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Cognitive Processes Underlying the Syllabification of French Print

Chantal Desmarais
School of Psychology
University of Ottawa

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I dedicate this thesis to my parents, René and Mariette Desmarais, and to my significant other, Barkley Barton, without whose continued support and unconditional love this would not have been possible.

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COGNITIVE PROCESSES UNDERLYING THE SYLLABIFICATION OF FRENCH PRINT

Abstract

This program of research sought an answer to the following question: What is the nature of the mechanism underlying French readers' ability to identify syllabic boundaries in print? Two complementary approaches were taken to shed some light on this problem: first, we examined how the structural properties of syllables influence syllabification decisions; and second, we explored the relationship between syllabic structure and the issue of syllabic mediation in visual word recognition (VWR). In the first study, university students were asked to syllabify a list of 248 words (Experiment 1) or pseudowords (Experiment 2), in a paper-and-pencil syllabification task. The data were coded and then analyzed according to a framework representing the realm of all possible environments in which syllabic boundaries can be identified, within any given letter string. In the second study, participants were asked to verify the proper location for a syllabic boundary marker, which was inserted between the letters of isolated words displayed at the center of a computer screen (e.g., 'ca/bane' [shack]). In the syllable boundary verification (SBV) task, trisyllabic stimuli that contained a single medial consonant or medial consonant pair were contrasted either at the first or second syllabic boundary (i.e., Experiments 1 and 3: CV.CV.CV vs. CVC.CV.CV; Experiment 2: CV.CV.CV vs. CV.CVC.CV). The results showed that lexicality was not a factor in the untimed syllabification task (Study 1), where participants relied on simple heuristics to parse letter strings (i.e., spelling-to-sound translation, prescribed rule for separating geminate consonants). In the timed verification task (Study 2), a location-specific effect of syllabic structure was observed in the critical marker position for all three experiments, in addition to a word-frequency effect. Moreover, a reliable effect of marker serial position revealed an increase in response times towards the end of words. The pattern of results for this series of experiments is most consistent with the idea of a lexically-derived syllabic structure effect and inconsistent with one form of the syllabic mediation hypothesis (i.e., syllable-as-access-code hypothesis). Overall, the findings of both studies converge towards the following conclusion: The mechanism underlying the ability to identify syllabic boundaries in French print relies on multiple sources of constraint that vary according to task demands.

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Chapter 1

General Introduction

This program of study was undertaken to examine the cognitive processes underlying the syllabification of French print and the role of syllables in visual word recognition (VWR). A small number of studies to date have dealt with the former issue uniquely from the standpoint of English readers, either in the context of children acquiring the language (i.e., Fallows, 1981) or skilled adult readers (i.e., Treiman and Danis, 1988; Treiman and Zukowski, 1990; Treiman, Gross, and Cwikiel-Glavin, 1992). The focus of the present study is on skilled readers of French. In contrast, the latter issue has been investigated in French, using a number of experimental paradigms (e.g., Mehler, Dommergues, Frauenfelder, and Segui, 1981; Peretz, Lussier, and Béland, 1998; Ferrand, Segui, and Grainger, 1996; Colé, Magnan, and Grainger, 1999). The goals of this research are three-fold: (a) to relate the present findings on the processing of French print to theoretical models of speech and VWR, (b) to develop a framework for studying syllabification responses and their underlying mechanism, and (c) to investigate the mechanism that underlies French readers' ability to identify syllabic boundaries during VWR.

A history of controversy characterizes the debate over the role of syllables in the processing of both print and speech. Some cognitive theorists maintain that the syllable should occupy a central role in language processing (e.g., Taft, 1979; Ans, Carbonnel and Valdois, 1998; Levelt, 1989), while others have argued strongly against the notion of syllables as real psychological units (e.g., Coltheart, 1978; Seidenberg and McClelland, 1989; Kwantes and Mewhort, 1999). The range of perspectives on the syllable has varied just as widely in the field of Linguistics: from Chomsky and Halle's (1968) ground-breaking work 'The Sound Pattern of English', in which no role was ascribed to the syllable, to other linguists (e.g., Pulgram, 1970; Kahn, 1976; Selkirk, 1982) that assigned a prominent role to the syllable in their phonological theories.

Hierarchical Syllabic Structure Hypothesis

The concept of the syllable originated in the realm of spoken language. As such, this phonological unit is comprised of three basic constituents: the <u>nucleus</u> or vowel, which represents a peak in sonority and is bordered by optional pre- or post-vocalic consonant groups that are referred to as the onset and coda, respectively (e.g., Giegerich, 1992). Although there is no widely-held consensus relative to any particular theory of syllabification, among the proponents of the syllable view (see Treiman and Danis, 1988), several theorists have demonstrated convincingly that the structure of the syllable can be thought of as more than a linear string of phonemes (e.g., Treiman, Fowler, Gross, Berch, and Weatherston, 1995; Spencer, 1996).

In essence, the hierarchical structure hypothesis holds that both nucleus and coda constituents are subsumed under a higher-order unit called the rime (i.e., onset-rime view). Several strands of evidence have substantiated this claim: (a) data on the distributional properties of phonemes, (b) consistent patterns emerging from the analysis of speech errors, and (c) laboratory tasks involving word games. First, linguistic evidence concerning the distributional properties of phonemes in English has shown that there are severe constraints imposed on the patterns of co-occurrence for rime constituents, whereas onsets and rimes can co-occur in virtually any combination (e.g., Fudge, 1969). Second, behavioral evidence for the onset-rime view is partially based on findings from speech-error analyses (e.g., Mackay, 1970; 1972; 1974; Fromkin, 1973; Shattuck-Hufnagel, 1979). To illustrate, Mackay (1972) showed that words with similar meanings were often blended together, producing a nonword; this type of error known as a 'synonymic intrusion', tends to involve a parsing before the vowel (e.g., 'grasp' + 'clutch' → 'grutch'). Third, behavioral evidence in the form of word games also supports the view that onsets and rimes behave as integral units. For example, Treiman (1983; Experiment 1) designed a task in which native speakers of English could manipulate spoken syllables according to two different sets of rules, the onset rule and the letter rule. During an initial training phase, participants repeated the sound of a CVC syllable and then transformed it into two distinct syllables, by inserting a constant phoneme sequence after the first consonant, which coincided with the onset-rime boundary (e.g., 'kig' → 'kaez_ig'). During a test phase, target stimuli with a CCVC structure were mixed in with control stimuli that had a CVC structure. The results showed that participants invariably chose the onset rule over the letter rule in parsing CCVC stimuli (e.g., 'skef' → 'skaez_ef' vs. 'skef' → 'saez_kef', respectively), thus preserving the integrity of the onset-rime boundary.

Functional Role of Syllables in Language Processing

Experimental studies have also demonstrated the relevance of syllables and subsyllabic units (i.e., onset, rime) as functional units involved in the processing of spoken and written language, albeit under particular conditions. The first study to address the issue of subsyllabic units involved in printed word recognition is that of Treiman and Chafetz (1987). To illustrate, one of their experiments involved a lexical decision task, in which participants had to judge the lexical status of stimuli with a CCVCC structure, that were presented with a double slash inserted either before or after the vowel (e.g., 'cr//isp' vs. 'cri//sp'; 'tr//isp' vs. 'tri//sp'). The results showed that participants were quicker to discriminate between words and nonwords with a parsing before the vowel. Thus, the hypothesis that the onset and rime behave as integral units during on-line processing of written stimuli was substantiated. The same issue was explored by Bowey (1990; 1993) using a partial priming technique. In this series of experiments, participants were shown either a two- or three-letter prime followed by a target word and asked to pronounce the word as quickly as possible. Facilitation effects were expected for words primed by a subsyllabic unit (compared to an unprimed condition), if such units play a role in the retrieval of lexical representations. In line with this prediction, the results showed that stimuli preceded by a prime that corresponded precisely with a subsyllabic unit (i.e., onset or rime) were named faster than those that were not (e.g., 'ail' → 'hail' pronounced faster than 'lew' → 'blew'). These findings were held as support for the claim that orthographic onsets and rimes serve as functional units in reading.

