Journal of Memory and Language 67 (2012) 371–388

Contents lists available at SciVerse ScienceDirect

Journal of Memory and Language

journal homepage: www.elsevier.com/locate/jml

The internal structure of *chaos*: Letter category determines visual word perceptual units

Fabienne Chetail *, Alain Content

Université Libre de Bruxelles, Laboratoire Cognition Langage et Développement (LCLD), Belgium

ARTICLE INFO

Article history:
Received 21 January 2012
revision received 8 July 2012
Available online 13 August 2012

Keywords:
Vowel clusters
Syllables
Hiatus word
Visual word recognition
Orthographic units

ABSTRACT

The processes and the cues determining the orthographic structure of polysyllabic words remain far from clear. In the present study, we investigated the role of letter category (consonant vs. vowels) in the perceptual organization of letter strings. In the syllabic counting task, participants were presented with written words matched for the number of spoken syllables and comprising either one vowel cluster less than the number of syllables (hiatus words, e.g., *pharaon*) or the same number of vowel clusters (e.g., *parodie*). Relative to control words, readers were slower and less accurate for hiatus words, for which they systematically underestimated the number of syllables (Experiment 1). The effect was stronger when the instructions emphasized response speed (Experiment 2) and when concurrent articulation was used (Experiment 3), and the effect did not stem from phonological structure (Experiment 4). Furthermore, hiatus words were more slowly and less accurately pronounced than control ones (Experiment 5). Finally, in lexical decision, opposite effects occurred as a function of word length, with shorter words producing a facilitatory effect and longer words showing interference (Experiment 6). Taken together, the results show that perceptual units extracted from visual letter strings are influenced by the orthographic status of letters. We discuss the implications of such findings in view of current theories of visual word recognition.

Introduction

What do we see when we read a word? What are the functional units of word perception? These questions opened a paper by Santa, Santa, and Smith in 1977, who stated that the issue 'has generated an impressive body of literature in the last 75 years, but there is little agreement on an answer' (p. 585). More than 30 years later, the situation has hardly changed, and the claim still holds true.

The issue of orthographic coding in the perception of letter strings has been of interest since the earliest times of research on reading (Huey, 1908). The interest keeps on being high currently because understanding the basic processes of visual word recognition constitutes a keystone of any theory of reading. Visual word recognition is not performed letter by letter, but rather operates on larger letter chunks that are processed simultaneously. Hence, a recurrent question in the field is to determine what processing units are involved in the early steps of written word identification and how the perceptual processing system organizes letter strings into larger units. In the present paper, we report a set of studies aimed at exploring the role of letter category (consonant vs. vowel letters) in determining the internal structure of polysyllabic words.

The issue of perceptual units has been approached from different angles according to periods and dominant trends in the field. Below, we present an overview of the major approaches and then discuss their relevance for the perceptual processing of polysyllabic words, which is of specific interest in the present study.

* Corresponding author. Address: Laboratoire Cognition Langage et Développement (LCLD), Université Libre de Bruxelles, Av. F. Roosevelt, 50/ CP 191, 1050 Brussels, Belgium. Fax: +32 2 650 22 09.

E-mail address: fchetail@ulb.ac.be (F. Chetail).

0749-596X/$ - see front matter © 2012 Elsevier Inc. All rights reserved.
http://dx.doi.org/10.1016/j.jml.2012.07.004

Orthographic redundancy

Among early theories about perceptual processes in reading, Gibson's views (Gibson, 1965, 1971) were influential in driving attention towards learning of letter features and orthographic regularities. Gibson considered three aspects of what needs to be learnt: letter identification, which was conceived as discovering a set of discriminant visual features sufficient to differentiate between letters; mapping letters to phonemes; and extracting higher-order units. Starting from the claim that print cannot be processed on a letter-by-letter basis, Gibson initially argued in favor of invariant functional "spelling patterns". Gibson, Pick, Osser, and Hammond (1962) found with tachistoscopic presentations that the recognition rates were higher for orthographically legal and pronounceable pseudowords (e.g., *sland*) than for unpronounceable and orthographically illegal nonwords (e.g., *ndasl*). However, the fact that a similar advantage for pseudowords over nonwords was found for both deaf and hearing participants led Gibson, Shurcliff, and Yonas (1970) to conclude that it was not the relationship of spelling to sound that was essential but rather orthotactic rules. Perceptual units within words would be formed based on orthographic principles acquired through the discovery of invariant features, relations and permissible orthotactic combinations, the aim being to reduce uncertainty and to give structure to the word (Gibson, 1970, 1971).

Aside from Gibson's rule-governed conception, other studies based on a statistical approach showed that readers were sensitive to transitional probabilities between letters and that orthographic redundancy may facilitate letter and word perception (e.g., Anisfeld, 1964; Massaro, Taylor, Venezky, Jastrzembski, & Lucas, 1980; Morton, 1969; Singer, 1980). As underlined by Henderson (1982), most of those studies eschewed wholism and generally assumed no perceptual units larger than individual letters. One exception is Adams (1979, 1981) who argued that orthographic redundancy helps create perceptual units larger than letters. In particular, she stated that "Any two internal units that are repeatedly activated at the same time, will come to be associated such that activity in one facilitates activity in the other" (Adams, 1979, p. 169). Regular exposure to print would therefore enable the creation of a network of associated letter units, and activation of such a network would produce word parsing into letter clusters during the early stages of letter string processing. One way to incorporate this hypothesis in current modelling frameworks would be to assume a hierarchy of detectors, from visual features to letter groups, with higher-order units sensitive to frequency (see Dehaene, Cohen, Sigman, & Vinckier, 2005; Grainger & van Heuven, 2003; Vinckier et al., 2007; Whitney, 2001).

Print to sound mapping

Although the idea that orthographic structure might be constrained by print to speech mapping was already present in earlier views, the notion became focal with the development of theories of lexical access in the 1970s. More specifically, the assumption of a pre-lexical rule-based conversion process, either as an obligatory pathway to retrieve lexical information (e.g., Gough, 1972; Rubenstein, Lewis, & Rubenstein, 1971), or as one among several parallel processes as in dual-route theories (e.g., Coltheart, 1978; Forster & Chambers, 1973; Meyer, Schvaneveldt, & Ruddy, 1974), appeared to logically require that letter strings be parsed into the orthographic counterparts of linguistic units. Further, Coltheart (1978) argued that the only plausible analytic possibility for phonological encoding was based on grapheme–phoneme conversion (GPC) rules. According to that view, when a letter string is processed through the indirect GPC procedure, it is first analyzed into its constituent graphemes and then graphemes are converted into phonemes and blended together. This analysis led to discard print-sound correspondences based on larger units such as syllable-sized units or vocalic center groups (Hansen & Rodgers, 1965; Spoehr & Smith, 1973).

Despite their logical plausibility, graphemes are neither the only nor the optimal solution for analytical print to speech conversion. Indeed, the description of consistency effects (Glushko, 1979) and the observation that many inconsistencies at the graphemic level could be resolved by taking higher-order correspondences into account, led many researchers to envisage multiple levels of orthographic segmentation and phonological conversion (e.g., Patterson & Morton, 1985; Shallice & McCarthy, 1985; Taft, 1991; see also Santa, Santa, & Smith, 1977).

The hypothesis of multiple unit activation during written word processing has been recently integrated in the psycholinguistic grain size theory of Ziegler and Goswami (2005). In their view, depending on language characteristics, some phonological units within words become more salient than others, with the growth of vocabulary during primary language acquisition. Reading acquisition then consists in learning to map pre-existing phonological representations of words to the corresponding written patterns and this mapping would preferentially rely on the most salient phonological units. Hence, while children have to understand that letters or letter groups (graphemes) correspond to phonemes, characteristics of their language can drive them to use both small and large unit recoding strategies in parallel. In agreement with such a view, experimental evidence supports the claim of activation of multiple levels of units in written word processing in adults (e.g., Carreiras, Alvarez, & de Vega, 1993; Peereman, Brand, & Rey, 2006; Ziegler & Perry, 1998).

Polysyllabic word processing

Most of the research described above is based on studies using short, monosyllabic letter strings. For longer words, syllable-sized units appeared as a natural and most plausible hypothesis (e.g., Carreiras et al., 1993; Mewhort & Beal, 1977; Spoehr & Smith, 1973; Taft & Forster, 1976), but different views mirroring the trends described above were voiced about the principles that would determine segmentation. Thus, whether the perceptual units driving polysyllabic word recognition are primarily determined by orthotactic knowledge such as co-occurrence frequencies or by the correspondence with spoken syllables remains controversial.

A first indication favoring an early orthographic parsing mechanism was provided by Taft (1979). Based on a series of lexical decision studies with split words, Taft observed that performance was more disrupted when the division corresponded to phonological syllables than when it was based on an orthographic principle, and he argued that the access code used for word recognition consisted in the "part of its first morpheme that includes after its first vowel all consonants that do not violate rules of orthographic co-occurrence" (p. 35).

Prinzmetal and colleagues (Prinzmetal, Hoffman, & Vest, 1991; Prinzmetal, Treiman, & Rho, 1986) further explored the issue, using a task not directly related to lexical access. They reported that illusory conjunctions between the color and the identity of the target letter were constrained by the orthographic structure. For words such as *VODKA*, which have unit boundaries defined both orthographically (i.e., *dk* is not an orthographic legal cluster at the end or the beginning of words) and phonologically (i.e., the syllabified phonological word form is /vod-ka/), the medial letter (D) tended to be erroneously perceived as sharing the color of the preceding letters. By contrast for words such as *NAIVE*, which have boundaries defined only phonologically (i.e., the syllabification is /na-iv/ but the cluster *ai* can also occur within a single syllable), the conjunction errors did not indicate a preferential attachment of the medial letter to the preceding or to the following letter group. According to the authors, readers store rules of spelling (identity and position of legal consonant and vocalic clusters, see also Gibson, 1965, 1971) and this orthographic knowledge on letter co-occurrences enables readers to extract perceptual units without relying on phonological information. Similarly, Seidenberg (1987) proposed that letter cluster frequencies are prominent cues for word parsing into perceptual units (see also Adams, 1981; Srinivas, Roediger, & Rajaram, 1992). In particular, Seidenberg (1987) suggested that illusory conjunction effects were determined by the relative frequencies of adjacent bigrams, and more specifically by a bigram trough pattern, that is, a low frequency bigram surrounded by higher frequency ones on both sides. Because bigrams straddling syllable boundaries are generally less frequent than bigrams flanking syllable boundaries, the bigram trough would most of the time define an orthographic boundary coinciding with the syllable boundary. However, although these results provide an elegant account of how orthographic regularities may underlie early perceptual unitization, follow-up studies reported illusory conjunction effects even when boundaries were not marked by a bigram trough (e.g., Conrad, Carreiras, Tamm, & Jacobs, 2009; Doignon & Zagar, 2005; Rapp, 1992). These findings led many to assume that orthographic redundancy characteristics are not the only properties determining the delimitation of perceptual units and to disregard the influence of orthographic factors in the perceptual organization of print.

