = .26$, $F2(1, 80) = 1.88$, $p = .17$. Participants made more underestimation than overestimation errors on bisyllabic hiatus words (10.00% vs. 1.46%), $F(1, 23) = 30.42$, $p < .001$, $\eta^2 = .57$, as well as on control words (8.13% vs. 1.88%), $F(1, 23) = 10.45$, $p = .004$, $\eta^2 = 31$. The interaction between word type and type of error was not significant, $F(1, 23) = 1.16$, $p = .29$.

Table 2. Mean reaction times and error rates in Experiment 2.

	Control	Hiatus	Difference
Reaction times (ms)	863	919	56
Error rates (%)	7.2	9.7	2.5

In sum, Experiment 2 replicated the vowel effect with a new and larger set of items without vowel reduction. This result confirms that the organisation of consonant and vowel letters influences syllable counting in English. The predominance of underestimation errors was again observed for hiatus as well as for control words, and in this experiment the pattern cannot be explained in terms of vowel reduction.

Experiment 3

In Italian, Chetail, Scaltritti and Content (2014) observed that the number of letters in a stimulus influenced the nature of errors. When bisyllabic words were only three or four letters long, participants made a high proportion of underestimation errors on both hiatus and control words. Although the bisyllabic words in Experiment 1 and 2 were longer than three letters, they were on average shorter than those used in previous experiments in French (4.8 letters vs. 5.3 letters in Experiments 1–4 of Chetail & Content, 2012, $p = .02$ for the difference). Experiment 3 examined whether this variable could explain the predominance of underestimation errors on control words. In Experiment 3a, word length was directly manipulated. We used short words such as *acid* and *riot* and longer words such as *exploit* and *triumph*. We expected underestimation errors in both bisyllabic hiatus and control words when stimuli are short, and we asked whether underestimation errors would be found predominantly on hiatus words when stimuli are longer. In Experiment

3b, we used words of three and four syllables instead of two and three as in the previous experiments. This enabled us to select longer words overall and gave us another opportunity to ask whether underestimation errors would be more common on hiatus words than control words when the items are longer.

Method

Participants. Twenty-five and 23 graduate or undergraduate students from Washington University in Saint Louis were paid to participate in Experiments 3a and 3b, respectively (Experiment 3a: mean age 19.2 years, 17 females; Experiment 3b: mean age 20.9 years, 16 females). They were native speakers of American English and had normal or corrected-to-normal vision.

Materials. In Experiment 3a, 84 pairs of bisyllabic or trisyllabic English words were selected, each comprising one hiatus word matched with a control word. Half of the pairs included short words (three to four letters for bisyllabic words, five to six letters for trisyllabic words) and the other half included longer words (five to seven and seven to nine letters for bisyllabic and trisyllabic words, respectively). Eighty-four monosyllabic words were added as fillers. In Experiment 3b, items were selected as in Experiment 2, except that half of the 70 pairs were three-syllable words and the other half were four-syllable words. Seventy bisyllabic fillers were added. Because it was not possible to select only words without vowel reduction, this factor was controlled for between the two conditions (Appendix C).

Procedure. The procedure was the same as in Experiment 1 except that in Experiment 3b the participants had to decide whether the target word had two, three, or four syllables.

Results

The results are presented Table 3. Outlier trials were excluded (0.33% and 0.58% for Experiment 3a and 3b, respectively). For each experiment, we also excluded the results of one participant who had a very high error rate.