Prinzmetal, Treiman, and Rho (1986) investigated the role of syllable-like units in the initial stages of reading, using an illusory conjunction task. They used bisyllabic five-letter words in which the syllabic boundary was formed by a medial consonant pair representing an illegal consonant cluster (e.g., 'dk' in 'vodka'). In this perceptually-based task, participants were presented with a written word and then asked to recall from memory, whether or not, a pre-designated target letter had been present within the word. In the event of an affirmative response, participants were asked to name the target's color, which shared the color of either the word's first or last two letters. The pattern of incorrect responses revealed that participants reported the target in the color of a letter in the same syllable more often than in the color of a different syllable (i.e., more conjunction errors within syllables). For example, participants reported that 'd' in 'vod.ka' was 'blue', although is was red: 'vo' = blue and 'dka' = red. Similar findings were obtained for words with a morpheme boundary (e.g., 'to.day'). Prinzmetal et al., (1986) argued that the unitization effect demonstrated in their task was caused by two separate mechanisms: (a) one that affects early perceptual processing of a letter string and relies on abstract orthographic knowledge, and (b) one that relies on morphological information and arises after lexical identification has taken place. The authors coined the term 'reading units' to refer to these syllable-like effects, since the results were not replicated with stimuli whose syllabic boundaries were phonologically-defined, based on stress assignment (e.g., 'ca.nal' and 'cam.el'). However, it may be possible to obtain syllabic effects at such an early processing stage, using a phonological variable other than stress or by attempting to replicate the findings in a different language such as French. Nevertheless, these findings were replicated in a subsequent study (i.e., Prinzmetal, Hoffman, and Vest, 1991) and, importantly, showed that sensitivity to reading units was correlated with reading ability.

With respect to the role of syllables in speech production, the work of Ferrand and his collaborators (e.g., Ferrand et al., 1996; Ferrand, Segui, and Humphreys, 1997) supports the view that the syllable represents a functional unit of output phonology in both French and English. In two series of experiments, the masked priming paradigm was used in the context of naming and lexical decision tasks. In each case, words and nonwords were preceded by the following visual sequence: mask, prime, mask, and stimulus (e.g., ###### + 'bal'+ ###### + 'balcon'). Facilitation effects on naming latencies were observed with a brief prime exposure (i.e., 29 ms), for stimuli preceded by a CV or CVC prime that coincided exactly with the word-initial syllable. In the lexical decision task, prime exposure did not influence response times. The differential effects of prime exposure across tasks were interpreted as support for the role of syllables as units of output phonology, since facilitation effects were only observed in a task which requires the construction of a phonological code (i.e., naming). It should be noted that this perspective differs fundamentally from other accounts presented in this section, where syllables (and subsyllabic units) have been shown to affect earlier processes involved in VWR and reading.

Cross-linguistic research in the area of speech perception suggests a more limited role for the syllable. In a seminal study conducted by Mehler et al. (1981), native speakers of French had to determine the presence or absence of a target phoneme sequence at the beginning of spoken words. On each trial, a target phoneme sequence was presented visually and followed by an auditory string of stimuli; the stimuli included one of two carrier words, whose initial syllable either did or did not match the target phoneme sequence (e.g., 'pa' in 'pa.lace' [palace] or 'pal.mier' [palm tree]), as well as, four bisyllabic filler words (e.g., 'jeudi', 'morceau', 'fichier', 'service' [Thursday-piece-file-service]). It was hypothesized that target sequences providing an exact match for the word-initial syllable of carrier words, would lead to faster detection times than those that did not (e.g., 'pa' in 'pa.lace' vs. 'pal' in 'pa.lace' [palace]), if words are segmented according to their syllabic structure in order to retrieve the representation of words stored in the mental lexicon (i.e., lexical identification). As predicted by the syllabic structure hypothesis, an interaction was observed between target phoneme sequence and word-initial syllable of carrier words. Thus, it was concluded that French listeners rely on a syllabified code to mediate lexical identification. Similar findings were obtained in Spanish using the syllable-monitoring task (e.g., Sebastian-Galles, Dupoux, Segui, and Mehler, 1992). However, these findings did not extend to native speakers of English (e.g., Cutler, Mehler, Norris, and Segui, 1986). Three reasons were offered to account for the discrepancy between the English and French data: (a) syllabic patterns are more regular in French (the typical pattern being CV) than they are in English; (b) stress assignment in French is fixed (on the ultimate syllable), whereas it is variable in English; and (c) medial consonants are harder to classify as onsets or codas in English than they are in French, due to ambisyllabicity[1] in the former.

Peretz et al. (1998) used a different experimental paradigm which, they claim, taps the same input processes as Mehler et al.'s (1981) syllable monitoring task. The stem completion task involved cued recall of words from memory. The hypothesis put forth was that native speakers of French rely on a syllabified code to retrieve the lexical entries of printed words. To elaborate briefly on the task itself, participants were first presented with a list of paired words to be memorized and later asked to complete as many words as possible from the original list, based on the presentation of either a CV or CVC stem. The main findings showed that CV stems elicited more words with a CV-initial syllable, whereas CVC stems elicited more words with a

[1] According to English syllabification rules (e.g., Kahn, 1976), the medial liquid in 'balance' can belong simultaneously to both the onset and coda.

CVC-initial syllable. These results are congruent with the syllabic mediation hypothesis, whereby the locus of the syllabic structure effect is attributed to the retrieval stage. The authors also investigated the nature of this syllabified code, by contrasting stimuli that contained a mute-e with those that did not include a silent letter. It was hypothesized that a CVC stem should elicit more mute-e words than a CV stem (e.g., 'cal(e)pin' [notebook]), if participants relied on a phonological rather than an orthographic code (i.e., CVC.CV vs. CV.CV.CV, respectively). This was the outcome, leading to the authors' conclusion that native speakers of French rely on a syllabified phonological code for lexical identification. A caveat to bear in mind concerns the oral response modality used in all experiments. As the authors themselves pointed out, it could be argued that the syllabic structure effect arose at a later processing stage (i.e., production), due to task requirements (i.e., oral responses require the construction of a phonological code). One way to eliminate this type of confound would be to use a manual response modality; should a syllabic structure effect be observed under these conditions, this would provide stronger support for the syllabic mediation hypothesis.

Colé et al. (1999) also extended the original syllable-monitoring task (from Mehler et al., 1981) to the visual modality. The goal of this study was to investigate the role of syllables during VWR, at various stages of reading development. Skilled adult and beginning readers of French were asked to decide, whether or not, a target CV or CVC syllable was present at the beginning of words and instructed to respond manually. A syllabic structure effect (i.e., interaction between target syllable and carrier word) was expected if readers relied on a syllabified code to mediate lexical access. In addition, word frequency was manipulated in this experiment. As predicted, the pattern of results varied according to the level of reading experience. For beginning readers, the pattern of results varied according to whether testing occurred early or late, during the first year of schooling. Responses from children tested earlier in the year revealed a significant effect of target length (i.e., faster responses to words beginning with a CV than CVC syllable, implying a letter-by-letter reading strategy), while those of children tested later the same year showed the predicted 2-way interaction between target syllable and carrier word. For skilled adult readers, this syllabic structure effect was observed in the context of low-frequency words only (i.e., 3-way interaction between target syllable, carrier word, and word frequency). The implication of these results is that syllabic mediation is a strategy that develops towards the end of the first year of school and is retained by skilled readers for the purpose of processing of low-frequency stimuli (while high-frequency stimuli are processed holistically via a whole-word code).