Furthermore, other studies reported syllabic effects associated with phonological syllable structure. The focal finding in this domain is the syllable frequency effect, first reported by Carreiras et al. (1993) and replicated several times afterwards (e.g., Chetail & Mathey, 2009b; Conrad, Grainger, & Jacobs, 2007; Conrad & Jacobs, 2004; Perea & Carreiras, 1998). The syllabic nature of the effect has been confirmed by priming studies showing that recognition is faster for words preceded by primes sharing the same first letters as well as the first syllable (e.g., *vi.rel – VI.RUS)* rather than the first letters only (*vir.ga – VI.RUS*; Alvarez, Carreiras, & Perea, 2004; Carreiras & Perea, 2002; Chetail & Mathey, 2009a). The phonological status of the effect has been supported by the finding that the priming effect was no larger when both the letter string and the syllable were shared between primes and targets (*vi.rel – VI.RUS)* than when there was an orthographic mismatch (*bi.rel – VI.RUS*; Spanish, Alvarez et al., 2004; see also Carreiras, Ferrand, Grainger, & Perea, 2005). A converging conclusion of this set of studies is that syllabic effects in reading ensue from the activation of (phonological) syllable representations stored in memory (e.g., Alvarez et al., 2004; Ashby & Rayner, 2004; Conrad, Tamm, Carreiras, & Jacobs, 2010; Conrad et al., 2007, 2009; Mathey, Zagar, Doignon, & Seigneuric, 2006). Whether this reflects only the activation of phonological syllabic units or also the existence of orthographic codes corresponding to the spoken syllables (henceforth, graphosyllables) remains an open question, and both possibilities have been proposed or even implemented (Ans, Carbonnel, & Valdois, 1998; Conrad et al., 2009, 2010; Mathey et al., 2006). The CDP++ model (Perry, Ziegler, & Zorzi, 2010) provides a detailed hypothesis of initial word parsing into graphemes mapping onto spoken syllables. Letter strings are parsed into graphemes and graphemes are assigned to onset, nucleus and coda constituent slots. To assign consonants between the nuclei of bisyllabic words to the coda of the first syllable or to the onset of the second one, the model relies on the onset maximization (e.g., Pulgram, 1970) and legality principles. Consonant graphemes are assigned to onset positions provided the resulting orthographic string has been attested in the given position during learning. Otherwise the assignment is revised by shifting the leftmost consonant back into the coda of the first graphosyllable.

In sum, two different views have been adopted to account for syllable structure effects within long words: orthographic regularities and phonological syllabic activation. The hypothesis of orthographic parsing seems to have crystallized on the bigram trough hypothesis, and has been put aside due to lack of clear-cut evidence. The hypothesis explored in the present study is that other orthographic cues – more specifically the categorization of letters in two classes, vowels and consonants – determines letter string perceptual structure (hereafter, *consonant letter* and *vowel letter* are used to refer to *written* consonant and vowels, and not to phonological ones). This hypothesis is supported by some recent studies in both spelling and reading. Kandel, Hérault, Grosjacques, Lambert, and Fayol (2009) analyzed children's handwriting productions and compared monosyllabic words with a final silent E (i.e., *barque*, /baʀk/) with bisyllabic words (e.g., balcon, /balkõ/). Both types of words were processed rather similarly, with writing and pause durations indicative of a two-part structure. Such results have been extended by Chetail and Content (2012) in off-line and on-line reading tasks. Skilled readers consistently parsed bisyllabic words with an internal silent E (e.g., *biberon*, /bi-bʀo~/) as a function of the number of vowel letters (i.e., *bi/be/ron*) thus leading to three parts. Consistently, letter detection performance showed that the consonant letter following the silent *E* (e.g., *R* in *biberon*) was processed as the first letter of a unit (i.e., *ron*) and not as a letter embedded in a multi-letter onset (i.e., *beron*). Taken together, these data suggest that vowel letters drive word parsing, an idea already proposed by Hansen and Rodgers (1965; see also Spoehr & Smith, 1973, 1975). According to them, polysyllabic word parsing into perceptual units occurs without directly relying on phonology in the first stages, but rather on the distinction between consonant and vowel letters. The procedure begins with the detection of vowel letters in the string. If several non consecutive vowels are detected, this implies that the letter string contains more than one unit and the string needs to be parsed according to precise rules.

This proposal has received little attention, most likely because Hansen and Rodgers (1965) assumed that the resulting orthographic structure served as the basis for phonological transcoding, a view thoroughly discussed and ruled out *a priori* by Coltheart (1978; see also Mewhort & Campbell, 1981). For words exhibiting a silent *E* (e.g., *force*) or a hiatus pattern (i.e., contiguous vowels that are pronounced separately, as in *chaos*), the orthographic structure predicted (e.g., two units in *force*, one unit in *chaos*) mismatches the phonological syllabic structure (e.g., one and two units respectively).

However the possibility that such a structure would exist, without constituting the support for ortho-phonological mapping has not been considered much. Moreover, the proposal that consonant/vowel (C/V) distinction drives word parsing into perceptual units is in line with the hypothesis of an early distinction between vowels and consonants during word recognition (Berent & Perfetti, 1995), which has received much support in the last 10 years in psycholinguistic (e.g., Lee, Rayner, & Pollatsek, 2001, 2002; New, Araújo, & Nazzi, 2008), brain imaging (e.g., Carreiras & Price, 2008; Vergara-Martínez, Perea, Marín, & Carreiras, 2010), as well as neuropsychological (e.g., Buchwald & Rapp, 2006; Caramazza, Chialant, Capasso, & Miceli, 2000; Miceli, Capasso, Benvegnu, & Caramazza, 2004) studies.

The present study

The aim of the present study was to examine the role of letter category (C/V) in the perceptual organization of polysyllabic written words. We focused on the proposal according to which the number of vowel clusters underlies unit perception within written words (Chetail & Content, 2012; Hansen & Rodgers, 1965; Kandel et al., 2009). To test this hypothesis, we used words having one vowel cluster less than the number of syllables (hiatus words, e.g., *pharaon*, /fa.ʀa.ɔ̃/) and compared them to words in which the number of syllables and the number of vowel clusters were identical (control words, e.g., *parodie*, /pa.ʀɔ.di/). Contrary to the English language, in which the same vowel cluster may often constitute either a single grapheme or two adjacent graphemes in different words (e.g., *waive* vs. *naive*, *real* vs. *reality*), most vowel clusters in French correspond either to a single grapheme (e.g., *au* → /o/, *eu* → /ø/, *ou* → /u/), or to two graphemes (e.g., *ao* → /ao/, *oa* → /oa/). All vowel clusters used in the present study very consistently corresponded to distinct graphemes. The hiatus clusters used were thus not ambiguous in terms of print-sound mapping.

In the first four experiments, readers performed a forced-choice syllable counting task, which allowed us to test whether people underestimate the number of syllables in hiatus words due to orthographic structure. Syllable counting with spoken words has been used in phonology to investigate syllabification preferences (see Content, Kearns, & Frauenfelder, 2001) and also with young children to assess phonological awareness (Liberman, 1973; Liberman, Shankweiler, Fischer, & Carter, 1974; see Morais, Alegria, & Content, 1987). We assumed that the analog with printed stimuli would be a simple and natural task for adults, also suited for reaction time analysis.

One potential limitation of the syllable-counting task is that it requires an explicit metalinguistic judgment, and many researchers in the field would hesitate to ascribe the properties identified in conscious metalinguistic judgments to perceptual representations (e.g., Morais & Kolinsky, 1994). It is however noteworthy that such metalinguistic tasks often produce evidence compatible or even convergent with on-line tasks (see Titone & Connine, 1997; Treiman, Kessler, & Bick, 2002). Furthermore, in the present case, the thrust of the study does not lie in the metalinguistic performance per se but rather in the indirect effect of a putative perceptual property of written words – namely the organization of letter strings into units according to vowel clusters – on those judgments.

Finally, given that syllable counting does not necessarily reflect the perceptual organization that is involved in visual word recognition, we conducted two further experiments to assess whether the presence of a hiatus pattern impacts on naming and lexical decision. Although such tasks provide no direct information on the nature and result of the orthographic parsing processes, they complement the first set of studies by documenting the influence of orthographic structure on word identification.

Experiment 1

To examine the role of vowel letter clusters in the perception of orthographic units, participants were presented with bi- and tri-syllabic printed words containing either two adjacent vowel graphemes (hiatus words) or not (control words). Readers had to decide as quickly and accurately as possible if the written words were one-, two-, or three-syllable long. Phonologically, both control and hiatus words are syllabified without any ambiguity because each full vowel constitutes the core of a syllable. In contrast, in the written form, contiguous vowels in hiatus words *visually* entail a single vowel cluster, and would therefore be the perceptual basis for a single unit if readers relied on C/V letter categories. If participants exhibit difficulties in performing their judgment when there is a discrepancy between the number of syllabic units and the number of vowel clusters (i.e., delayed reaction times

Table 1
Characteristics of the experimental words used in Experiments 1–3.

	Number of syllables			
	Two		Three	
	Hiatus word	Control word	Hiatus word	Control word
Example	*cruel*	*rugir*	*pharaon*	*parodie*
Number	45	45	45	45
Lexical frequency	12.64	8.80	5.11	6.10
Number of letters	5.09	5.11	7.02	7.00
Number of phonemes	4.38	4.38	5.93	6.09
Summed bigram frequency	9756	10,956	13,773	12,029

Note: Lexical frequency and summed bigram frequency are given in number of occurrences per million.

and more errors for hiatus words than for control words), it would demonstrate that vowel clusters constrain perceptual structure.

Method

Participants

Forty-two students participated in the experiment for course credits. They were all native French speakers and reported having normal or corrected-to-normal vision.

Stimuli

A set of 180 French words was selected in the Lexique database (New, Pallier, Brysbaert, & Ferrand, 2004) according to the orthogonal combination of two factors in a 2 × 2 design: Number of syllables and Type of words (see Table 1). Half of the words were bisyllabic (e.g., *cruel*, *récif*) and the other half were trisyllabic (e.g., *goéland*, *onéreux*). Similarly, 90 words (hiatus words) contained a hiatus, that is, two contiguous vowel graphemes (e.g., *cr<u>ue</u>l*, *go<u>é</u>land*), while the remaining words exhibited no hiatus (e.g., *récif*, *onéreux*), and were matched on lexical frequency, number of letters, number of phonemes, and summed bigram frequency (control words). None of the 180 words contained a final or internal schwa (see Appendix A for the complete list of the stimuli). Phonologically, all the items were thus non-ambiguous concerning syllabic length and syllable boundaries. Ninety monosyllabic words were added as fillers so that the same number of "1", "2", and "3" responses should be elicited.

Procedure

Participants performed a number of units judgment task programmed with the DMDX software (Forster & Forster, 2003). For each trial, a fixation cross was presented for 500 ms in the center of the screen, followed by a centered lowercase word which remained on the screen until the participants responded or 3000 ms had elapsed. Words were displayed in Courier New font. Participants had to decide as quickly and as accurately as possible whether the target word had one, two, or three syllables. To give their responses, participants had to press one of three contiguous keys on the keyboard with the three central fingers of their dominant hand. The leftmost finger was use to respond one syllable, the forefinger to respond two syllables, and the rightmost finger to respond three syllables. Response times were measured from target onset. Participants performed nine practice trials before receiving the 270 trials in a variable random order.

Results and discussion

The mean correct reaction times and mean error rates averaged over participants are presented in Table 2. The data were submitted to separate analyses of variance on the participant means ($F1$) and on the item means ($F2$) with Word Type (hiatus, control) and Number of Syllables (2, 3) as factors.

Analyses on reaction times showed that hiatus words elicited longer reaction times than control words, $F1(1,41) = 148.25$, $p < .001$, $F2(1,176) = 125.00$, $p < .001$. In addition, trisyllabic words were processed more slowly than bisyllabic words, $F1(1,41) = 28.61$, $p < .001$, $F2(1,176) = 23.00$, $p < .001$, and the effect of word type was stronger for trisyllabic words than bisyllabic words, $F1(1,41) = 41.27$, $p < .001$, $F2(1,176) = 15.38$, $p < .001$.

In the error rate analyses, there was a significant effect of word type, $F1(1,41) = 30.69$, $p < .001$, $F2(1,176) = 41.28$, $p < .001$, hiatus words producing more errors than control words. There was no significant effect of syllabic length, $F1(1,41) = 1.09$, $p = .30$, $F2 < 1$. The interaction between these two factors was significant in the participant analysis only, $F1(1,41) = 5.47$, $p = .02$, $F2(1,176) = 3.22$, $p = .07$.