Experiment 3a

The data were submitted to ANOVAs with word type (hiatus, control) and length (short, long) as factors. In the reaction time analyses, the main effect of word type was significant, $F1(1, 23) = 26.42$, $p < .001$, $\eta^2 = .53$, $F2(1, 164) = 10.68$, $p = .001$, $\eta^2 = .06$, but neither the main effect of length, $F1(1, 23) = 1.23$, $p = .29$, $F2(1, 164) = 1.23$, $p = .27$, nor the interaction of word type and length, $F1(1, 23) = 6.89$, $p = .02$, $\eta^2 = .23$, $F2(1, 164) = 2.05$, $p = .15$, reached significance in both the participant and the item analysis. In the error rate analyses, significant effects were found for word type, $F1(1, 23) = 8.58$, $p = .008$, $\eta^2 = .27$, $F2(1, 164) = 3.46$, $p = .06$, $\eta^2 = .02$, and length, $F1(1, 23) = 20.29$, $p < .001$, $\eta^2 = .47$, $F2(1, 164) = 22.56$, $p < .001$, $\eta^2 = .12$, but not for the interaction, $Fs < 1$.

Most errors on short bisyllabic words were underestimations than overestimations, both for hiatus words, $F(1, 23) = 22.96$, $p < .001$, $\eta^2 = .50$ (11.51% vs. 0.20% for under- and overestimations, respectively) and control words $F(1, 23) = 10.27$, $p = .004$, $\eta^2 = .31$ (10.32% vs. 0.20%). For longer words, there were more underestimation than overestimation errors for hiatus words (4.61% vs. 3.19%), but not for control words (1.60% vs. 2.21%). However, neither the interaction, $F(1, 23) = 1.77$, $p = .20$, nor the simple effects, $ps > .30$ respectively, approached significance.

Experiment 3b

Hiatus words were processed more slowly than control words, $F1(1, 21) = 4.24$, $p = .05$, $\eta^2 = .17$, $F2(1, 138) = 2.94$, $p = .09$, $\eta^2 = .02$. The effect failed to reach significance in the error rate analysis, $F1(1, 21) = 2.19$, $p = .15$, $F2(1, 138) = 2.32$, $p = .13$.

We analysed the nature of errors on trisyllabic words, because only with these items was it possible to observe both underestimations and overestimations. Participants made more underestimation than overestimation errors for hiatus words (9.02% vs. 3.26%), $F(1, 21) = 10.13$, $p = .004$, $\eta^2 = .32$, whereas the effect was marginally significant for control words (5.99% vs. 3.38%), $F(1, 21) = 4.11$, $p = .06$, $\eta^2 = .16$. The interaction between word type and nature of errors missed significance, $F(1, 21) = 3.50$, $p = .08$, $\eta^2 = .14$.

In sum, Experiment 3 replicated the vowel effect on reaction times and error rates, although not significantly so in Experiment 3b on errors. Regarding the nature of errors, Experiment 3a demonstrated that length influences syllable counting judgements. Experiment 3b showed a trend towards a higher underestimation rate for hiatus words than for control words, although underestimations were still more prevalent than overestimations in control words.

Table 3. Mean reaction times and error rates in Experiment 3.

		Control	Hiatus	Difference
Experiment 3a	*All words*			
	Reaction times (ms)	1,005	1,059	54
	Error rates (%)	5.4	7.5	2.1
	Short words			
	Reaction times (ms)	1,013	1,035	22
	Error rates (%)	8.4	9.7	1.3
	Long words			
	Reaction times (ms)	997	1,082	85
	Error rates (%)	2.2	5.2	2.9
Experiment 3b	Reaction times (ms)	1,236	1,277	41
	Error rates (%)	10.5	12.4	1.9

General discussion

The issue addressed in this study was whether the organisation of consonant and vowel letters within words determines their perceptual structure in English. If so, we expected English readers to be sensitive to the CV pattern. In the syllable counting task, this sensitivity should result in longer reaction times and more errors on hiatus words than on control words because hiatus words exhibit a mismatch between phonological and orthographic CV structure. This effect was obtained in all three experiments. Hiatus words were processed more slowly than control words and also tended to produce more errors.

The difference between hiatus and control words in the syllable counting task is consistent with the view that letter strings are automatically structured into a number of letter groups corresponding to the number of vowel clusters (Chetail, Drabs, & Content, 2014). In this framework, each vowel cluster in the stimulus word activates a distinct node, providing an overall cue to string length. Very quickly, too, phonological information about the word is activated, leading to the activation of phonological syllabic nodes. In hiatus words, additional time is necessary to resolve the conflict between the two discrepant structures that are activated. In control words, no discrepancy exists and so responses can be faster.