In sum, the aforementioned studies highlight several conditions in which syllables may be expected to play a role in VWR. With respect to skilled readers of French, the work of Colé et al. (1999) suggests that lexical identification is mediated by a syllabified code (i.e., syllabic mediation hypothesis), in the case of low-frequency words, whereas it is achieved via an orthographic whole-word code, in the case of high-frequency words. The work of Peretz et al., (1998) further suggests that the syllabified code is phonological in nature.

Universal Syllabification Principles

In terms of identifying the nature of the mechanism underlying the ability to segment written stimuli, a number of syllabification principles have been proposed in the linguistic literature and, to a much lesser extent, in the psycholinguistic literature (e.g., Kahn, 1976; Selkirk, 1982; Pulgram, 1970; Giegerich, 1992; Treiman and Zukowski, 1990; Treiman and Danis, 1988). In alphabetic scripts, similar principles may govern the syllabification of words in their spoken and written form. However, it could be argued that there is an added layer of complexity associated with the latter, since the stimuli are presented as a whole rather than as a continuous stream. A straightforward way for a listener to discriminate between consonants and vowels in a spoken word would be to identify peaks in sonority (i.e., relative loudness) associated with vowels. Coupled with the knowledge that each syllable must contain a single peak in sonority, the location of syllabic boundaries could be approximated between two peaks in sonority. This notion is embodied by the sonority sequencing principle. The sonority principle states that the syllable is formed by segments that tend to follow an ideal sonority profile: a steady rise in sonority from the onset to the nucleus, followed by a corresponding decrease towards the coda (e.g., 'quilt').

Although sonority may be a useful segmentation cue, this factor alone will oftentimes not suffice to pinpoint the precise location of syllabic boundaries. As a starting point, let us consider a simple example, such as 'co.py', in which the medial stop consonant is parsed as the onset of the second syllable. This parsing presupposes a preference for maximizing the onset (i.e., known in the linguistic literature as the 'maximum onset principle' or MOP). The MOP states that the onset should contain as many consonants as possible, while respecting the phonotactic rules of the language. This approach is justified on the grounds that there are more severe constraints within the rime than the onset. To proceed with our investigation, let us consider some slightly more complex examples, like 'a.gree' and 'ar.gue', which contain a medial consonant cluster or medial consonant pair, respectively. For these examples, the correct location for a syllabic boundary can be predicted based on the MOP, if one possesses the requisite knowledge about the distribution of phonemes in the language (e.g., 'gr' but not 'rg' is a permissible word-initial sequence). Sonority is also a likely factor here. Based on the sonority principle, a syllabic boundary would be predicted before the medial consonant cluster 'gr', which represents a rise in sonority, and between the medial consonant pair 'rg', which represents a sonority reversal. There exists a third syllabification principle, which is implicit in the definition of the MOP. The legality principle states that syllable-initial or -final sequences can be considered legal if they satisfy a prerequisite condition, that is, they form permissible word-initial or -final sequences.

The issue of stress assignment is a relatively trivial one for French, in comparison to English syllabification, because it is fixed in the former and variable in the latter. Nevertheless, it is worth a brief mention here. In a written syllabification task, Treiman and Danis (1988) demonstrated that stressed syllables tend to attract medial consonants. Skilled readers of English chose between two syllabification alternatives for bisyllabic stimuli receiving either first- or second-syllable stress (e.g., 'prop-er' vs. 'pro-per' and 'prop-el' vs. 'pro-pel', respectively). The results showed a greater proportion of first-syllable responses with the former ('prop-er' = .60) than the latter ('prop-el' = .14). Another factor that has little or no influence on French syllabification is ambisyllabicity. For example, in a word like 'quarter', the medial stop has as much affinity for the first syllable, as it does the second, and is sometimes considered to belong simultaneously to both syllables (e.g., Kahn, 1976).

Vowel length and speech rate are two other factors that have been cited in the linguistic literature. Syllables may end with either a consonant or a long vowel, but not with a short vowel. One way to explain this is by reference to a slots-and-fillers model (e.g., Shattuck-Hufnagel, 1979) for describing syllabic structure, where short and long vowels extend over one or two timing slots, respectively. For example, the words 'demon' and 'lemon' each contain two syllables (represented at the syllable tier), which can be further subdivided into slots (represented at the skeletal / timing tier) and together form the frame into which segmental information may be inserted (represented at the segmental tier; Levelt, 1989). Consequently, the syllabic boundary in the word 'de.mon' falls before the medial consonant, because the preceding vowel is long, and falls after the medial consonant in 'lem.on'[2], since the preceding vowel is short. With respect to speech rate, Kahn (1976) has argued that there are two levels of syllabification, that distinguish between slow speech and normal or fast speech (for a different view see Selkirk, 1982). Essentially, this theory holds that all syllable onsets should be made long in slow speech (e.g., 'le.mon'), subject to resyllabification during normal / fast speech (e.g., 'lem.mon').

Lastly, although psychologists have not traditionally shown much interest in the linguistic principles outlined above, it would appear as though the tide has slowly started to turn (e.g., Treiman and Zukowski, 1990). An additional factor, rooted in the psychological literature on VWR and reading, has been proposed as a mechanism for identifying syllabic boundaries. More specifically, Seidenberg (1987) proposed that syllabic boundaries coincide with a particular spelling pattern referred to as a bigram trough. The bigram trough hypothesis predicts a lower frequency of co-occurrence for letter pairs forming a syllabic boundary than those within a syllable. It is important to bear in mind that, according to the connectionist theory of word recognition which supports the bigram trough hypothesis (i.e., Seidenberg and McClelland, 1989), syllables are not considered to be real psychological units. In fact, syllables are viewed merely as by-products resulting from orthographic redundancy.[3]

In sum, it is possible to identify a core group of syllabification principles for written French; these include (a) sonority, (b) legality (MOP), and (c) bigram frequencies.

Theoretical Models

It is not surprising, given the intense debate surrounding the issue of syllables and their role in language processing, that there would be more than one theoretical model capable of

[2] Note that some theorists (e.g., Kahn, 1976) consider the medial consonant in 'lem.mon ' to be ambisyllabic.

providing a compelling account of this issue. Therefore, a set of six theoretical models will be presented, which together, span the last three decades: (1) Multiple-Trace model (Ans et al., 1998), (2) LEX model (Kwantes and Mewhort, 1999), (3) Taft's model of lexical retrieval (1979; Taft and Forster, 1976), (4) Dual-Route model (Coltheart, 1978; Coltheart, Curtis, Atkins, and Haller, 1993; Coltheart, Rastle, Perry, Langdon, and Ziegler, 2001), (5) Parallel-Distributed-Processing (PDP) model (Seidenberg and McClelland, 1989), and (6) Levelt's model of phonological encoding (1989). These models differ according to, whether or not, they posit a level of representation for syllables and also in terms of their potential locus for syllabic structure effects (i.e., lexical vs. non-lexical).