The data clearly showed that hiatus words were more difficult to process than control words. Readers made more errors for such words, and it took them longer to judge that words such as *cruel* had two syllables compared to words such as *rugir*, and that words such as *pharaon* had three syllables compared to words like *parodie*. The prediction that it is more difficult to count the number of units in hiatus words was therefore confirmed. Further, if printed word structure is based on vowel clusters, readers should underestimate the number of syllables in hiatus words. We thus examined the nature of errors on bisyllabic items. As expected, readers produce many more "1" than "3" responses for hiatus words, 10.9% vs. 1.4% respectively, $F(1,41) = 31.65$, $p < .001$, while there was no difference for control words, 3.0% vs. 3.4% respectively, $F < 1$. Errors on bisyllabic control words appear therefore distributed randomly whereas hiatus words led to frequent underestimation errors, suggesting that participants relied on the number of vowel clusters rather than on the number of syllables per se.

If perception of units within written words was entirely driven by orthography, error rates for hiatus words should approach 100%. Clearly this was not the case as the rate of errors on hiatus words was much lower (approximately 13%). On the other hand, if the number of vowel clusters did not influence written word structure, the percentage of errors should not differ for hiatus and control words, and both type of items should have elicited similar latencies. Again, this was not the case. A possible explanation for the intermediate results we found is that readers relied both on the orthographic structure and on the phonological form to perform the task. Actually, at debriefing most of the participants declared that they would resort to

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

	Word type		
	Hiatus	Control	*Differences*
Number of syllables			
Two	1110 (12.3)	996 (6.5)	*114 (5.8)*
Three	1253 (13.5)	1016 (2.9)	*237 (10.6)*

subvocal pronunciation. We thus hypothesized that the underestimation errors are caused by early processes of visuo-orthographic analysis based on the detection of vowel clusters. However, the influence of this analysis on performance may be limited by the intentional recourse to phonological structure which provides counteracting information since phonologically, each vowel constitutes a syllabic nucleus. If this is the case, we reasoned that the influence of the number of vowel letter groups on number of unit judgments (henceforth, the *vowel effect*) should increase if the task is made simpler so that performance would be faster. This was the aim of Experiment 2.

Experiment 2

In the second experiment, participants had to perform a simpler version of the same task as in Experiment 1. We set up a 2- rather than a 3-alternatives forced-choice situation by blocking the presentation of bisyllabic and trisyllabic words, and we used instructions that emphasized speed rather than accuracy. Under such conditions, we expected participants to resort less to subvocal pronunciation than in Experiment 1, which should produce a stronger vowel effect (i.e. larger difference of error rates between hiatus and control words).

Method

Participants

Forty-four students participated in the experiment for course credits. They were all native French speakers and reported having normal or corrected-to-normal vision. None of them had participated in the previous experiment.

Stimuli

The same stimuli as in Experiment 1 were used, except that 90 additional bisyllabic words were selected from Lexique (New et al., 2004) as fillers.

Procedure

The procedure was the same as in Experiment 1 except that the presentation of the bisyllabic and trisyllabic words was blocked. The 90 experimental bisyllabic words (45 hiatus and 45 controls) plus 90 monosyllabic fillers were used in one block, while the 90 experimental trisyllabic words plus 90 bisyllabic fillers were presented in the other block. In each, participants used their two index fingers to respond by pressing one of the two shift keys, the rightmost key corresponding to the highest number. The order of the two blocks was counterbalanced across participants.

Results and discussion

The mean correct reaction times and mean error rates averaged over participants are presented in Table 3. For one participant, reaction time data were not considered because the error rates were very high (93% for bisyllabic hiatus words and 100% for trisyllabic hiatus words) but his data were retained in the error analysis. As in Experiment 1, the data were submitted to separate analyses of variance on the participant means ($F1$) and on the item means ($F2$) with Word Type (hiatus, control) and Number of Syllables (2, 3) as factors.

The pattern of results was highly similar to that of Experiment 1. Hiatus words elicited reaction times longer than control words, $F1(1,42) = 84.34$, $p < .001$, $F2(1,176) = 148.26$, $p < .001$. Additionally, trisyllabic words were processed significantly more slowly than bisyllabic words, $F1(1,42) = 55.55$, $p < .001$, $F2(1,176) = 177.92$, $p < .001$. Finally, the effect of Word Type was larger for trisyllabic words than for bisyllabic words, $F1(1,42) = 18.62$, $p < .001$, $F2(1,176) = 11.18$, $p = .001$.

In the error rate analysis, the effect of word type was significant, $F1(1,43) = 24.87$, $p < .001$, $F2(1,176) = 67.98$, $p < .001$, hiatus words producing more errors than control words. There was no significant effect of syllabic length, $F1(1,43) = 1.91$, $p = .17$, $F2(1,176) = 1.47$, $p = .23$. The interaction between these two factors was not significant, $Fs < 1$.

Participants were faster in Experiment 2 than in Experiment 1, $F(1,84) = 4.15$, $p < .001$. To test whether this effect was accompanied by an increase of the vowel effect, we compared error rates for hiatus words and control words as a function of Experiment (1 vs. 2). The interaction was significant only in the item analysis, $F1(1,84) = 2.12$, $p = .15$, $F2(1,178) = 16.77$, $p < .001$ (see Fig. 1).

The results were thus fully consistent with those of Experiment 1. Participants processed hiatus words more slowly and less accurately than control words. The error rate for hiatus words was still far from 100%, but the number of vowel clusters again reliably influenced accuracy and processing time. However, although the instructions emphasizing speed over accuracy and the procedural changes introduced in the present experiment did lead to somewhat shorter response times overall, they induced only a limited increase in the size of the vowel effect. Yet, response times were well above the time required to access phonology and participants could still rely on phonological information. To reduce as much as possible the intentional resort to phonology, we conducted a third experiment using concurrent articulation. Participants

Table 3
Mean reaction times (in ms) and percentage of errors (in parentheses) on target words in Experiment 2.

	Word type		
	Hiatus	Control	*Differences*
Number of syllables			
Two	868 (17.3)	776 (5.6)	*92 (11.7)*
Three	1077 (19.6)	891 (6.5)	*186 (13.1)*

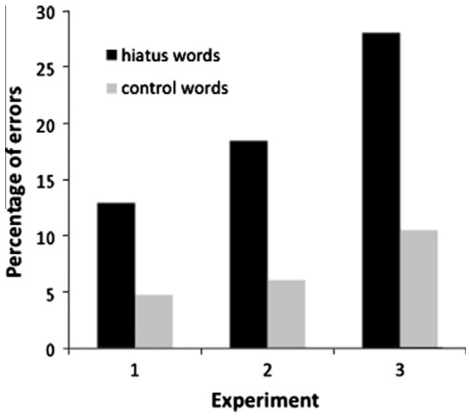

Fig. 1. Error rates for words according to Experiment and word type.

had to overtly and continuously repeat a phonological sequence while performing the number of units task.

Experiment 3

Participants performed the same task as in Experiment 2, but the influence of phonology was limited by asking participants to overtly and continuously repeat the phonological sequence /patipato/. They were also asked to perform the task as quickly as possible. In these conditions, we expected a stronger vowel effect than in Experiment 1, because concurrent articulation should disrupt access to phonological information.

Method

Participants

Forty students participated in the experiment for course credits. They were all native French speakers and reported having normal or corrected-to-normal vision. None of them had participated in the previous experiments.

Stimuli

The same stimuli as in Experiment 2 were used.

Procedure

The procedure was identical to that of Experiment 2 except that participants had to continuously repeat aloud /patipato/ during each block of trials without speech errors. The maintenance of concurrent articulation was monitored by the experimenter throughout the task.

Results and discussion

The mean correct reaction times and mean error rates averaged over participants are presented in Table 4. For three participants, the mean reaction times for one of the four conditions were not considered because the corresponding error rate was very high (73%, 93%, and 96%). Similarly, the mean reaction times for three items were not considered (error rates of 70%, 80%, and 80%). The corresponding data were nevertheless retained in the error analyses. As in previous experiment, the data were submitted to separate analyses of variance on the participant means ($F1$) and on the item means ($F2$) with Word Type (hiatus, control) and Number of Syllables (2, 3) as main factors. Once again, the pattern of results was similar to that of Experiments 1 and 2.

Table 4
Mean reaction times (in ms) and percentage of errors (in parentheses) on target words in Experiment 3.

	Word type		
	Hiatus	Control	*Differences*
Number of syllables			
Two	949 (25.4)	917 (9.6)	*32 (15.8)*
Three	1147 (30.7)	1008 (11.6)	*139 (19.1)*

Hiatus words elicited reaction times longer than control words, $F1(1,36) = 38.94$, $p < .001$, $F2(1,173) = 55.51$, $p < .001$. Trisyllabic words were processed significantly more slowly than bisyllabic words, $F1(1,36) = 31.65$, $p < .001$, $F2(1,173) = 99.93$, $p < .001$, and the effect of type of words was larger for trisyllabic words than bisyllabic words, $F1(1,36) = 19.74$, $p < .001$, $F2(1,173) = 12.82$, $p < .001$. In the error rate analysis, the effect of word type was highly significant, $F1(1,39) = 66.42$, $p < .001$, $F2(1,176) = 68.15$, $p < .001$, hiatus words producing more errors than control words. The effect of number of syllables reached significance in the participant analysis, $F1(1,39) = 4.77$, $p = .04$, $F2(1,176) = 3.05$, $p = .08$, and the interaction was not significant, $Fs < 1$.

To test whether the use of concurrent articulation produced an increase in the vowel effect, we compared error rates for hiatus words and control words as a function of Experiment (2, 3). The vowel effect was larger in Experiment 3, although the interaction failed to reach significance in the participant analysis, $F1(1,82) = 2.34$, $p = .13$, $F2(1,178) = 17.49$, $p < .001$. To assess whether the two manipulations produced gradual increases of the vowel effect on errors (computed as the error rate difference between hiatus and control words), we conducted a two-way ANOVA on participant error rates with Experiment (1, 2, 3) as main factor. The vowel effect varied, $F(2,123) = 4.86$, $p = .009$, and as predicted, the linear polynomial contrast was significant, showing that the vowel effect increased gradually from Experiment 1 to Experiment 3, $F(1,123) = 9.70$, $p = .002$ (see Fig. 1).

To summarize, the data in Experiment 3 were consistent with those of the two previous experiments. The pattern of results was similar, except that error rates for hiatus words increased relative to control words, thus providing additional evidence for a strong influence of vowel clusters on length judgments.

Nevertheless, accuracy remained relatively high for hiatus words even with concurrent articulation, which raises the question of how participants reached the correct decision. We believe that it is likely that they could still rely on phonological information. Besner (1987) argued that concurrent articulation does not prevent phonological recoding and access to phonological information. Indeed, interference due to concurrent articulation arose only in tasks requiring phonological manipulations (e.g., phonemic segmentation, rhyming judgment), but not in tasks requiring simple homophony judgments. Even in tasks in which concurrent articulation was detrimental, performance remained largely above floor (e.g., Besner, Davies, & Daniels, 1981). Moreover, Levelt and Wheeldon (1994) proposed that once word form is retrieved for phonological encoding, metrical information becomes quickly available, with the metrical frame specifying at least the number of syllables and stress pattern of the word. Hence, despite concurrent articulation participants may have retrieved sufficient phonological information to perform the syllable counting task.