The results cannot be explained by other models that include an intermediate level of units between the letter and word levels of representation. In models including syllabic units, for example (e.g., Conrad et al., 2009; Mathey et al., 2006), multi-letter orthographic units are conceived as direct counterparts of phonological units (i.e., syllables), so no mismatch between the number of phonological and orthographic units can occur. Models that include units defined by orthographic properties such as open bigrams (e.g., Grainger & Van Heuven, 2003) do not offer a straightforward way to explain the results either. Hiatus and control words have the same number of bigrams and open bigrams because they were matched on number of letters. Moreover, open-bigram models entail no distinction between consonant and vowel categories. Finally, in the same-different task, Chetail, Drabs, and Content (2014), found that two similar items were judged more rapidly as different if they have different CV patterns, as with *POIVRER/povirer*, than if they have the same CV pattern, as with *POIVRER/poirver*. They showed that such CV pattern effects cannot be explained by open-bigram models or other letter position coding models (e.g., Davis & Bowers, 2006; Gomez, Ratcliff, & Perea, 2008).

An influence of the arrangement of consonant and vowel letters on the syllable counting task has been demonstrated in French and Italian (Chetail & Content, 2012; Chetail, Scaltritti, & Content, 2014), and the present study found similar results for English. As detailed in the Introduction, English differs from these two languages in its rhythmic characteristics, print-to-sound mapping, and syllabification. In addition, the correspondence between consonant and vowel letters and consonant and vowel phonemes is arguably less clear in English, perhaps making the distinction between consonant and vowel letters less salient. In spite of these differences, we found an effect of the CV pattern in all of the experiments reported here with English. This effect is consistent with recent findings based on the English Lexicon Project (ELP) (Balota et al., 2007) showing less efficient processing of hiatus words than control words (Chetail, Balota, Treiman, & Content, 2015) in the naming and lexical decision tasks. Hence, together with previous findings, the present results suggest that the role of the arrangement of consonant and vowel letters as an essential cue to the perceptual structure of letter strings is independent of the idiosyncratic features of languages. Although it would be premature to claim that the vowel effect should be observed in any alphabetic writing system, we propose that it may be expected in any language that uses symbols for both consonant and vowel letters.

The diagnostic markers of the influence of the CV pattern in the syllable counting task are higher reaction times and higher error rates for OP hiatus words compared to control words, and we observed both of these markers in the present experiments. Because the task makes it possible, analyses on the nature of errors can also be conducted. In the previous studies (Chetail & Content, 2012; Chetail, Scaltritti, & Content, 2014), the higher proportion of underestimation errors than overestimation errors for hiatus words was taken as additional support for the hypothesis that readers are influenced by the number of vowel cluster units. Indeed, when a participant responds that a word like *client* has one syllable, this response is erroneous regarding the number of syllables (two) but is consistent with the CV pattern of the word (e.g., *client*, one vowel cluster unit). This pattern of errors is contrasted with the one found for control words, which are expected to show as many one-syllable as three-syllable errors. Although such results were found in French (Chetail & Content, 2012) and Italian (Chetail, Scaltritti, & Content, 2014), we did not replicate that pattern in the present study. Readers were prone to underestimate the number of syllables in hiatus words, but underestimation also occurred for control words.[1] Hence, other factors may influence the distribution of errors, and neither vowel reduction (Experiment 2) nor length (Experiment 3) appears to provide a complete explanation.