The Multiple-Trace model (Ans et al., 1998) is arguably the most relevant one to be presented here, since it is a computational model that has been tested with polysyllabic French stimuli and also includes an explicit mechanism for identifying syllabic boundaries. According to this model's representational assumptions, the lexicon contains both word and segment traces; the latter of which include a level of representation for syllables, onsets, rimes, and phonemes. In terms of processing assumptions, the model posits two kinds of reading strategies that operate successively on any type of letter string (i.e., words and nonwords). The global reading procedure relies on knowledge of whole words and serves as the default strategy; the analytic reading procedure relies on the activation of syllables and other subword units and is used as a backup strategy, whenever the global procedure fails to retrieve an appropriate lexical match.

A tagging mechanism is responsible for identifying syllabic boundaries when the system operates in the analytic mode. We shall first describe the sequence of steps leading up to the use of this procedure. As mentioned previously, the default for processing any letter string is the global reading procedure. In this mode, the stimulus is encoded as a whole over a layer of orthographic units, which means that all letters and word boundaries belong to a focal window. Next, an alignment mechanism is responsible for encoding the position of all focal elements, using the rightmost element of the first vocalic grapheme as a starting point (i.e., zero cluster). For example, positional encoding of the word 'fourmi' [ant] would be as follows: [#f<u>ou</u>rmi#] → [–3, -2, -1, 0, +1, +2, +3, +4]. Orthographic encoding of the stimulus triggers the creation of a

[3] The orthographic redundancy hypothesis claims that, for alphabetic languages, the characteristics of spoken language tend to be reflected in the written form (e.g., phonotactic constraints).

phonological representation, in parallel with a second orthographic representation; the latter of which is achieved through the activation and blending of multiple traces in episodic memory. The final step involves a lexical check to verify an exact match between both orthographic representations. If no match is found, the system then shifts into the analytic mode, where the size of the focal window is reduced and the retrieval mechanism operates on a syllable-by-syllable basis (or finer-grained level, as required). Once the processing of a single syllable is completed, the last letter of the current syllable (i.e., partial representation of the stimulus over the second orthographic layer) is tagged as the leftmost boundary of the next syllable to be processed (i.e., full representation of the stimulus over the first orthographic layer), and so on and so forth.

Although the Multiple-Trace model was not developed to study written syllabification behavior per se, certain predictions can be made based on its fundamental tenets. First, the probability of segmentation for any given letter string is directly proportional to its printed word frequency. Descriptive statistics reported by Ans et al. (1998) suggest that the vast majority (i.e., close to 97%) of words in their database, including 13,165 French words, can be read successfully using the global reading procedure; analytic processing is typically reserved for stimuli in the frequency range of .04 to 5.36 occurrences per million (Mdn = 1.31). This would suggest the possibility of different loci for syllabic structure effects, observed in the context of an on-line syllabification task, depending on the type of reading procedure. In other words, when stimuli are processed in the global mode, syllabic structure effects may occur at a post-identification stage, whereas the locus of these effects may occur earlier, at the retrieval stage, when stimuli are processed in the analytic mode.

Second, with respect to the explicit tagging mechanism for identifying syllabic boundaries during analytic processing of a letter string, there is one crucial point that remains unclear: How does the mechanism identify the rightmost boundary of a word-initial syllable? One possibility is that the formation of a syllabic representation over the second orthographic layer is influenced more so by segment traces (i.e., syllables) that are common to many words in the language than those which are infrequent. However, this kind of explanation is not very appealing for models which posit a level of representation for syllables, since it hinges on the distributional properties of the language. Another possibility is that the tagging mechanism operates with an implicit legality principle (i.e., to assess the cohesiveness of medial consonant sequences), as a minimal requirement.

In contrast to the preceding account, Kwantes and Mewhort (1999) developed a computational model, LEX, which has no level of representation for syllables. The only relevant subword units in this model are letters and phonemes. Nevertheless, LEX can account for syllabic effects observed in various language-processing experiments (e.g., lexical decision, naming). In terms of processing, retrieval from the lexicon occurs in three distinct stages: (a) a letter identification stage - where letters are identified in parallel and stored as an ordered list; (b) a retrieval stage (not unlike that of the Multiple-Trace model) - in which a reiterative mechanism samples from cohorts of lexical items, in order to generate orthographic and phonological representations in parallel, through blending of lexical information; and (c) a response generation stage – where a response is produced on the basis of orthographic or phonological knowledge, depending on task requirements.

We shall provide a brief overview of a study by Taft and Forster (1976), in order to demonstrate how LEX was able to replicate the observed syllabic effects, without positing a level of representation for syllables. In the original lexical decision task, native speakers of English were presented with three types of nonword stimuli: (a) nonwords like 'trup', which do not form the beginning of a word; (b) nonwords like 'brot', which can appear word-initially; and (c) nonwords like 'plat', which correspond to a syllable that is defined on orthographic and morphological grounds (i.e., Basic Orthographic Syllable Structure or BOSS)[4]. The behavioral results showed higher latencies associated with nonwords that had a BOSS-beginning than with the two other types of nonwords. This finding was interpreted as support for the claim that the lexical entries of polysyllabic words are accessed via a representation of their first syllable. A radically different interpretation was offered by Kwantes and Mewhort (1999), who successfully simulated this pattern of results using the LEX model. Basically, LEX's sensitivity to the BOSS unit was attributed to knowledge of statistical regularities associated with the representation of words stored in memory. More specifically, their claim rests on the fact that words with BOSS-beginnings were found to be more frequent in the LEX model's lexicon, than words with non-

[4] The Basic Orthographic Syllable Structure (BOSS) is thought to be a relevant structure for VWR in English and is defined on orthographic / morphological grounds.

BOSS-beginnings. Consequently, longer decision latencies were observed for nonwords corresponding to the BOSS of a real word, compared to nonwords that did not, due to increased competition resulting from the activation of more lexical entries, in the former.

The preceding account explains how LEX was able to replicate syllabic effects in a (lexical decision) task which requires the discrimination between letter strings that represent either real words or nonwords. However, we need to push the argument a bit farther in order to explain how syllabic boundaries may be identified in an on-line syllabification task with written stimuli. In order to identify the proper location for a syllabic boundary, based on this scenario, the system would have to tap into a source of phonological information. Although the phonological representation is generated in parallel with the (second) orthographic representation, it only becomes available at a post-identification stage (i.e., once the correct lexical item has been identified). Therefore, knowledge of syllabic boundaries is lexically-derived.

Taft and Forster (1976) argued that words are encoded in the lexicon as representations of their first syllable or BOSS, which is defined on orthographic and morphological grounds. According to this model of lexical retrieval, a reiterative left-to-right parsing mechanism is used to locate the BOSS, which serves as a retrieval cue for the corresponding lexical entry. To illustrate, when the word 'candle' is presented to the system, the letter string is parsed successively after each letter and a cumulative search of the lexicon ensues (i.e., 'c-ca-can-cand') until a match is found for the BOSS 'cand'. This theory of lexical retrieval is based on a model proposed by Forster (1976), in which a master file contains a list of lexical entries that are ordered by frequency and can only be retrieved via peripheral access files; the BOSS constitutes an example of an orthographic access file for English. Taft and Radeau (1995) presented data which suggest the use of a different access code in French, the phonological-first syllable. A naming study was designed to test the hypothesis that the pronunciation of a nonword could be biased by a visual word prime sharing its phonological-first syllable, rather than its BOB or Body of the BOSS (as in English; see Taft, 1992). For example, the first vowel in the nonword 'MERANE' was pronounced as /e/ instead of /ɛ/ when preceded by 'MEDUSE' (phonological-first syllable prime), but not 'FEROCE' (BOB-sharing prime), compared to a control condition 'SALAUD' (unrelated prime).