Common analyses

Additional post hoc analyses were run to ensure that the effects we reported were genuine letter category effects and not due to other orthographic properties of the stimuli. In particular, the fact that bigrams that straddle graphosyllabic boundaries are naturally less frequent than bigrams preceding and following boundaries (i.e., bigram trough pattern) may provide an orthographic cue for letter string segmentation (e.g., Seidenberg, 1987; Seidenberg & McClelland, 1989). If bigram frequency patterns determine segmentation, one would predict no vowel effect for hiatus words exhibiting a bigram trough pattern at the assumed syllabic boundary, because the location of the lowest bigram is consistent with a phonologically based judgment, leading to the correct response. To test this hypothesis, two subsets were constituted among the hiatus words, according to the presence (62 items) or not (20 items) of a bigram trough pattern. Contrary to the hypothesis, item analyses showed that both items with and without a bigram trough pattern were processed more slowly and less accurately than control words in all three experiments (for all *t*-tests: $p < .001$).

Similarly, the frequency of the bigram straddling the critical syllabic boundary did not explain the pattern of results. Both words containing relatively frequent vowel bigrams (45 items, e.g., *ie*, *ue*, *io*) and words containing less frequent bigrams (45 items, e.g., *uo*, *oa*, *éo*) were less easily processed by the participants than the corresponding control words (for all *t*-tests: $p < .001$). Finally, roughly one third of the hiatus words exhibited a diacritic mark on one of the vowel letters (31 items, e.g., *éa*, *aï*, *éo* vs. 59 items), which could have provided an additional orthographic cue to segment within the critical vowel cluster. Once again however, both words with and without diacritic marks were processed more slowly and less accurately than control words (all *t*-tests: $p < .001$).

Experiment 4

The first three experiments provide clear-cut evidence favoring a critical role of vowel letters in unit perception within polysyllabic words. A vowel effect was observed while participants can or cannot rely on subvocal pronunciation, and post hoc analyses showed that this effect could not be attributed to orthographic redundancy cues or diacritic marks.

To strengthen the claim that the vowel effect is driven by the arrangement of vowel and consonant *letters* in the orthographic string and not by phonological cues, we conducted a fourth experiment where the C/V alternation in hiatus word was manipulated separately at the phonological and orthographic level. We compared two kinds of hiatus words, both exhibiting two contiguous phonological full vowels. In one case, the hiatus coincided with contiguous vowel letters (e.g., *chaos*, /kao/) thus entailing one vowel cluster in bisyllabic words. These items were of the same sort as the hiatus words used in Experiment 1–3. In the other case, the hiatus pattern coincided with two vowel letters separated by a consonant (e.g., *bahut*, /bay/, with the *h* silent), thus leading to two vowel clusters. In such words, although the phonological form contains two contiguous vowels, the alternation of orthographic consonants and vowels is fully compatible with word syllabification (i.e., two distinct vowel clusters in bisyllabic words). Hence, if the vowel effect found in the previous experiments genuinely stems from the arrangement of consonant and vowel letters, only hiatus words such as *chaos* should be processed more slowly and less accurately. In contrast, if the effect is due to the presence of two contiguous *phonological* vowels, it should be noticeable in both sets of hiatus words, compared to control items.

Method

Participants

Thirty-three students participated in the experiment for course credits. They were all native French speakers and reported having normal or corrected-to-normal vision. None of them had participated in any of the previous experiments.

Stimuli

Forty-five triplets of French words were selected from the Lexique database (New et al., 2004). In each triplet, two words exhibited a phonological hiatus pattern (i.e., two contiguous full vowels). In one of them, the two adjacent vowels coincided with two contiguous vowel letters, as in Experiments 1–3 (e.g., *chaos*, /kao/). The hiatus was thus present both in written and spoken form (OP Hiatus set). In the other (P Hiatus set), the two vowels producing the hiatus pattern were separated by one or two mute consonant letters (e.g., *bahut*, /bay/, *h* being a silent letter). In that case, the hiatus pattern is present at the phonological level but not orthographically, since the two vowel graphemes are separated by at least one consonant letter. The third word of the triplet was a control word exhibiting no hiatus pattern at all and matched with the two hiatus words for lexical frequency, number of letters, number of syllables, and summed bigram frequency (see Table 5). Though the 45 triplets included both bi- and tri-syllabic words, it was not possible to equate triplets according to the number of syllables, and there were 29 trisyllabic triplets and 16 bisyllabic ones. None of the 135 words contained a final or internal schwa (see Appendix B for the complete list of the stimuli). Phonologically, all items were thus non-ambiguous concerning their number of syllables and syllable boundaries. Monosyllabic (87 words) and bisyllabic (39 words) fillers were added, so that the same number of mono-, bi- and tri-syllabic words would be presented overall.

Procedure

The procedure was identical to that of Experiment 1.

Results and discussion

The mean correct reaction times and mean error rates averaged over participants are presented in Table 6. One trial with an extreme reaction time (<300 ms) was removed before conducting the analyses. The data were submitted to separate analyses of variance on the participant means ($F1$) and on the item means ($F2$) with Word Type (OP hiatus, P hiatus, control) as single factor.

For reaction times, there was a significant effect of word type, $F1(2,64) = 40.29$, $p < .001$, $F2(2,132) = 26.26$, $p < .001$. Planned comparisons showed that OP hiatus words were responded to more slowly than control words, $F1(1,32) = 55.67$, $p < .001$, $F2(2,132) = 39.65$, $p < .001$, while there was no significant difference between P hiatus and control words, both $Fs < 1$.

Similarly in the error rate analysis, there was a significant effect of word type, $F1(2,64) = 17.70$, $p < .001$, $F2(2,132) = 13.38$, $p < .001$. OP hiatus words produced more errors than control words, $F1(1,32) = 20.92$, $p < .001$, $F2(2,132) = 20.39$, $p < .001$, while there was no significant difference between P hiatus and control words, both $Fs < 1$.

The present data thus clearly show that only OP hiatus words were processed more slowly and less accurately than control words. This provides a further demonstration that the vowel effect is not due to the phonological hiatus pattern but rather to the presence of a sequence of adjacent vowel letters in the printed stimuli. It appears as easy to judge the number of syllables in P hiatus words as in control words. In both cases the alternation of consonant and vowel letters helps structure letter strings according to the number of vowel clusters, which in this case is consistent with the number of syllables (e.g., *envahir, épatant*, respectively, both three-syllable long). In OP hiatus words in contrast, the fact that the two vowel letters coding for the hiatus pattern were not separated leads to parse the string into two orthographic units, (e.g., *croasser*), which is inconsistent with the number of syllables.

As in Experiment 1, we examined the nature of errors for hiatus and control bisyllabic words. We conducted a three-way ANOVA with word type (OP hiatus, P hiatus, control) and error type (1 syllable, 3 syllables) on the number of errors made by participants for the bisyllabic stimuli. As expected, readers made more underestimation than overestimation errors for OP hiatus words, 12.0% vs. 2.8% respectively, $F(1,32) = 9.30$, $p = .005$, while there was no difference for either P hiatus words, 2.5% vs. 5.1% respectively, $F(1,32) = 1.61$, $p = .21$, or control words, 5.3% vs. 2.8% respectively, $F(1,32) = 1.04$, $p = .32$. In sum, errors for OP hiatus words correspond to underestimation of syllabic length, whereas they are distributed randomly for P hiatus and control words.

Table 5
Characteristics of the experimental words used in Experiment 4.

	Word type		
	OP hiatus	P hiatus	Control
Example	*chaos*	*bahut*	*enjeu*
Number	45	45	45
Number of bi-/tri-syllabic words	16/29	16/29	16/29
Lexical frequency	3.28	5.91	5.80
Number of letters	6.89	6.89	6.89
Number of phonemes	5.64	4.82	5.53
Summed bigram frequency	11,192	13,257	11,170

Note: Lexical frequency and summed bigram frequency are given in number of occurrences per million.

In the first four experiments, we found clear-cut evidence that vowel organization within letter strings influences syllable counting. This effect would reflect readers' sensitivity to vowel clusters as perceptual cues to printed word structure.

However, an alternative explanation of the vowel effect would be in terms of strategic processes rather than perceptual processes. For instance, participants might have counted the number of vowel clusters as a proxy to the number of syllables. This strategy might seem sensible in French given the existence of numerous vowel clusters that constitute graphemes and correspond to syllabic nuclei. 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. Interestingly, at debriefing, some participants declared that they tried to use a strategy based on vowel cluster counting at the beginning of the task, but quickly gave up because such a strategy often led them to erroneous responses (given that one third of the items were hiatus words). In contrast, almost all the participants reported resorting to pronunciation. Nevertheless, although participants reported relying on phonological syllabification – a strategy that enabled them to give correct responses –, their responses were less accurate and slower for hiatus words. Our claim is that this effect occurs because of a conflict between phonological syllabic structure and the perceptual orthographic structure which derives from the organization of the letter string into vowels and consonants. We assume that visual word perception is driven by a hierarchy of increasingly complex detectors, all the way from local elementary visual features to more abstract multiletter structures. This system would be shaped through perceptual learning during reading acquisition and experience, so that the highest level of orthographic units would capture conjunctive properties determined by co-occurrence statistics and linguistic (phonological, morphological) relevance. Both for statistical as well as for linguistic reasons, the consonant/vowel categorization would seem likely to constrain the organization of that system. Given the quasi-systematic mapping of vowel *letters* to vowels and consonant *letters* to consonants, orthographic units would most often correspond in number to (phonological) syllables. Hence, in a syllable counting task, participants would quite naturally use *orthographic* units information as a proxy to the number of syllables, in addition to proper phonological information. The hiatus effect observed in the previous experiments thus arises from the influence of the perceptual orthographic organization. As we have shown, the influence of orthographic structure manifests itself more when task conditions make access to phonological information harder.

Table 6
Mean reaction times (RTs, in ms) and percentage of errors on target words for Experiment 4.

	RTs (% of errors)	Difference (with control words)
Word type		
OP hiatus	1009 (16.55)	118 (8.87)
P hiatus	896 (7.86)	5 (0.18)
Controls	891 (7.68)	

One remaining issue however is to establish what influence the putative orthographic structure determined by C/V organization may have on word recognition processes. Chetail and Content (2012) showed that the presence of a mute vowel (silent E, as in *biberon*, /bibʀõ/) led participants to overestimate the number of units in a syllable counting task, again suggesting that orthographic structure constrains syllabic counting. Moreover, letter detection performance provided supporting evidence by showing that the consonant following the silent *E* (e.g., *R* in *biberon*) was processed as the first letter of a unit and not as a letter embedded in a multi-letter onset. Here we examined whether orthographic structure impacts on common measures of word recognition, using naming (Experiment 5) and lexical decision (Experiment 6) tasks.

Experiment 5

In this experiment, we tested the vowel effect in naming. According to Coltheart (1978), one reason to discard the notion of orthographic units based on vowel clusters is that it would create difficulties in mapping print to pronunciation through analytical conversion rules. Therefore, if words are structured into orthographic units based on vowel letters, pronunciation may be disrupted when the number of vowel clusters does not match the number of syllables, as in hiatus words. The effect was also tested in pseudowords to examine whether it is associated to lexical processing. Since we assumed that the orthographic structure is extracted at an early stage of processing, before graphemic parsing, a mismatch between orthographic structure and graphemic parsing would be expected to disturb pseudoword naming.

Method

Participants

Thirty-eight students participated in the experiment. They were all native French speakers and reported having normal or corrected-to-normal vision. None of them had participated in any of the previous experiments.