One possible reason why participants produced many underestimation errors even for control words is that they were influenced by the number of feet in the items. The foot is a phonological unit comprising one strong syllable and one or several unstressed weak syllables (McMahon, 2002), and it is thought to play an essential role in determining speech rhythm in English. By contrast, French and Italian are considered to be syllable-timed languages, because syllables constitute the most important rhythmic units, with approximately identical durations. In spoken word processing especially, several studies have shown that English speakers are sensitive to the rhythmic structure produced by the alternation of weak and strong syllables and use it for lexical segmentation (e.g., Cutler & Norris, 1988; Grosjean & Gee, 1987). For example, listeners more rapidly detected monosyllabic words (e.g., *mint*) in pseudowords like *mintesh* /ˈmɪntəʃ/ (strong syllable followed by a weak syllable, i.e., one foot) than in pseudowords like *mintayve* /ˈmɪntˌeɪv/ (two strong syllables, i.e., two feet) (Cutler & Norris, 1988). Over 95% of the bisyllabic words in our experiments had only one foot, in agreement with the fact that almost all bisyllabic words in English consist of one iambic (weak–strong) or trochaic (strong–weak) foot, and many trisyllabic words have dactylic (strong–weak–weak) foot structure. An influence of the foot structure could explain the general trend to make underestimation errors, as the number of feet was smaller than the number of syllables in both hiatus and control words. Some support for this view comes from an analysis of errors on the four-syllable words of Experiment 3b. Of 70 such items, 27 had one foot and 43 had two feet, and the two groups of items were matched on the variables considered in the three experiments. If number of feet influences error rates in the syllable counting task, then items with one foot should lead to more errors (i.e., "three syllable" responses) than items with two feet. Indeed, more errors were found for one-foot than two-foot words (14.70 and 10.35%, respectively), $F(1, 68) = 4.73$, $p = .03$. Although this post-hoc analysis should be considered with caution, it provides some support for the idea that foot structure influences syllable counting in English.

One side implication of the present findings concerns syllabification. The accepted view is that English speakers easily agree on the number of syllables in words even though syllable boundaries may be ambiguous (see e.g., Laks, 1995; Treiman & Danis, 1988). The errors observed in the present experiments indicate that syllabification decisions based on print are influenced by several extraneous factors, such as word length and feet. Thus, speakers' intuitions about syllable quantity may not be as reliable as generally assumed. Further research

[1]Even though at a descriptive level the underestimation effect was always stronger for hiatus words than control words, a Bayesian analysis (see Masson, 2011) of the combined data of all the experiments led to no clear evidence in favour of the hypothesis that underestimation is more prevalent for hiatus words than control words, $p\text{BIC}(H1|D) = .45$ (whereas, consistent with the main analyses reported in the text, very strong evidence was found for the word type effect in both reaction times, $p\text{BIC}(H1|D) \approxeq 1$, and errors, $p\text{BIC}(H1|D) = .9999$).

would be necessary to confirm these conclusions and establish whether it is specific to the visual presentation modality or is also observed with oral presentation.

To conclude, the present study provides convergent evidence for the influence of the CV pattern in English. Although the syllable counting task does not allow us to draw conclusions about early or automatic effects, the results are consistent with other studies showing CV pattern effects with perceptual or visual word recognition tasks (Chetail & Content, 2014; Chetail, Drabs, & Content, 2014). The similarity of the present findings to those from previous experiments in French and Italian indicates the importance of consonant and vowel letter arrangement and suggests that this influence is independent of the specific features of alphabetically written languages.

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Appendix A: Experimental Stimuli in Experiment 1