Two key implications can be drawn from these findings. First, because this model assigns a critical role to word-initial syllables in VWR, it follows that the reiterative left-to-right processing of a letter string will stop after the appropriate access code has been located (i.e., syllable-as-access-code hypothesis). Thus, in a on-line syllabification task, this means that serial-based processing of the letter string would occur up to the first syllabic boundary. Decisions about the proper location of syllabic boundaries for subsequent syllables in a word would be based on lexically-derived phonology. Second, the data from the French study (i.e., Taft and Radeau, 1995) suggest that the phonologically-defined first syllable of words acts as a code for retrieving a word's lexical representation. The latter finding is consistent with the regularity of the CV structure in French.

The original Dual-Route model of reading (Coltheart, 1978) has made a lasting impact on all subsequent models in the area of Cognitive Psychology and Language, as well as, in related fields of study (i.e., Neuropsychology, Education). More importantly, this model merits our attention with respect to the issue at hand for two other reasons: first, the argument that led Coltheart (1978) to the rejection of a syllabified code for phonological encoding, in favor of a grapheme-to-phoneme (GPC) procedure; and second, Coltheart et al.'s (2001) interpretation of 'consistency effects', a phenomenon which posed a significant threat to the Dual-Route model (see Glushko, 1979). According to the original Dual-Route model (i.e., Coltheart, 1978), written words are processed via two independent mechanisms which operate in parallel: (a) the lexical route – which uses a whole-word orthographic / visual code for retrieving the representation of words from the mental lexicon; and (b) the nonlexical route - which relies on a set of grapheme-to-phoneme correspondence (GPC) rules for translating print-to-sound. The lexical route is required in order to yield the correct pronunciation of exception words (i.e., for words like 'yacht' the GPC procedure will yield an incorrect output, known as a 'regularization error'); the nonlexical route is necessary in order to pronounce nonwords, since they have no corresponding entry in the mental lexicon.

Coltheart (1978) initially considered the mental syllabary hypothesis as an alternative to the GPC procedure. However, this possibility was rejected on the grounds that it could not account for a number of key phenomena observed in the literature (e.g., naming latency differences observed between skilled readers' responses to regular and exception words, the ability to pronounce nonwords, and the pattern of errors that arises in surface dyslexia). Moreover, Coltheart (1978) argued convincingly against a set of English parsing rules, that were developed by Hansen and Rodgers (1973)[5]. These parsing rules yield incorrect pronunciations for common words like 'lion' and 'pole'; in the former, the rules fail to predict a parsing between adjacent nuclei belonging to separate syllables, while in the latter, the rules lead to an incorrect parsing before the medial liquid, since the mute-e is identified as a nucleus). A noteworthy point here is that the mental syllabary hypothesis remains a theoretically viable option, insofar as it is possible to define a set of unequivocal parsing rules.

With respect to consistency effects, Glushko (1979) showed that naming latencies were greater for regular words like 'have' that have a pronunciation which is inconsistent with that of visually similar words sharing the same rime or orthographic body (e.g., 'save' or 'gave'), compared to regular words like 'hope' which have a consistent pronunciation with all rime-sharing words (e.g., 'cope' or 'rope'). Coltheart et al. (2001) re-interpreted Glushko's (1979) body-consistency effect as a neighborhood-consistency effect, both of which are highly correlated. In dual-route terms, words that differ from a target stimulus by one letter (i.e., orthographic neighbors) can either facilitate or inhibit its pronunciation, depending on the number of shared units that are activated in the phoneme system. The key point here is that the DRC model was able to replicate the consistency effect, despite the fact that it contains no intermediary level of representation for subsyllabic units.

In sum, Coltheart et al. (2001) were able to dispense, at least for the time being, with the notion of correspondence rules at the subsyllabic level (i.e., head-to-onset and body-to-rime rules) as a non-lexical source of explanation for consistency effects. However, as the authors themselves pointed out, future research may require the model to include correspondence rules at the subsyllabic level. In this light, syllabic boundary identification could be envisioned as a process whereby boundaries are identified on-the-fly, during the assembly of a phonological code.

The Parallel Distributed Processing (PDP) model put forth by Seidenberg and McClelland (1989) provides a radically different view of the reading process than the Dual-Route model. First, print-to-sound translation occurs via a single mechanism. Second, there are

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[5] First set of rules: V + CV, VC +CV, VC + CCV; second set of rules: VC + V, V +CCV, V + CCCV.

no localized representations in the lexicon or abstract conversion rules. Third, the activation of orthographic, phonological, and semantic knowledge occurs in parallel and none of these codes take precedence over one another. Fourth, knowledge is distributed and encoded on weights between units in a distributed three-layered network (i.e., orthographic units, hidden units and phonological units). Stimulus encoding consists of parsing a letter string into sets of letter triplets called Wicklegraphs, each of which is encoded as a distributed pattern of activation over a set of input and output units (e.g., 'make' = {#ma, mak, ake, ke#} → /mAk/ = {#mA, mAk, Ak#}). This coding scheme allows mapping rules learned in one context to be generalized to a different context (i.e., contextual sensitivity); for example, 'm' → /m/ rule learned for 'make' generalizes to 'made'.

Although the PDP model does not incorporate localized representations associated with units of any grain-size, it does provide a straightforward account of how syllabic boundaries may be identified in print. In this model, syllables are viewed as an emergent property of the language; "syllables derive from articulatory-motor properties of spoken language; essentially, they reflect the opening and closing movements of the jaw cycle" (Seidenberg and McClelland, 1989, p. 524). In alphabetic scripts, the properties of speech, such as syllables, will tend to be reflected in the written form of language (i.e., orthographic redundancy hypothesis). Syllabic boundaries are thought to coincide with a pattern called a bigram trough (i.e., bigram frequencies are lower for inter- than intra-syllabic letter pairs). Nevertheless, it should be noted that the bigram trough hypothesis has been an inconsistent predictor across various language processing experiments (e.g., Rapp, 1992; Treiman and Danis, 1988).

In contrast to the preceding models on VWR and reading, Levelt's (1989) model deals with phonological encoding in the context of speech production. Although there has been no attempt to extend this model into the domain of VWR, we argue that it is relevant to the discussion at hand for two main reasons: first, it constitutes one of the most comprehensive models of syllabification articulated to date; and second, Levelt and Wheeldon (1994) have put forth some convincing data in support of the mental syllabary hypothesis. We shall first provide an overview of the processing stages in this model, highlight relevant research findings as per the mental syllabary hypothesis, and conclude with some possible directions for extending this speech model into the domain of reading.

By Levelt's (1989) account, speech production involves five qualitatively different stages: (1) phonological encoding, (2) phonological word formation, (3) segment-to-frame association, (4) phonetic encoding, and (5) articulation. Phonological encoding involves accessing two types of information in the mental lexicon, segmental (i.e., phonemic structure) and metrical (e.g., number of syllables in a word, stress pattern). The idea of having the skeleton of a word constructed independently from the segments that are inserted into it is supported by research on speech errors and the 'tip-of-the-tongue' phenomenon (e.g., Shattuck-Hufnagel, 1979; Brown and McNeill, 1966). The next stage involves the formation of a phonological word, which is accomplished by concatenating the metrical frames of lexical words (e.g., 'Très_actif' [Very active] becomes /trɛzaktif/) in order to achieve a smoother utterance on the part of the speaker. A word's frame specifies various metrical aspects of word structure, such as, the number of syllables it contains, its stress pattern, and CV structure. The production of connected text requires the resyllabification or abstract grouping of segments into syllables within the boundaries of a phonological word (e.g., '/trɛ/_/aktif/' → 'trɛ.zak.tif'). Hence, the stored syllabification of individual lexical items is not sacrosanct, since the formation of a phonological word implies the dissolution of lexical word boundaries. Segment-to-frame association is a process by which the segmental information associated with a phonological word is inserted into a metrical frame or abstract phonological structure. Next, access to the mental syllabary (which contains a store of syllable programs or gestural scores needed for articulation) occurs at the phonetic encoding stage; input to the syllabary is a fully syllabified version of the phonological word. Finally, at the articulation stage, actual motor responses are derived from syllabic gestural scores that were accessed from the syllabary.