Stimuli

A set of 32 word pairs was selected from the Lexique database (New et al., 2004). Each pair included a word with a hiatus and a control word matched on lexical frequency, number of letters, number of phonemes, number of syllables, identity of the first phoneme (and as much as possible, of the first biphone), orthographic and phonological neighborhoods, frequencies of first bigrams and first syllable, and summed bigram frequencies (see Table 7). Given that the vowel effect is stronger in longer words, 17 out the 32 pairs comprised trisyllabic words, and the remaining pairs were four syllable long. None of the 64 words contained a final or internal schwa (see Appendix C for the complete list of stimuli). Thirty-two pseudoword pairs were constructed according to the same criteria. In each pair, pseudowords were matched on the same relevant variables. As mentioned previously, hiatus patterns in French have a consistent pronunciation (e.g., *éo* in *créovant* can be pronounced only /eo/) so the pseudowords were unambiguous and mispronunciations affecting specifically the hiatus pattern could be easily identified.

Procedure

Participants performed a naming task programmed in Matlab using the Psychtoolbox extension (Brainard, 1997). Each trial began by a fixation cross, presented during 500 ms at the center of the screen, and followed by a lowercase stimulus written in Courier New, which remained on the screen until the participant responded. Participants were instructed to name the stimuli as rapidly and accurately as possible. Words and pseudowords were presented in two different blocks, the order of the blocks being counterbalanced across participants. Naming latencies were measured from target onset to the triggering of the voice key by the participant's response. The experimenter sat next to the participant to check his or her re-

Table 7
Characteristics of words in Experiments 5 and 6.

	Item lexicality							
	Words				Pseudowords			
	Three syllables		Four syllables		Three syllables		Four syllables	
	Hiatus word	Control word	Hiatus word	Control word	Hiatus word	Control word	Hiatus word	Control word
Example	*réussir*	*réparer*	*accordéon*	*accumuler*	*réaptoin*	*répadoin*	*accurméat*	*accurivat*
Number	17	17	15	15	17	17	15	15
Lexical frequency	6.19	5.05	3.87	4.20	–	–	–	–
Number of letters	7.76	7.76	9.27	9.27	7.71	7.65	9.13	9.20
Number of phonemes	6.76	6.76	8.33	8.40	6.65	6.53	8.13	8.07
Number of orthographic neighbors	1.00	1.12	0.93	0.53	0.12	0.06	0	0
First bigram frequency	3820	4120	5044	5798	3586	3479	5244	4468
Summed bigram frequency	16,968	15,676	12,748	16,370	12,301	11,928	11,267	11,219

Note: Frequencies are given in number of occurrences per million.

Table 8
Mean reaction times (in ms) and percentage of errors (in parentheses) on items in Experiment 5 (naming task).

Number of syllables	Item type		*Differences*
	Hiatus	Control	
Words			
Three	564 (2.2)	558 (1.1)	*6 (1.1)*
Four	594 (6.0)	572 (1.9)	*22 (4.1)*
Pseudowords			
Three	865 (8.5)	868 (9.5)	*−3 (−1.0)*
Four	989 (24.6)	993 (12.6)	*−4 (12.0)*

sponses. All participants performed practice trials before receiving the 128 trials in a variable random order.

Results and discussion

The mean correct reaction times and mean error rates averaged over participants are presented in Table 8. The data were submitted to separate analyses of variance on the participant means (F1) and on the item means (F2) with Target Type (hiatus, control) and Number of Syllables (3, 4) as main factors.

Words

Response times corresponding to incorrect voice key triggering (0.86% of the data), mispronunciation and hesitant responses (2.74%), and latencies outside the range of two standard deviations from the individual mean of the participants per condition (5.78%) were discarded. Only mispronunciation and hesitations were considered as errors. Hiatus words elicited reaction times longer than control words, $F1(1,37) = 36.37$, $p < .001$, $F2(1,60) = 4.71$, $p = .03$. Quadrisyllabic words were processed more slowly than trisyllabic words, $F1(1,37) = 40.64$, $p < .001$, $F2(1,60) = 12.00$, $p < .001$. The interaction between the two factors was significant in the participant analysis only, $F1(1,37) = 8.62$, $p = .006$, $F2(1,60) = 1.76$, $p = .19$. A similar pattern was found in the error rate analysis. Hiatus words produced more errors than control words, $F1(1,37) = 17.40$, $p < .001$, $F2(1,60) = 6.35$, $p = .01$, and quadrisyllabic words produced more errors than trisyllabic words, $F1(1,37) = 11.26$, $p = .001$, $F2(1,60) = 5.61$, $p = .02$. The interaction was significant in the participant analysis only, $F1(1,37) = 6.00$, $p = .02$, $F2(1,60) = 2.26$, $p = .14$.

Pseudowords

Response times corresponding to incorrect voice key triggering (0.58% of the data), mispronunciation and hesitant responses (13.47%), and latencies outside the range of two standard deviations from the individual mean of the participants per condition (4.46%) were removed from the data. Only mispronunciations and hesitations were considered errors. Three participants were excluded from the analyses because of high percentage of errors (33%, 38%, and 45%). In the reaction time analysis, only the effect of number of syllables was significant, $F1(1,34) = 37.91$, $p < .001$, $F2(1,60) = 30.41$, $p < .001$ (all other Fs < 1). In the error rates, hiatus items elicited more errors than control items, $F1(1,34) = 17.42$, $p < .001$, $F2(1,60) = 3.70$, $p = .06$. Quadrisyllabic pseudowords produced more errors than trisyllabic ones, $F1(1,34) = 49.14$, $p < .001$, $F2(1,60) = 13.12$, $p < .001$. The interaction between the two factors was significant, $F1(1,34) = 22.68$, $p < .001$, $F2(1,60) = 6.01$, $p = .02$, showing that the effect of target type was stronger in quadrisyllabic pseudowords than in trisyllabic ones.

As mentioned previously, one essential reason why the notion of orthographic structure has been received with skepticism is that it would not always map onto phonological structure. The hypothesis therefore predicts that access to phonology and pronunciation would be disrupted when the number of vowel clusters does not match on the number of phonological syllables. The present results partly support that analysis, inasmuch as responses were less accurate (words and pseudowords) and slower (words) for hiatus items than for control ones, at least for four-syllable items. A hiatus word like *caméléon* would be orthographically structured into three orthographic units, which conflicts with the phonological word form required for pronunciation.

In localist visual word recognition models incorporating parallel pathways (e.g., Coltheart, Rastle, Perry, Langdon, & Ziegler, 2001; Perry et al., 2010), orthographic unit nodes could be implemented as a common layer shared by the two pathways, after the letter detector units. In the frame-

Table 9
Types of errors in pseudoword naming (Experiment 5).

Error type	Proportion	Example	
		Target	Mispronunciation
Errors not related to hiatus	39%	atéangir, /ateɑ̃ʒiʀ/	/ateɑ̃giʀ/
Errors related to hiatus	61%		
Mispronunciations	25%	ibraéton, /ibʀaetɔ̃/	/ibʀeatɔ̃/
Reductions	15%	pinclier, /pɛ̃klije/	/plɛ̃sje/
Shifts	14%	convriader, /kɔ̃vʀijade/	/kɔ̃vadʀije/
C/V structure alterations	8%	réaptoin, /ʀeaptwɛ̃/	/ʀepatwɛ̃/

Table 10
Mean reaction times (in ms) and percentage of errors (in parentheses) on items in Experiment 6 (lexical decision task).

Number of syllables	Item type		*Differences*
	Hiatus	Control	
Words			
Three	621 (1.8)	641 (2.1)	*−20 (−0.3)*
Four	668 (8.0)	651 (4.1)	*17 (3.9)*
Pseudowords			
Three	764 (4.8)	778 (6.0)	*−14 (−1.2)*
Four	769 (1.7)	774 (2.4)	*−5 (−0.7)*

work of the CDP++ model (Perry et al., 2010) for example, orthographic C/V parsing should precede graphemic parsing. When the orthographic structure does not coincide with the graphemic and syllabic structure, a reanalysis is necessary to extract the correct graphemic parsing, and this additional process may explain the longer naming latencies and pronunciation errors for hiatus items. Accordingly, a qualitative analysis of the pseudoword errors showed that, out of the total number of mispronunciations (79% out of the total number of errors, the remaining 21% being hesitations), 61% were errors related to the hiatus pattern (see Table 10). Errors on word items were too scarce to conduct a similar analysis. However, it remains unclear why the hiatus effect emerges only for quadrisyllabic items. Moreover, since the present experiment compared OP hiatus items to controls rather than OP hiatus to P hiatus as in Experiment 4, the effect observed could be due to production processes. Differences at the production level would seem even more plausible given that hiatus and control items were paired on number of consonants and number of vowels, so that hiatus words and pseudowords would necessarily contain more complex consonant clusters than the controls.

Experiment 6

In the final experiment, we examined the vowel effect in the lexical decision task. Due to item selection constraints for the naming task, only OP hiatus words were used in Experiment 5. The effect found in naming could thus be attributed to pronunciation preparation or output processes. One way to rule out a production explanation is to compare hiatus and control words in the lexical decision task, given than no overt pronunciation is required. Based on recent studies arguing for a sequential component in the processing of polysyllabic letter strings (see Ans et al., 1998; Carreiras et al., 2005; Ferrand & New, 2003; Stenneken, Conrad, & Jacobs, 2007; Yap & Balota, 2009), we hypothesized that hiatus words might be processed faster than control words in the lexical decision task, as the former comprise fewer orthographic units than the latter.

Method

Participants

Thirty-seven students participated in the experiment. They were all native French speakers and reported having normal or corrected-to-normal vision. None of them had participated in any of the previous experiments.

Stimuli

The same stimuli as in Experiment 5 were used.

Procedure

The procedure was identical to that of Experiment 5 except that participants had to decide as quickly and as accurately as possible whether the target was a French word or not by pressing one of two buttons on the keyboard. Visual feedback was provided when they failed to respond.

Results and discussion

The mean correct reaction times and mean error rates averaged over participants are presented in Table 9. The data were submitted to separate analyses of variance on the participant means (F1) and on the item means (F2) with Target Type (hiatus, control) and Number of Syllables (3, 4) as main factors.

Words

For the reaction times, there was no significant difference between hiatus and control words, *F*s < 1. Quadrisyllabic words were processed more slowly than trisyllabic words, $F1(1,36) = 26.99$, $p < .001$, $F2(1,60) = 7.04$, $p = .01$. The interaction between the two factors, $F1(1,36) = 22.13$, $p < .001$, but $F2(1,60) = 2.93$, $p = .09$ showed that in trisyllabic items, hiatus words were processed faster than control words, while the reverse was found for quadrisyllabic words. In the error rate analysis, there was a main effect of number of syllables, $F1(1,36) = 23.13$, $p < .001$, $F2(1,60) = 5.19$, $p = .03$. The effect of word type, $F1(1,36) = 4.93$, $p = .03$, $F2 < 1$, and interaction, $F1(1,36) = 6.16$, $p = .02$, $F2(1,60) = 1.13$, $p = .29$, failed to reach significance in the item analysis.

Pseudowords

In the reaction analysis, there was no significant effect (all *p*s > .30). On the error rates, trisyllabic pseudowords elicited more errors than quadrisyllabic pseudowords, presumably because the latter were more wordlike than the former, $F1(1,36) = 21.32$, $p < .001$, $F2(1,60) = 5.69$, $p = .02$ (all other *p*s > .20).

In sum, for words, we found inverse hiatus effects as a function of length, with a RT gain for three-syllable words and an increase for four-syllable words. In fact, as shown in Fig. 2, the hiatus effect tended to switch gradually from benefit to cost as a function of number of letters, $r = .37$, $p = .037$. As stated before, polysyllabic word identification involves sequential processes. The faster recognition of trisyllabic hiatus words compared to control words may therefore stem from the smaller number of orthographic units of the former.