Controlled variables	Type of words			
	Control	OP hiatus	P hiatus	*p*-Values[a]
Lexical frequency	9.67 (17.90)	10.86 (17.17)	11.33 (20.67)	.43, .52, .89
Number of letters	6.38 (1.56)	6.38 (1.56)	6.38 (1.56)	–
Number of syllables	2.52 (0.51)	2.52 (0.51)	2.52 (0.51)	–
Token summed bigram frequency[b]	15,815 (7,097)	15,404 (7,186)	14,105 (10,063)	.85, .43, .58
Number of morphemes	1.05 (0.70)	1.43 (0.85)	1.43 (0.79)	.73, .68, 1.00
A posteriori controls				
Token positional syllable frequency (averaged over all syllables)[b]	4,148 (7,910)	883 (915)	960 (1,529)	.06, .08, .85
Token positional bigram frequency at syllabic boundaries (averaged over all bigrams straddling syllabic boundaries)[b]	3,349 (3,429)	1,918 (3,318)	1,040 (1,317)	.18, .006, .27
Number of parts of speech[c]	1.42 (0.59)	1.61 (0.91)	1.42 (0.50)	.46, .97, .44
OLD20[b]	2.54 (0.56)	2.49 (0.59)	2.63 (0.62)	.78, .62, .46
Number of HFON[b]	0.29 (0.78)	0.23 (0.88)	0.19 (0.51)	.85, .64, .83
PLD20[b]	2.41 (0.53)	2.22 (0.43)	2.24 (0.57)	.23, .32, .95
Number of HFPN[b]	0.85 (2.41)	0.47 (0.68)	0.76 (2.05)	.49, .89, .56

Notes: HFON: number of higher frequency orthographic neighbours (words with the same number of letters with identical letters except one). HFPN: number of higher frequency phonological neighbours (words with the same number of phonemes with identical phonemes except one). When not specified, values come from Celex (Baayen et al., 1993).

[a]T-tests between control and OP hiatus conditions, control and P hiatus conditions, and OP hiatus and P hiatus conditions, respectively.

[b]Measures computed by the authors from Celex (lemmas forms, with exclusion of compound words, $N = 41{,}703$).

[c]Values extracted from Brysbaert, New, and Keuleers (2012) (five words were in the present experiment were not in Brysbaert et al., 2012).

Control words: frugal, pudding, kimono, mimosa, inertia, idol, pulsation, disappoint, avert, artisan, arsenic, caribou, agent, villa, gala, elegant, adoption, astonish, larva, pedal, ambush

OP hiatus words: pliant, triumph, bionic, paella, Messiah, bias, quiescent, highflying, pious, cardiac, diurnal, sciatic, trial, prior, doer, violent, reappear, supplier, chaos, druid, bluish

P hiatus words: crayon, buoyant, papaya, payola, bayonet, soya, buoyantly, flamboyant, foyer, voyager, Malayan, layover, royal, buyer, ewer, loyalty, employee, employer, rayon, kayak, boyish

Appendix B: Experimental Stimuli in Experiment 2

Controlled variables	Type of words		
	Control	Hiatus	*p*-Values
Lexical frequency	12.71 (29.23)	13.63 (44.32)	.81
Number of letters	5.76 (29.23)	5.71 (44.32)	.16
Number of syllables	2.51 (0.51)	2.51 (0.51)	–
Summed bigram frequency	15,233 (13,068)	18,999 (12,654)	.12
Number of morphemes	1.07 (0.68)	1.12 (0.71)	.72
Word with a reduced vowel (%)	0	0	–
A posteriori controls			
Token positional syllable frequency (averaged over all syllables)[a]	6,981 (13,268)	4,706 (12,379)	.42
Token positional bigram frequency at syllabic boundaries (averaged over all bigrams straddling syllabic boundaries)[a]	3,581 (5,396)	3,809 (4,416)	.84
Number of part-of-speech[b]	1.48 (0.63)	1.65 (0.76)	.27
OLD20[a]	2.45 (0.57)	2.32 (0.49)	.29
Number of HFON[a]	0.34 (0.85)	0.62 (1.33)	.26
PLD20[a]	2.38 (0.66)	2.28 (0.59)	.49
Number of HFPN[a]	0.61 (1.20)	1.12 (3.32)	.35

Notes: HFON: number of higher frequency orthographic neighbours (words with the same number of letters with identical letters except one). HFPN: number of higher frequency phonological neighbours (words with the same number of phonemes with identical phonemes except one). When not specified, values come from Celex (Baayen et al., 1993).

[a]Measures computed by the authors from Celex (lemmas forms, with exclusion of compound words, $N = 41{,}703$).

[b]Values extracted from Brysbaert et al. (2012).