Levelt and Wheeldon (1994; Experiment 1) investigated the syllabary theory using a naming task, in which participants had to learn to associate particular symbols with written words during initial learning trials (e.g., % was paired with 'percent'). The mental syllabary hypothesis predicts a word frequency effect (i.e., faster naming times for high- than low-frequency words) on naming latencies, that is independent from a syllable frequency effect. Bisyllabic stimuli were selected according to a 2 X 2 experimental design in which word frequency (high vs. low) and positional or overall syllable frequency (high vs. low) were manipulated orthogonally. As predicted by the mental syllabary hypothesis, the results showed independent effects of word and syllable frequency.

Based on the preceding account, one logical way to extend the model into the area of VWR and reading is to reverse the order of processing steps. From this standpoint, the cognitive system could attempt to process a letter string in at least three ways: (a) by searching for a whole-word match in the mental lexicon, (b) by searching for a partial match of syllables contained in the syllabary, and / or (c) by computing each syllable on-the-fly. According to Levelt (1989), the mental syllabary contains the vast majority of syllable programs known to adult readers, therefore accessing the syllabary should be faster than computing syllables on-the-fly. Although Levelt (1989) describes syllabic gestural scores as abstract syllable programs needed to guide articulation, we may speculate that the notion of syllabic structure is relevant here. Perhaps, the organization of the syllabary includes an ordered set of syllable typologies, stored in order of their relative frequency of occurrence. If this was the case, then one could predict faster detection times for syllabic boundaries formed by high- than low-frequency syllabic structures (e.g., CV.CV vs. CVC.CV), in an on-line syllabification task. There is some preliminary evidence from the reading literature (i.e., Sevald, Dell, and Cole, 1995) which suggests that a schema view of the syllable (i.e, metrical info) may be more appropriate than a chunk view (i.e., segmental info). Briefly, Sevald et al., (1995) asked native speakers of English to repeat pairs of phonological nonwords as frequently as possible, during a four-second interval. For each pair of stimuli, the first member repeated the content and / or abstract syllabic structure of the second member (e.g., KIL_KIL.PER vs. KIL_KILP.NER). The results revealed no additional advantage to repeating both content and structure over structure alone. For present purposes, the idea that the abstract syllabic structure of words can be separated from their segmental content suggests that different syllable patterns (e.g., CV or CVC) could help to focus the search for a word in memory during retrieval.

In sum, each of the models presented in this section purport to explain syllabic effects observed in various language processing experiments, regardless of whether or not they posit a level of representation for syllables. At present, there is no easy resolution concerning the issue of syllabic boundary identification and the potential role of syllables in printed word recognition; each of the models outlined has its share of shortcomings as well as benefits. The main drawback for some of the computational models (i.e., Dual-Route, PDP), is that they have been elaborated solely in the context of monosyllabic stimuli. Nevertheless, each of the models reviewed here can be logically categorized according to the kinds of hypotheses they can generate with respect to syllabification: (a) phonemic hypothesis (i.e., Kwantes and Mewhort, 1999; Coltheart, 1978; Coltheart et al., 1993; 2001; Seidenberg and McClelland, 1989); (b) syllabic mediation / syllable-as-access-code hypotheses (i.e., Ans et al., 1998; Taft, 1979); and (c) syllabary hypothesis (i.e., Levelt, 1989).

Overview of the Research

Two series of experiments were undertaken in order to examine how native speakers of French identify syllabic boundaries in print. The scope of the first series of experiments was purposefully broad in order to delineate the entire landscape of possibilities regarding the syllabification of letter strings. In the second series of experiments, a more focused approach was taken in order to probe more deeply into specific issues of interest. We shall outline, in turn, the main goals, methodology, hypotheses, and implications of each study.

Study 1

An untimed syllabification task was used in the first series of two experiments. The main objectives of this series were to: (a) work out a comprehensive classification scheme of syllabic environments, and (b) analyze the probability of segmentation responses for native speakers of French in each type of syllabic environment. The same methodology was used in both experiments; participants were tested as a group and instructed to syllabify a list of 248 monosyllabic and polysyllabic French words (Experiment 1) or pseudowords (Experiment 2), by inserting a slash at the appropriate locations within the letter strings (see Appendix A). A classification scheme was devised a priori and words were chosen according to their orthographic properties. Pseudoword stimuli were constructed by preserving the syllabic structure of their corresponding base word from Experiment 1. The results were analyzed in terms of proportions of correct insertions or omissions, across five categories of responses: (1)

mandatory segmentation, (2) illegitimate segmentation, (3) optional segmentation, (4) ambiguous segmentation, and (5) letter cluster segmentation. Various types of syllabic environments were represented as particular subtypes or cases of these five broad categories. Examples of words containing these syllabic environments are presented in Table 1.

For the two main categories of segmentation, it was hypothesized that skilled readers would invariably choose to segment syllabic environments that are considered mandatory (i.e., inter-syllabic boundaries) and consistently omit parsing for syllabic environments classified as illegitimate (i.e., intra-syllabic boundaries). Similarly, it was hypothesized that letter cluster segmentation would be nil (e.g., 'o-ublier' [to forget]). In the case of optional and ambiguous segmentation, it was hypothesized that participants may feel uniformly ambivalent towards parsing in various types of syllabic environments, which would yield an arbitrary pattern of segmentation responses (i.e., near chance-level). The hypothesis of ambivalence / non-differentiation is applicable to syllabic boundaries formed by all types of segments under study (i.e., optional segmentation: semivowel, mute-e, and geminate consonant environments; ambiguous segmentation: s-clusters and aspirated-h environments). In the event that the results should lead to a rejection of the main hypothesis, a conditional set of hypotheses was proposed for these syllabic environments.

This study has major implications not only for the study of French syllabification, but for other languages as well, since the classification scheme is meant to serve as a universally-applicable tool for the study of syllabification behavior. This tool is likely to shed some light on a host of issues. For example, on the issue of separate processing mechanisms required for word and pseudoword segmentation, a divergent pattern of segmentation responses for each would strongly suggest that lexicality plays a determining role in the syllabification of print. Another issue relates to the influence of orthographic (e.g., spelling, onset complexity) and phonological factors (e.g., sonority) on syllabification responses. The validity of common assumptions regarding syllabification may be called into question, if for instance, any differences were observed in the probability of segmentation for mandatory or illegitimate syllabic environments. More importantly, this new paradigm has the potential to uncover many unexplored issues, since

Table 1

Examples of the graphemic decomposition of stimulus words in experiment 1

	Serial Position in the Letter String							
Sample Stimuli	1-2	2-3	3-4	4-5	5-6	6-7	7-8	8-9
C/a/n/a/r/i	O-N	N-O	O-N	N-O	O-N			
S/e/m/b/l/a/b/l/e	O-N	NV	N-O	CC	O-N	N-O2e	CC	O-N
A/l/l/é/g/e/r	N-C	GC	O-N	N-O	O-N	OV		
I/s/o/l/o/i/r	N-O	O-N	N-O	O-N	OV	N-C		

O=onset, N=nucleus, C=coda, NV=nasal vowel, OV=oral vowel, CC=consonant cluster, O2e=complex onset before a mute-e, GC=geminate consonant.

it is the first large-scale study of its kind to document the segmentation behavior of skilled readers of French.