On the other hand, longer words tend to be less frequent and would also require more refixations, thus lengthening lexical identification time (see New, Ferrand, Pallier, & Brysbaert, 2006). The difference in length may explain why quadrisyllabic hiatus words (9.3 letters in average) take longer than trisyllabic control words (7.8 letters), de-

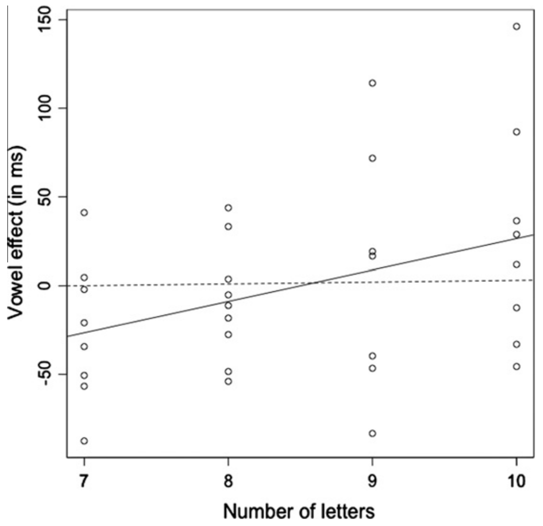

Fig. 2. Vowel effect as a function of word length in Experiment 6 (lexical decision task). The vowel effect corresponds to the difference of reaction times between hiatus and control words in each pair.

spite both comprising three orthographic units. In addition, the longer identification time would increase the likelihood that phonological assembly processes noticeably influence performance, so that conflicts between orthographic structure and graphemic or phonological structure would have more impact on response times, leading to the hiatus cost observed for the quadrisyllabic words.

Although the present interpretation is speculative, it offers the additional interest of providing a tentative explanation for the pattern of naming times in Experiment 5, assuming that phonological transcoding has a stronger impact on naming than on lexical decision. With shorter hiatus words, the increased load on phonological transcoding due to structural mismatch would be counterbalanced by the gain in sequential processing associated with less units, whereas for the longer items, the impact of assembly processes would weigh more, leading to slower naming of hiatus words. Finally, the unexpected absence of a hiatus effect with trisyllabic pseudowords in the naming task could be related to their particularly high wordlikeness, as reflected by the numerous false positive errors in the lexical decision task. Indeed many of the trisyllabic pseudowords included embedded words, and it is thus possible that their pronunciation could be assembled with little recourse to grapheme–phoneme correspondences.[1]

General discussion

The aim of the present study was to investigate the role of letter category (consonant vs. vowel letters) in the perceptual organization of letter strings. Participants were presented with written words matched for the number of spoken syllables and either comprising a hiatus pattern or not (e.g., *pharaon* vs. *parodie*). Relative to control words, syllabic counting was slower and less accurate for hiatus words for which readers systematically underestimated the number of syllables (Experiment 1 & 4). The effect was larger when instructions emphasized response speed (Experiment 2), and it was also stronger when the resort to phonological codes was hindered through articulatory suppression (Experiment 3). Importantly, the effect was present only if the vowel letters coding for the hiatus pattern were contiguous in the orthographic form (Experiment 4). Furthermore, C/V organization influenced reading performance. Hiatus words were more slowly and less accurately pronounced than control words (Experiment 5). In the lexical decision task, the direction of the effect depended on word length, with shorter words producing a facilitatory effect and longer words producing an inhibitory effect (Experiment 6).

During the last decades, the syllable has been considered an important unit of polysyllabic word processing for speech (Mehler, Dommergues, Frauenfelder, & Segui, 1981). Although the exact role of the syllable in spoken word recognition is still a matter of debate (Content, Meunier, Kearns, & Frauenfelder, 2001; Cutler, Mehler, Norris, & Segui, 1986), and the processes through which syllables boundaries are delineated are unclear, most linguists and psycholinguists would agree that the number of syllables in an utterance corresponds to the number of vocalic nuclei (Martinet, 1960). We suggest that a similar process may be at work in the written modality and that there is a level of representation in printed word processing such that groups of vowel letters (i.e., vowel clusters) determine orthographic units to which consonant letters are attached. The present data further indicate that this structure is based on letter identities and letter categories, rather than on their phonemic counterparts.

Given the quasi-systematic mapping between graphemic and phonemic strings in alphabetical systems, perceptual analyses based on letter codes and phonemic codes would often lead to the same segmentation, and alphabetic writing systems offer few possibilities to establish whether letter string clustering operates on orthographic or on phonological vowels. French provides two such opportunities. One, which we began exploring (Chetail & Content, 2012) concerns the silent E, and the other, which is the focus of the present study, is based on hiatus words, which contain a sequence of two adjacent vowel phonemes (e.g., *chaos*), creating a mismatch between the number of syllables and the number of vowel clusters. Although the two contiguous vowels constituting the hiatus are the core of distinct syllables, they *orthographically* entail a single vowel letter cluster, and would therefore be the basis for a single perceptual orthographic unit.

Accordingly, the present findings showed that the visual organization of vowel letters influences unit perception within written items, both in syllable counting and visual recognition tasks. In the syllable counting task, bisyllabic and trisyllabic words were responded to more quickly and more accurately when the number of vowel clusters exactly matched the number of syllables. Experiments 1 and 4 provided the strongest support in favor of a process of visuo-orthographic parsing based on C/V letter categorization. First, error analyses for bisyllabic words clearly showed that the participants did not make random errors on the hiatus

[1] We thank Marcus Taft for attracting our attention to that particular aspect of the experiment.

words, but rather underestimated the number of units. Second, the task left participants completely free to resort to the pronounced form of words, which systematically provides the correct response. Despite that, they either erred or took longer to give the correct answer for the hiatus words. Additionally, the results of Experiments 2 and 3 suggest that part of the correct responses in Experiment 1 was attributable to intentional resort to phonology, since the error rate increased when access to phonology is restricted because of time pressure, or concurrent articulation. Finally, Experiment 4 clearly showed that the vowel effect can be attributed to the organization of consonant and vowel letters within written words rather than to the presence of a phonological hiatus pattern.

Using tasks that directly tap into reading processes enabled us to rule out a strategic account of the vowel effect and to strengthen the claim that orthographic structure is determined by C/V letter categorization, at least in word processing. In the naming task, the longer and less accurate responses for hiatus words ensue from a conflict between orthographic structure based on vowel clusters and phonological structure. A similar phenomenon may be at work for long words in the lexical decision task, whereas a trend towards a reverse, facilitatory vowel effect was obtained for the shorter words. In the latter case, word recognition is faster because hiatus words comprise fewer orthographic units that need to be processed in sequence. Thus, lexical access for polysyllabic words may be mediated by a level of orthographic representations based on vowel clusters.

The claim according to which written words are perceptually structured into orthographic units based on C/V letter categorization presupposes two conditions: First, that this process occurs before phonological transcoding, and second that letters are categorized as consonants and vowels at an early stage during word identification. Concerning the former issue, the fact that the vowel effect was found in both words and pseudowords in the naming task suggests that word structuring into vowel clusters arises early during written word processing. As explained previously, further support is provided by the facilitatory vowel effect found in the lexical decision task with the shortest words. Concerning syllabic counting, the fact that it took longer to give correct responses in hiatus words than in control words also suggests that the vowel effect occurs before phonological encoding. Indeed, in control words, orthographic word structure yields a count compatible with that ensuing from phonological information, thus leading to fast responses from readers. In contrast, longer reaction times in hiatus words can be accounted for by the fact that phonological information is accessed *after* the activation of C/V letter information. This produces a conflict concerning unit count, thus delaying readers in giving correct responses. This occurred even in case of concurrent articulation because some phonological information such as the metrical frame may remain available (see Besner, 1987; Levelt & Wheeldon, 1994). A second argument favoring the assumption that vowel cluster influence occurs prior to phonological encoding is that the faster participants respond, the larger the effect of orthographic word structure on responses. In a temporal view, the fact that participants failed more when they were speeded up shows that the number of trials where phonological word information did not have time to influence responses increased. In that case, readers' decisions were influenced by the early stage of orthographic parsing based on vocalic groups only, leading to erroneous responses because the number of vowels clusters does not match the number of syllable-like units.

Furthermore, the hypothesis of a level of representation based on vowel clusters and C/V letter distinction is in line with studies showing that consonants and vowels are distinguished early on during visual word recognition processes (e.g., Acha & Perea, 2010; Carreiras, Gillon-Dowens, Vergara, & Perea, 2008; Lee et al., 2001; New et al., 2008; Vergara-Martínez et al., 2010) as well as studies indicating a neuroanatomical basis for the distinction between consonant and vowel letters (e.g., Caramazza et al., 2000; Miceli et al., 2004). In particular, Buchwald and Rapp (2006) provided strong support to the hypothesis of representations containing specific orthographic information about C/V letter identity, distinct from phonological information. They analyzed the misspellings of dysgraphic patients for words exhibiting mismatches between orthographic and phonological C/V forms, like *thigh* (i.e., phonological C/V form: CV, /t-aI/, vs. orthographic C/V form: CCVCC, *t-h-i-g-h*). The rationale was that when the identity of the *g* in *thigh* was disrupted, a repair mechanism for spelling production could lead to substitute the *g* by another letter. If the letter was replaced by a vowel letter (e.g., *thioh*), this would be consistent with the phonological C/V form, but not with the orthographic C/V form. Conversely, if the letter *g* was replaced by a consonant letter (e.g., *thich*), this would be consistent with the orthographic C/V form, but not with the phonological C/V one. Analysis of substitution errors showed that the dysgraphic patients made more errors favoring the orthographic C/V form hypothesis than the phonological C/V one. The authors concluded that orthographic coding includes an abstract representation based on the orthographic C/V status of letters and distinct from the phonological C/V skeleton. Our data are consistent with this view and show how the distinction of consonant and vowel letter classes reported in previous studies could serve as the basis for early orthographic parsing of written words into perceptual units.

Obviously, the hypothesis of an early level of representations based on letter categories does not exclude the possibility that other kinds of codes are extracted later on, such as a graphemic representation. However, a model relying only on a graphemic parsing stage cannot account for the vowel effect. Thus, although the CDP++ model (Perry et al., 2010) takes into account the distinction between consonants and vowels for parsing letter strings, it would fail to accommodate our results because the distinction is considered at a graphemic level. Indeed, given that the vowel cluster *ao* in the hiatus word *chaos* does not constitute a grapheme, the model would most likely detect two successive vocalic graphemes, and each would be assigned to a different syllable nucleus slot, as occurs in a control word like *fever*. In contrast, our results both in syllable counting and in visual word recognition tasks suggest that the reading system first parses written words based on vowel clusters, even when the clusters entail distinct graphemes. This supports the need to implement a level of representation based on vowel clusters in the early stages of written word perception. However, as the CDP++ model has been developed for and tested on English, further studies would be required to ascertain whether the vowel effect also occurs in this language. More generally, cross-linguistic studies would be necessary to determine whether the role of vowel/consonant letter organization is universal in alphabetic scripts or related to specific properties of the language or the orthography.

To conclude, the present study provides evidence for an orthographic organization of polysyllabic words, distinct from phonological parsing, and based on C/V letter alternation. This conclusion supports the hypothesis of abstract orthographic representations based on vowel letter clusters and distinct from phonemic structure and C/V phonological organization. Lexical access for polysyllabic words may involve a level of orthographic representations based on vowel clusters at early stages of word identification. Such a conclusion diverges from the hypothesis that polysyllabic written words are structured according to their syllabic phonological form (e.g., Carreiras et al., 1993; Conrad et al., 2010; Mathey et al., 2006) and from the hypothesis of orthographic parsing based on graphosyllables (Perry et al., 2010). In contrast, the present view is in agreement with previous claims that perceptual units within written words are primarily determined by orthographic cues (e.g., Prinzmetal et al., 1986; Seidenberg, 1987).