Control words: biting, photo, epic, banjo, puny, emu, venue, ego, auto, memo, mini, cigar, duvet, sonic, polo, enjoy, argue, lasso, movie, outlaw, galvanic, embargo, erratic, albino, tornado, indigo, volcano, organic, inexact, revalue, embody, untidy, exotic, psychotic, ironic, elitist, escapee, risotto, embellish, Mexico, uneasy

Hiatus words: bluish, chaos, coed, druid, duet, duo, kiosk, leo, meow, neon, noel, react, rearm, stoic, trio, being, doing, gluey, going, seeing, altruist, archaic, atheist, bionic, cardiac, caveat, caviar, chaotic, coexist, Hebraic, heroic, maniac, mosaic, patriarch, poetic, prosaic, sciatic, scorpio, matriarch, studio, video

Appendix C: Experimental Stimuli in Experiment 3

	Experiment 3a						Experiment 3b		
Controlled variables	Short control words	Short hiatus words	*p*-Values	Long control words	Long hiatus words	*p*-Values	Control words	Hiatus words	*p*-Values
Lexical frequency	12.78 (31.43)	13.43 (35.13)	.93	10.74 (15.57)	10.63 (15.10)	.97	14.59 (39.26)	12.33 (30.66)	.17
Number of letters	4.74 (1.08)	4.74 (1.08)	–	6.69 (1.35)	6.69 (1.35)	–	7.69 (1.04)	7.69 (1.04)	–
Number of syllables	2.5 (0.51)	2.5 (0.51)	–	2.5 (0.51)	2.5 (0.51)	–	3.5 (0.50)	3.5 (0.50)	–
Summed bigram frequency	13,366 (9,965)	13,205 (9,737)	.94	19,826 (13,008)	18,269 (9,473)	.53	23,804 (25,872)	20,906 (20,430)	.37
Number of morphemes	0.89 (0.50)	0.86 (0.63)	.82	1.15 (0.85)	1.02 (0.78)	.49	1.29 (0.80)	1.19 (0.88)	.50
Word with a reduced vowel (%)	43 (50)	37 (49)	.64	44 (50)	42 (50)	.82	51 (50)	40 (49)	.18
Controlled variables									
Token positional syllable frequency (averaged over all syllables)[a]	3,142 (5,787)	2,025 (4,219)	.31	2,084 (5,539)	518 (705)	.07	1,914 (84)	1,213 (114)	.10
Token positional bigram frequency at syllabic boundaries (averaged over all bigrams straddling syllabic boundaries)[a]	3,841 (4,282)	3,241 (5,504)	.58	4,087 (3,869)	4,042 (4,847)	.96	6,115 (5,564)	5,655 (4,617)	.60
Number of part-of-speech[b]	1.45 (0.59)	1.70 (0.64)	.07	1.61 (0.62)	1.48 (0.74)	.42	1.36 (0.48)	1.24 (0.46)	.12
OLD20[a]	2.14 (0.40)	2.12 (0.40)	.85	2.51 (0.54)	2.57 (0.62)	.66	2.93 (0.51)	2.92 (0.48)	.49
Number of HFON[a]	0.43 (0.80)	0.81 (1.71)	.23	0.28 (0.80)	0.18 (0.46)	.48	0.05 (0.28)	0.02 (0.16)	.48
PLD20[a]	2.31 (0.48)	2.12 (0.51)	.10	2.48 (0.64)	2.54 (0.54)	.66	3.01 (0.59)	3.06 (0.55)	.64
Number of HFPN[a]	0.27 (0.69)	1.00 (3.39)	.20	0.57 (1.58)	0.21 (0.52)	.18	0.08 (0.32)	0.02 (0.16)	.20

Notes: HFON: number of higher frequency orthographic neighbours (words with the same number of letters with identical letters except one). HFPN: number of higher frequency phonological neighbours (words with the same number of phonemes with identical phonemes except one). When not specified, values come from Celex (Baayen et al., 1993).

[a]Measures computed by the authors from Celex (lemmas forms, with exclusion of compound words, $N = 41{,}703$).