Study 2

The second series of three experiments investigated the behavior of native speakers of French in a timed syllable boundary verification [SBV] task. Two related issues of interest were examined: (a) the influence of syllabic structure on syllabification decisions, for stimuli which contain either one or two medial consonants (e.g., CV.CVCV or CVC.CVCV); and (b) the role that syllables play in VWR. The methodology used in each experiment was basically similar, barring a few modifications. Participants were tested on an individual basis and presented with a list of trisyllabic French words (see Appendix B) that appeared randomly at the center of a computer screen, with a marker inserted in one of four possible locations within the letter string. For each trial, participants were asked, whether or not, they agreed with a proposed location for a cut and indicated their response with a key-press (i.e., 'yes' or 'no'). Legitimate and illegitimate syllabification responses were analyzed separately. The experimental design included a core group of three independent variables, in addition to two other variables that were each manipulated in a single experiment: (1) syllabic structure (e.g., CV.CV.CV vs. CVC.CV.CV), (2) marker serial position (early vs. late in the letter string), (3) word frequency (high vs. low), (4) instruction type (hyphenation vs. syllabification task), and (5) final phoneme (mute-e vs. voiced phoneme). The dependent measures were response latency and accuracy.

The issue of syllabic structure and its role in syllabic boundary identification was addressed by contrasting two types of stimuli, that is, words that contained either a single medial consonant or medial consonant pair (Experiment 1: CVCVCV vs. CVCCVCV). It was hypothesized that faster response times and lower error proportions would be observed in the former than the latter, due to the regularity of syllabic structure in French (i.e., predominantly of the CV-type). To address the issue of syllabic mediation, the predicted performance pattern was derived from an inter-related set of hypotheses. First, based on extant data in French (i.e., Colé et al., 1999), word frequency was expected to interact with syllabic structure and marker position, if skilled adult readers rely on syllabic mediation in order to process low-frequency words, but not high-frequency words. Second, marker position was manipulated in order to determine whether or not a left-to-right scanning mechanism underlies VWR in the SBV task. Experiment 1 additionally manipulated the type of instructions received by participants, in order to determine how task demands or context influence segmentation decisions. In Experiment 2, the syllabic structure issue was examined using stimuli with a single medial consonant or medial consonant pair that occurred later rather than earlier in the letter string (Experiment 2 : CV.CV.CV vs. CV.CVC.CV). This manipulation (involving a change in the serial position of medial consonant pairs) was devised in an attempt to reverse the slope of the syllabic structure effect anticipated in the first experiment. In Experiment 3, the main goals were to replicate the pattern of responses observed in Experiment 1 (using stimuli with an identical structure) and to test a rival account of the serial processing effect, by adding a condition in which the type of segment in the final phoneme position was manipulated.

The findings of this study are expected to shed some light on the role of syllabic structure in the discrimination of syllabic boundaries in print. In addition, the findings have implications for the real-time processing of written words in French.

Chapter 2

Isomorphic Segmentation of Printed French Words and Pseudowords: Effects of Syllabic Environment and Serial Position

Abstract

A comprehensive framework was developed to study syllabification behavior, as it relates to various categories of segmentation within a letter string. Native speakers of French were asked to divide 248 words (Experiment 1) or pseudowords (Experiment 2) into syllables. Their responses were coded and then analyzed according to five categories of segmentation (i.e., mandatory, illegitimate, optional, ambiguous, and letter cluster). The key findings are as follows: (a) lexical status did not influence syllabification, (b) participants relied on simple heuristics to parse letter strings (i.e., spelling-to-sound translation, prescribed rule for separating geminate consonants), and (c) both orthographic (i.e., spelling, onset complexity) and phonological (i.e., sonority) factors influenced syllabification. The theoretical implications of these results for written language processing are discussed.

Introduction

All writing systems represent the spoken form of language, whether they be of the logographic-phonetic (e.g., Chinese), syllabic (e.g., Japanese), or alphabetic (e.g., French) variety (Katz and Frost, 1992). Different alphabetic languages vary in terms of their orthographic depth (i.e., Liberman, Liberman, Mattingly, and Shankweiler, 1980), meaning that there exists a variable relationship between graphemes and phonemes in terms of consistency and completeness. French orthography is considered deep (e.g., Véronis, 1986), because the relationship between graphemes and phonemes in either direction can be: (a) one-to-one (e.g., 'd' ↔ /d/), (b) one-to-many (e.g., 'ch' maps onto /k/ and /ʃ/; also /s/ maps onto 's', 'c', 'ss', 't', 'ç', 'sc', 'x'), or (c) many-to-one (e.g., 'c', 'qu', 'cc', 'k', 'ch', 'q', 'cqu' all map onto /k/; also /s/ and /z/ both map onto 's'). In contrast to French and other deep orthographies (e.g., English, Hebrew), the spelling system of shallow orthographies (e.g., Serbo-Croatian, Spanish) follows the phonemic structure of spoken words much more closely. The implication, in terms of word recognition processes, is that the mechanisms underlying reading in deep or shallow orthographies may differ.[6] For present purposes, it suffices to say that assembled phonology (as opposed to lexically-derived phonology) is more likely to be accessible to readers of shallow than deep orthographies for the purpose of lexical identification (see Frost, 1998 for a more in depth analysis of the debate over phonological recoding in reading). Although lexical identification may occur during the syllabification of written stimuli, this is not necessarily so if this task is carried out strictly through grapheme-to-phoneme conversion.

Past research on written syllabification is quite sparse (e.g., Treiman and Danis, 1988; Treiman and Zukowski, 1990; Treiman, Gross, and Cwikiel-Glavin, 1992; Fallows, 1981) and has tended to focus on seemingly isolated cases. For example, the focus of Treiman et al.'s, (1992; Experiment 1) study was to determine whether or not medial s-clusters should be viewed as legal onsets. Participants were instructed to choose between three syllabified versions of a nonword (e.g., 'nusp-eem', 'nus-peem', or 'nu-speem'). The pattern of results differed for non-s-

[6] The strong version of the orthographic depth hypothesis (ODH) predicts that shallow orthographies will make exclusive use of assembled phonology in lexical decision and naming tasks, whereas the weak version of the ODH is consistent with the idea that deep and shallow orthographies may make use of both assembled and stored phonology. Extant data supports the weak version of the ODH (Katz and Frost, 1992).

clusters and s-clusters (e.g., 'nu-fleem' vs. 'nus-leem' and 'nus-peem'), suggesting that 's' may be viewed as an extra-syllabic segment. Another pointed issue that was investigated by Treiman and Danis (1988; Experiments 1 and 2), concerned the effects of spelling on the assignment of medial consonants to an onset or coda position. Participants chose between two syllabification alternatives for stimuli with medial consonants that had either single or double letter spellings (e.g., 'prop-er' vs. 'pro-per'; 'comm-a' vs. 'co-mma'). Although the choice of dividing between geminate consonants was not presented in Treiman and Danis' (written) task, it is easy to see how readers might have otherwise exploited such an option.