A. Words used in Experiments 1–3

A.1. Bisyllabic words

A.1.1. Hiatus words

Fluor, clouant, bleuir, criard, fluet, boa, truand, clouer, yaourt, haïr, gluant, chaos, cruel, naïf, pays, trieur, priant, friand, rieur, grief, trier, pliant, criant, trio, prieur, païen, plier, fléau, bleuet, prier, fluo, client, maïs, crier, laïc, laïus, créer, préau, noël, trouer, caïd, néon, réel, géant.

A.1.2. Control words

Menu, puma, curé, pâlir, assis, coma, pavé, média, panda, fusée, série, récif, jasmin, flacon, lama, doré, pinçon, repli, divin, engin, jeton, lutin, tyran, acier, juger, remis, déni, muni, aval, navet, vendu, rugir, étang, déclic, canard, renard, fessée, chimie, drogué, captif, emploi, fleuri, social, podium, dédain.

A.2. Trisyllabic words

A.2.1. Hiatus words

Paysan, sablier, truander, vitriol, paella, renflouer, baobab, février, nauséeux, sanglier, pharaon, éblouir, brioché, abbaye, oasis, monstrueux, cruauté, sangria, maestro, sucrier, fainéant, léopard, embryon, encrier, caïman, triomphal, publier, ouvrier, tablier, haïtien, étrier, rhéostat, nuageux, maugréer, lauréat, croasser, goéland, oublié, canoë, mécréant, créatif, théorie, réussir, koala, poésie.

A.2.2. Control words

Opéra, amputé, otarie, safari, lavabo, domino, avocat, aperçu, acajou, avancé, comédie, parodie, galaxie, mélangé, rescapé, relatif, négatif, minéral, végétal, artisan, abdomen, citadin, magasin, augurer, ameuter, aboutir, amateur, papyrus, habitat, élément, abricot, épineux, onéreux, colonie, décaler, floraison, vagabond, spontané, impulsif, nutritif, infernal, ambition, saladier, synergie, atrophie.

B. Words used in Experiment 4

Number of syllables	PO hiatus words	P hiatus words	Control words
2	chaos	bahut	enjeu
2	cruel	cohue	égout
2	fluet	trahi	hamac
2	fluor	cahot	empan
2	bleuet	mohair	rameur
2	truand	chahut	aimant
2	clouer	trahir	berger
2	yaourt	cahier	tunnel
2	gluant	dehors	accord
2	trieur	vrillé	cédant
2	strier	millet	gasoil
2	friand	billot	choqué
2	criard	piller	piteux
2	pliant	grillé	nageur
2	prieur	sillon	préfet
2	client	billet	crever
3	cacao	ébahi	épaté
3	oasis	ahuri	apéro
3	caïman	ébahir	otarie
3	boréal	éhonté	adouci
3	baobab	ahaner	émotif
3	stéréo	vahiné	parano
3	féodal	ahurir	ériger
3	lycéen	envahi	aviron
3	lauréat	prohibé	calumet
3	préavis	cahoter	rotatif
3	créatif	envahir	épatant
3	béarnais	tahitien	purgatif
3	croasser	prohiber	désister
3	réacteur	déhanché	purulent
3	gaufrier	grillagé	nénuphar
3	maugréer	cahoteux	musarder
3	nauséeux	chahuter	enrouler
3	mécréant	véhément	disloqué
3	théâtral	cohérent	indécent
3	créateur	cohésion	anarchie
3	panthéon	brouhaha	délivrer
3	création	trahison	supposer
3	rhéostat	saharien	occulter
3	saoudien	bohémien	inculper
3	créancier	déhancher	signaleur
3	renflouer	chahuteur	charlatan
3	confluent	rehausser	pervertir
3	préemption	préhension	infectieux
3	triomphant	quadriller	goudronner

C. Stimuli used in Experiment 5 and 6

Number of syllables	Words		Pseudowords	
	Hiatus	Control	Hiatus	Control
3	réussir	réparer	réucrer	régorer
3	léopard	limiter	léovail	lévucer
3	créatif	crudité	préalor	prétolé
3	réacteur	ravageur	réaptoin	répadoin
3	création	cavalier	créovant	capadant
3	renflouer	roucouler	rendrouir	raufondir
3	monstrueux	mentionner	vointrueux	voincanner
3	peuplier	purifier	pinclier	pivocif
3	sucrier	salarié	savrier	sabucié
3	sablier	surdité	budrier	buvirer
3	février	faculté	roplier	rovurté
3	éblouir	égorger	aplouir	aporgir
3	dépliant	dépourvu	macliant	mavidant
3	sanglier	saladier	caodron	capivon
3	publier	positif	pucéart	pérucin
3	bouclier	bavarder	bancrier	banvirer
3	triompher	trébucher	trianfeux	tridaleux
4	caméléon	calamité	coviléon	covamicé
4	anéantir	anatomie	atéangir	atévamie
4	israélien	inaugural	ibraéton	inautadon
4	accordéon	accumuler	accurméat	accurivat
4	coalition	coloniser	coabister	cobaniler
4	récréation	répétition	dévréolain	dénérovain
4	échéancier	échafauder	ochéarbin	ochunavin
4	coordonner	consolider	coamprevel	culadriver
4	désobéir	décoloré	désutéir	dépunilé
4	propriété	proximité	prodriévon	progitévon
4	rapatrier	répétitif	rapaovac	ragamolé
4	calendrier	complicité	camonclier	cindorcité
4	approprier	affirmatif	annondrier	allumontif
4	cambrioler	consécutif	convriader	condévaper
4	patriarcat	partialité	vabriadoin	vactanidol

References

Acha, J., & Perea, M. (2010). On the role of consonants and vowels in visual-word processing: Evidence with a letter search paradigm. *Language and Cognitive Processes, 25*, 423–438. http://dx.doi.org/10.1080/01690960903411666.

Adams, M. J. (1979). Models of word recognition. *Cognitive Psychology, 11*, 133–176.

Adams, M. J. (1981). What good is orthographic redundancy? In O. J. L. Tzeng & H. Singer (Eds.), *Perception of print: Reading research in experimental psychology* (pp. 197–221). Hillsdale: Lawrence Erlbaum Associates.

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

Anisfeld, M. (1964). Comment on "The role of grapheme-phoneme correspondence in the perception of words" by Gibson et al.. *American Journal of Psychology, 77*, 320–321.

Ans, B., Carbonnel, S., & Valdois, S. (1998). A connectionist Multiple-Trace Memory model for polysyllabic word reading. *Psychological Review, 105*, 678–723. http://dx.doi.org/10.1037/0033-295X.105.4.678-723.

Ashby, J., & Rayner, K. (2004). Representating syllable information during silent reading: Evidence from eye movements. *Language and Cognitive Processes, 19*, 391–426. http://dx.doi.org/10.1080/01690960344000233.

Berent, I., & Perfetti, C. A. (1995). A rose is a REEZ: The Two-Cycles Model of phonology assembly in reading English. *Psychological Review, 102*, 146–184. http://dx.doi.org/10.1037/0033-295X.102.1.146.

Besner, D. (1987). Phonology, lexical access in reading, and articulatory suppression: A critical review. *The Quarterly Journal of Experimental Psychology, 39A*, 467–478. http://dx.doi.org/10.1080/14640748708401799.

Besner, D., Davies, J., & Daniels, S. (1981). Reading for meaning: The effects of concurrent articulation. *Quarterly Journal of Experimental Psychology, 33A*, 415–437. http://dx.doi.org/10.1080/14640748108400801.

Brainard, D. H. (1997). The psychophysics toolbox. *Spatial Vision, 10*, 433–436. http://dx.doi.org/10.1163/156856897X00357.

Buchwald, A., & Rapp, B. (2006). Consonants and vowels in orthographic representations. *Cognitive Neuropsychology, 23*, 308–337. http://dx.doi.org/10.1080/02643290442000527.

Caramazza, A., Chialant, D., Capasso & Miceli (2000). Separable processing of consonants and vowels. *Nature, 403*, 428–430. http://dx.doi.org/10.1038/35000206.

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

Carreiras, M., Ferrand, L., Grainger, J., & Perea, M. (2005). Sequential effects of phonological priming in visual word recognition. *Psychological Science, 16*, 585–589. http://dx.doi.org/10.1111/j.1467-9280.2006.01821.x.

Carreiras, M., Gillon-Dowens, M., Vergara, M., & Perea, M. (2008). Are vowels and consonants processed differently? Event-related potential evidence with a delayed letter paradigm. *Journal of Cognitive Neuroscience, 21*, 275–288. http://dx.doi.org/10.1162/jocn.2008.21023.

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

Carreiras, M., & Price, C. (2008). Brain activation for consonants and vowels. *Cerebral Cortex, 18*, 1727–1735. http://dx.doi.org/10.1093/cercor/bhm202.

Chetail, F., & Content, A. (2012). *Segmentation of written words in French*. Language & Speech. http://dx.doi.org/10.1177/0023830912442919.

Chetail, F., & Mathey, S. (2009a). Syllabic priming in lexical decision and naming tasks: The syllable congruency effect re-examined in French. *Canadian Journal of Experimental Psychology, 63*, 40–48. http://dx.doi.org/10.1037/a0012944.

Chetail, F., & Mathey, S. (2009b). The syllable frequency effect in visual recognition of French words: A study in skilled and beginning readers. *Reading and Writing, 22*, 955–973. http://dx.doi.org/10.1007/s11145-008-9135-9.

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

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

Conrad, M., Carreiras, M., Tamm, S., & Jacobs, A. M. (2009). Syllables and bigrams: Orthographic redundancy and syllabic units affect visual word recognition at different processing levels. *Journal of Experimental Psychology: Human Perception and Performance, 35*, 461–479. http://dx.doi.org/10.1037/a0013480.

Conrad, M., Grainger, J., & Jacobs, A. M. (2007). Phonology as the source of syllable frequency effects in visual word recognition: Evidence from French. *Memory & Cognition, 35*, 974–983. http://dx.doi.org/10.3758/BF03193470.

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

Conrad, M., Tamm, S., Carreiras, M., & Jacobs, A. M. (2010). Simulating syllable frequency effects within an interactive activation framework. *European Journal of Cognitive Psychology, 22*, 861–893. http://dx.doi.org/10.1080/09541440903356777.

Content, A., Kearns, R. K., & Frauenfelder, U. H. (2001a). Boundaries versus Onsets in Syllabic Segmentation. *Journal of Memory and Language, 45*(2), 177–199. http://dx.doi.org/10.1006/jmla.2000.2775.

Content, A., Meunier, C., Kearns, R. K., & Frauenfelder, U. H. (2001b). Sequence detection in pseudowords in French: Where is the syllable effect? *Language and Cognitive Processes, 16*, 609–639. http://dx.doi.org/10.1080/01690960143000083.

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

Dehaene, S., Cohen, L., Sigman, M., & Vinckier, F. (2005). The neural code for written words: A proposal. *Trends in Cognitive Sciences, 9*, 335–341. http://dx.doi.org/10.1016/j.tics.2005.05.004.

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

Ferrand, L., & New, B. (2003). Syllabic length effects in visual word recognition and naming. *Acta Psychologica, 113*, 167–183. http://dx.doi.org/10.1016/S0001-6918(03)00031-3.

Forster, K. I., & Chambers, S. M. (1973). Lexical access and naming time. *Journal of Verbal Learning and Verbal Behavior, 12*, 627–635. http://dx.doi.org/10.1016/S0022-5371(73)80042-8.

Forster, K. I., & Forster, J. C. (2003). DMDX: A Windows display program with millisecond accuracy. *Behavior Research Methods, Instruments, & Computers, 35*, 116–124. http://dx.doi.org/10.3758/BF03195503.

Gibson, E. J. (1965). Learning to read. *Annals of Dyslexia, 15*, 32–47.

Gibson, E. J. (1970). The ontogeny of reading. *American Psychologist, 25*, 136–143. http://dx.doi.org/10.1037/h0029419.