[b]Values extracted from Brysbaert et al. (2012) (five and two words from Experiment 3a and 3b, respectively, were not in Brysbaert et al., 2012). In Experiment 3a, nine words (absent from Celex) were selected in the ELP (Balota et al., 2007) to increase the number of items per conditions (*Lois, Noah*, *Joey*, *Leon*, *Rio*, *cooing*, *Boeing*, *Brian*, *preempt*). To ensure that frequency was controlled overall, the matched items in the control condition were also chosen from the ELP, with very close values of frequency (*Rosa*, *Reno*, *Anna*, *Dana*, *Ada*, *unroll*, *heater*, *Japan*, *lampoon*). However, given that the measure of frequency in Celex was not identical to that of ELP, the lexical frequency values reported here were obtained only for the pool of words from Celex.

Experiment 3a

Short control words: ego, emu, era, ado, vary, sofa, acid, exam, kilo, kiwi, Eden, lava, acne, ibis, saga, halo, Rosa, Reno, Anna, Dana, Ada, arena, alibi, aroma, karate, saliva, exotic, overdo, agora, okapi, omega, retina, Angola, elicit, elated, unison, Mexico, casino, elixir, albino, ironic, united

Short hiatus words: boa, ion, via, Leo, diet, lion, riot, bias, Noel, meow, neon, trio, coed, iamb, Zion, fiat, Lois, Noah, Joey, Leon, Rio, idiot, Korea, opium, violin, stereo, heroic, poetic, aorta, koala, tibia, podium, mosaic, maniac, caviar, phobia, studio, albeit, egoist, bionic, orient, period

Long control words: exploit, picker, fulfil, fisher, tumult, phonic, biceps, unroll, heater, fever, lucid, sonic, fatal, April, arrow, Japan, riser, tulip, debug, peril, lampoon, pacific, admiral, pitiful, arsenal, somatic, coconut, unicorn, limited, refusal, religious, refurbish, embroider, contusion, demolish, cosmetic, granular, implicit, rotation, pectoral, vocalist, condiment

Long hiatus words: triumph, pliant, client, fluent, truant, phooey, bluish, cooing, Boeing, react, kiosk, stoic, chaos, giant, fluid, Brian, rearm, triad, druid, pious, preempt, reactor, creator, pianist, archaic, soloist, copious, viaduct, curious, furious, scientist, quietness, diaphragm, congruent, affluent, Austrian, ganglion, nutrient, reappear, pancreas, vitreous, compliant

Experiment 3b

Control words: Eskimo, kimono, recipe, elixir, ironic, hexagon, casino, conical, orator, salami, editor, karate, amoral, abdomen, coconut, conifer, residue, minimal, diploma, benefit, lunatic, caribou, deficit, samurai, caravan, elastic, marital, belated, radical, kilogram, relation, proximal, horrific, indecent, thematic, funicular, avocado, aromatic, agitated, molecular, enigmatic, atomizer, Colorado, abdominal, emanation, economic, imitator, basilica, academic, epidemic, liberated, depositor, oracular, education, examiner, harmonica, perimeter, navigator, macaroni, agitator, honorific, agitation, dedicated, identical, executor, educated, catamaran, automatic, universal, adoration

Hiatus words: bionic, caveat, cereal, egoist, heroic, soloist, mosaic, meander, podium, stereo, studio, violin, zodiac, archaic, cardiac, chaotic, deviant, diagram, dialect, nuclear, pianist, prosaic, reactor, requiem, sangria, stadium, variant, viaduct, violent, affluent, creation, ganglion, pancreas, scorpion, vitreous, algebraic, Algeria, aquarium, radiator, valuation, biologist, dietetic, Colombia, diagnosis, deodorant, European, diabetic, diagonal, diameter, euphoria, geologist, gladiator, diabolic, situation, inferior, insomniac, intuition, mediation, meteoric, poetical, paranoiac, patriotic, radiation, coalition, zodiacal, situated, coagulant, realistic, variation, geometric