Gibson, E. J. (1971). Perceptual learning and the theory of word perception. *Cognitive Psychology, 2*, 351–368. http://dx.doi.org/10.1016/0010-0285(71)90020-X.

Gibson, E. J., Pick, A., Osser, H., & Hammond, M. (1962). The role of grapheme-phoneme correspondence in the perception of word. *American Journal of Psychology, 75*, 554–570. http://dx.doi.org/10.2307/1420279.

Gibson, E. J., Shurcliff, A., & Yonas, A. (1970). Utilization of spelling patterns by deaf and hearing subjects. In H. Levin & J. P. Williams (Eds.), *Basic studies on reading*. New York: Basic Books.

Glushko, R. J. (1979). The organization and activation of orthographic knowledge in reading aloud. *Journal of Experimental Psychology: Human Perception and Performance, 5*, 674–691. http://dx.doi.org/10.1037/0096-1523.5.4.674.

Gough, P. (1972). One second of reading. In J. P. Kavanagh & I. G. Mattingly (Eds.), *Language by eye and bye ear*. Cambridge, Massachusetts: M.I.T. Press.

Grainger, J., & Van Heuven, W. (2003). Modeling letter position coding in printed word perception. In P. Bonin (Ed.), *The mental lexicon* (pp. 1–24). New York: Nova Science Publishers.

Hansen, D., & Rodgers, T. (1965). An exploration of psycholinguistic units in initial reading. In *Proceedings of the symposium on the psycholinguistic nature of reading process*. Detroit: Wayne State University Press.

Henderson, L. (1982). *Orthography and word recognition in reading*. London: Academic Press.

Huey, E. B. (1908). *The psychology and pedagogy of reading*. Cambridge: The MIT Press.

Kandel, S., Hérault, L., Grosjacques, G., Lambert, E., & Fayol, M. (2009). Orthographic vs. phonologic syllables in handwriting production. *Cognition, 110*, 440–444. http://dx.doi.org/10.1016/j.cognition.2008.12.001.

Lee, H.-W., Rayner, K., & Pollatsek, A. (2001). The relative contribution of consonants and vowels to word identification during reading. *Journal of Memory and Language, 44*, 189–2001. http://dx.doi.org/10.1006/jmla.2000.2725.

Lee, H.-W., Rayner, K., & Pollatsek, A. (2002). The processing of consonants and vowels in reading: Evidence from the fast priming paradigm. *Psychonomic Bulletin & Review, 9*, 766–772. http://dx.doi.org/10.3758/BF03196333.

Levelt, W. J. M., & Wheeldon, L. (1994). Do speakers have access to a mental syllabary? *Cognition, 50*, 239–269. http://dx.doi.org/10.1016/0010-0277(94)90030-2.

Liberman, I. Y. (1973). 1. Segmentation of the spoken word and reading acquisition. *Annals of Dyslexia, 23*, 64–77. http://dx.doi.org/10.1007/BF02653842.

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

Martinet, A. (1960). *Eléments de linguistique générale*. Paris: Armand Colin.

Massaro, D. W., Taylor, G. A., Venezky, R. L., Jastrzembski, J. E., & Lucas, P. (1980). Letter and word perception. *Advances in psychology* (Vol. 4). Elsevier: North-Holland.

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

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

Mewhort, D. J. K., & Beal, A. L. (1977). Mechanisms of word identification. *Journal of Experimental Psychology: Human Perception and Performance, 3*, 629–640. http://dx.doi.org/10.1037/0096-1523.3.4.629.

Mewhort, D., & Campbell, A. (1981). Toward a model of skilled reading: An analysis of performance in tachistoscopic tasks. *Reading research: Advances in theory and practice* (Vol. 3, pp. 39–118). London, UK: Academic Press.

Meyer, D. E., Schvaneveldt, R. W., & Ruddy, M. G. (1974). Functions of graphemic and phonemic codes in visual word-recognition. *Memory & Cognition, 2*, 309–321. http://dx.doi.org/10.3758/BF03209002.

Miceli, G., Capasso, R., Benvegnu, B., & Caramazza, A. (2004). The categorical distinction of vowel and consonant representations: Evidence from dysgraphia. *Neurocase, 10*, 109–121. http://dx.doi.org/10.1080/13554790409609942.

Morais, J., Alegria, J., & Content, A. (1987). The relationships between segmental analysis and alphabetic literacy: An interactive view. *Cahiers de Psychologie Cognitive/Current Psychology of Cognition, 7*, 415–438.

Morais, J., & Kolinsky, R. (1994). Perception and awareness in phonological processing: The case of the phoneme. *Cognition, 50*, 287–297. http://dx.doi.org/10.1016/0010-0277(94)90032-9.

Morton, J. (1969). Interaction of information in word recognition. *Psychological Review, 76*, 165–178. http://dx.doi.org/10.1037/h0027366.

New, B., Araújo, V., & Nazzi, T. (2008). Differential processing of consonants and vowels in lexical access through reading. *Psychological Science, 19*, 1223–1227. http://dx.doi.org/10.1111/j.1467-9280.2008.02228.x.

New, B., Ferrand, L., Pallier, C., & Brysbaert, M. (2006). Re-examining the word length effect in visual word recognition: New evidence from the English Lexicon Project. *Psychonomic Bulletin & Review, 13*, 45–52.

New, B., Pallier, C., Brysbaert, M., & Ferrand, L. (2004). Lexique 2: A new French lexical database. *Behavior Research Methods, Instruments, & Computers, 36*, 516. http://dx.doi.org/10.3758/BF03195598.

Patterson, K. E., & Morton, J. (1985). From orthography to phonology: An attempt at an old interpretation. In K. E. Patterson, J. C. Marshall, & M. Coltheart (Eds.), *Surface dyslexia* (pp. 335–359). London: Erlbaum.

Peereman, R., Brand, M., & Rey, A. (2006). Letter-by-letter processing in the phonological conversion of multiletter graphemes: Searching for sounds in printed pseudowords. *Psychonomic Bulletin & Review, 13*, 38–44. doi: 10.3758/BF03193810.

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

Perry, C., Ziegler, J. C., & Zorzi, M. (2010). Beyond single syllables: Large-scale modeling of reading aloud with the Connectionist Dual Process (CDP++) model. *Cognitive Psychology, 61*, 106–151. http://dx.doi.org/10.1016/j.cogpsych.2010.04.001.

Prinzmetal, W., Hoffman, H., & Vest, K. (1991). Automatic processes in word perception: An analysis from illusory conjunctions. *Journal of Experimental Psychology: Human Perception and Performance, 17*, 902–923. http://dx.doi.org/10.1037/0096-1523.17.4.902.

Prinzmetal, W., Treiman, R., & Rho, S. H. (1986). How to see a reading unit. *Journal of Memory and Language, 25*, 461–475. http://dx.doi.org/10.1016/0749-596X(86)90038-0.

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

Rapp, B. C. (1992). The nature of sublexical orthographic organization: The bigram trough hypothesis examined. *Journal of Memory and Language, 31*, 33–53. http://dx.doi.org/10.1016/0749-596X(92)90004-H.

Rubenstein, H., Lewis, S. S., & Rubenstein, M. A. (1971). Evidence for phonemic recoding in visual word recognition. *Journal of Verbal Learning and Verbal Behavior, 10*, 645–657. http://dx.doi.org/10.1016/S0022-5371(71)80071-3.

Santa, J. L., Santa, C., & Smith, E. E. (1977). Units of word recognition: Evidence for the use of multiple units. *Perception & Psychophysics, 22*, 585–591. http://dx.doi.org/10.3758/BF03198767.

Seidenberg, M. S. (1987). Sublexical structures in visual word recognition: Access units or orthographic redundancy? In M. Coltheart (Ed.), *Attention and performance, XII: The psychology of reading* (pp. 245–263). Hillsdale: Lawrence Erlbaum Associates.

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

Shallice, T., & McCarthy, R. (1985). Phonological reading: From patterns of impairment to possible procedures. In K. E. Patterson, J. C. Marshall, & M. Coltheart (Eds.), *Surface dyslexia: Neuropsychological and cognitive studies of phonological reading* (pp. 361–397). London: Erlbaum.

Singer, M. H. (1980). The primacy of visual information in the analysis of letter strings. *Attention, Perception, & Psychophysics, 27*, 153–162. http://dx.doi.org/10.3758/BF03204304.

Srinivas, K., Roediger, H. L., & Rajaram, S. (1992). The role of syllabic and orthographic properties of letter cues in solving word fragments. *Memory & Cognition, 20*, 219–230. http://dx.doi.org/10.3758/BF03199659.

Spoehr, K. T., & Smith, E. E. (1973). The role of syllables in perceptual processing. *Cognitive Psychology, 5*, 71–89. http://dx.doi.org/10.1016/0010-0285(73)90026-1.

Spoehr, K. T., & Smith, E. E. (1975). The role of orthographic and phonotactic rules in perceiving letter patterns. *Journal of Experimental Psychology: Human Perception and Performance, 104*, 21–34. http://dx.doi.org/10.1037/0096-1523.1.1.21.

Stenneken, P., Conrad, M., & Jacobs, A. M. (2007). Processing of syllables in production and recognition tasks. *Journal of Psycholinguistic Research, 36*, 65–78. http://dx.doi.org/10.1007/s10936-006-9033-8.

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

Taft, M. (1991). *Reading and the mental lexicon*. Exeter: Lawrence Erlbaum Associates.

Taft, M., & Forster, K. I. (1976). Lexical storage and retrieval of polymorphemic and polysyllabic words. *Journal of Verbal Learning and Verbal Behavior, 15*, 607–620. http://dx.doi.org/10.1016/0022-5371(76)90054-2.

Titone, D., & Connine, C. M. (1997). Syllabification strategies in spoken word processing: Evidence from phonological priming. *Psychological Research, 60*, 251–263. http://dx.doi.org/10.1007/BF00419410.

Treiman, R., Kessler, B., & Bick, S. (2002). Context sensitivity in the spelling of English vowels. *Journal of Memory and Language, 47*, 448–468. http://dx.doi.org/10.1016/S0749-596X(02)00010-4.

Vergara-Martínez, M., Perea, M., Marín, A., & Carreiras, M. (2010). The processing of consonants and vowels during letter identity and letter position assignment in visual-word recognition: An ERP study. *Brain and Language, 118*, 105–117. http://dx.doi.org/10.1016/j.bandl.2010.09.006.

Whitney, C. (2001). How the brain encodes the order of letters in a printed word: The SERIOL model and selective literature review. *Psychonomic Bulletin & Review, 8*, 221–243. http://dx.doi.org/10.3758/BF03196158.

Vinckier, F., Dehaene, S., Jobert, A., Dubus, J. P., Sigman, M., & Cohen, L. (2007). Hierarchical coding of letter strings in the ventral stream: Dissecting the inner organization of the visual word-form system. *Neuron, 55*, 143–156. http://dx.doi.org/10.1016/j.neuron.2007.05.031.

Yap, M. J., & Balota, D. A. (2009). Visual word recognition of multisyllabic words. *Journal of Memory and Language, 60*, 502–529. http://dx.doi.org/10.1016/j.jml.2009.02.001.

Ziegler, J. C., & Goswami, U. (2005). Reading acquisition, developmental dyslexia, and skilled reading across languages: A psycholinguistic grain size theory. *Psychological Bulletin, 131*, 3–29. http://dx.doi.org/10.1037/0033-2909.131.1.3.

Ziegler, J. C., & Perry, C. (1998). No more problems in Coltheart's neighborhood: Resolving neighborhood conflicts in the lexical decision task. *Cognition, 68*, B53–B62. http://dx.doi.org/10.1016/S0010-0277(98)00047-X.