Syllabification is a more complex task for written than oral stimuli. The visual medium provides a rich context for syllabification decisions, since the opportunities for parsing within a letter string necessarily outnumber the subset of legitimate syllabic boundaries within a word. An important issue that is raised by the preceding examples is the way in which individual cases of syllabification relate to the overall context or opportunity space that the written word provides. Any systematic attempt to answer this question needs to start with the premise that the distribution of all real and potential cuts within a letter string must be known. One objective of the present study was to design a framework for studying various types of environments in which syllabic boundaries may be identified. From this perspective, parsing a letter string into syllables can be viewed as a task involving a finite number of possible outcomes. Theoretically, the number of permutations involving the syllable's three basic constituents (i.e., onset, nucleus, and coda) is equal to nine (Table 2). However, when combinations that violate the well-formedness of syllables are excluded (i.e., sequences that do not include a nucleus), the realm of potential syllabic boundary environments (henceforth referred to as syllabic environments) is reduced to six. These combinations can be categorized into legitimate (i.e., nucleus-onset, nucleus-nucleus, coda-onset, and coda-nucleus) and illegitimate (i.e., onset-nucleus, nucleus-coda) segmentation. Skilled readers of French should recognize with ease that breaks inserted within the letter string are not permissible in the latter, whereas they are mandatory in the former.

In addition to broadly demarcating legitimate (mandatory) and illegitimate segmentation, we also distinguished between optional and ambiguous segmentation and included letter cluster segmentation as a fifth category in the framework. If decisions about the legitimacy of syllabic segmentation seem clear-cut, based on predictions related to mandatory and illegitimate

Table 2

Complete combinatorics of syllabic constituents and potential syllabic boundaries

	Syllable (n + 1)		
Syllable (n)	Onset	Nucleus	Coda
Onset	Impossible	Illegitimate	Impossible
Nucleus	Legitimate	Legitimate	Illegitimate
Coda	Legitimate	Legitimate	Impossible

Legitimate: The contiguity of these two syllabic constituents can indicate a syllabic boundary;
Illegitimate: The contiguity of these two syllabic constituents cannot indicate a syllabic boundary;
Impossible: The contiguity of these two syllabic constituents cannot occur.

segmentation, this is merely apparent. There are specific types of segments (i.e., semivowels, mute-e, geminate consonants, s-clusters, and aspirated-h) occupying the onset, nucleus or coda positions, that could be considered less straightforward to syllabify. The primary distinction between these two categories is that optional segmentation consists of probabilistic or categorical rules, while ambiguous segmentation involves unspecified or arbitrary rules. The inclusion of letter clusters as a fifth category of segmentation afforded completeness, by capturing non-syllabic errors (e.g., 'tab-le' [table]). Table 1 illustrates how stimuli were analyzed within this framework through a process of graphemic decomposition, that served to identify all types of syllabic environments for each serial position in a letter string.

Before elaborating on the specific hypotheses for each category of segmentation, we shall outline some of the basic rules of French syllabification (Grévisse, 1964) and relate these to a group of universal syllabification principles from the linguistic literature. If we start with the basic notion that every syllable must contain a vowel, the problem of identifying syllabic boundaries can be refined to deciding upon the assignment of medial (i.e., inter-vocalic) consonants to either the onset or coda position of adjacent syllables. A single medial consonant is generally assigned to the onset position (V-CV; e.g., 'ca-deau' [present]). This rule is congruent with the maximum onset principle (MOP), whereby as many consonants as possible are placed into the onset position, while respecting the phonotactic rules of the language (e.g., Pulgram, 1970; Treiman and Zukowski, 1990). It is also compatible with the notion of open syllabification (i.e., syllabic boundaries fall after a vocalic segment), which is particularly fitting in French, due to the regularity of syllabic structure (i.e., CV structure; Valdman, 1976).

The general case for consonant sequences formed by two consecutive medial consonants has each consonant assigned to the coda and onset position of separate syllables (VC-CV; e.g., 'cap-tiver' [to captivate]). An exception to this general rule occurs when both medial consonants form a cohesive unit or cluster, as is the case for stop-liquid sequences (i.e., bl, cl, gl, pl, cr, dr, fr, gr, pr, tr, vr; e.g., 'ca-pricorne' [capricorn]) and a few other kinds of sequences (i.e., ch, ph, th, gn), that are invariably assigned to the onset position. For medial sequences formed by three consecutive consonants, the general case has the first two consonants assigned to a coda position and the third to the onset of the next syllable (VCC-CV; e.g., 'comp-ter' [to count]). There are two notable exceptions to this general rule. First, when a pair of medial consonants forms a cohesive unit of the stop-liquid variety, this unit is assigned to the onset position and separated from the preceding consonant (e.g., 'ac-trice' [actress] or 'ap-plaudir' [to applaud]). Second, when a medial consonant pair contains an 's' this segment may be assigned interchangeably to the coda or onset position (e.g., 'subs-tance' or 'sub-stance' [substance]). The rules concerning the separation of medial consonant sequences can be based on the legality and sonority contour principles (e.g., Kahn, 1976; Vennemann, 1988; Treiman and Danis, 1988). The legality principle is based on the idea that certain sequences, which are inadmissible in word-initial or -final positions (based on the phonotactic rules of the language), will also be illegal at the beginning or end of syllables (e.g., /rn/ in 'car-net' [notebook] must be divided since it is illegal in a word-initial position). In terms of the sonority contour principle, there is an ideal sonority profile that guides the formation of a syllable and involves a steady rise in relative loudness from the onset toward the nucleus and may also involve a corresponding decrease from the nucleus to the coda. This ideal sonority pattern constrains the possible sequencing of elements found within the onset; consonant clusters of the stop-liquid variety follow this ideal sonority pattern, whereas other types of medial consonant sequences like s-clusters represent a sonority plateau or reversal (i.e., Treiman and Zukowski, 1990).

We are now in a position to examine the set of hypotheses related to different types of syllabic environments subsumed under each of the five broad categories of segmentation included in the framework (Table 3). The primary focus of this investigation was placed on evaluating responses to legitimate and illegitimate segmentation. The first of these categories represents mandatory segmentation, where inter-syllabic parsing occurs in the following environments: (1) nucleus-onset (e.g., 'pa-pillon' [butterfly]), (2) coda-onset (e.g., 'ac-tualité' [actuality]), and (3) nucleus-nucleus (e.g., 'o-asis' [oasis]); note that coda-nucleus was excluded from the analyses since it is non-occurring. Theoretically, skilled readers should be able to identify all syllabic boundaries within a letter string. Therefore, the proportion of cuts (or proportion of occurrences) in each of these syllabic environments was not expected to differ significantly from a probabilistic criterion value of one. The second category represents illegitimate segmentation, where breaks occur intra-syllabically. Two types of syllabic environments were included in this analysis: (1) onset-nucleus (e.g., 'c-uisson' [cooking]), and

Table 3

Expected and observed probabilities for various categories of segmentation in word and pseudoword stimuli

Category / Sub-category	Case	Example	Expected	Observed: Words Propn	Words t-value	Observed: Pseudowords Propn	Pseudowords t-value
Mandatory	1) N-O	pa-pillon	near 1	.82	-22.87	.81	-19.57
	2) C-O	ac-tualité	near 1	.95	- 6.90	.94	- 6.98
	3) N-N	o-asis	near 1	.88	- 6.10	.85	- 7.20
Illegitimate	1) O-N	c-uisson	near 0	.01	6.89	.02	5.20
	2) N-C	épe-rvier	near 0	.03	6.88	.03	7.68
Optional							
Semivowel	1) Sv-N	balanci-er	near .50	.46	n.s.	.51	n.s.
	2) N-Sv	poitra-il	near .50	.04	-29.92	.06	-26.65
Mute-e	1) N-O1e	grou-pement	near .50	.39	- 4.71	.39	- 4.27
	2) N-O2e	encom-brement	near .50	.66	- 5.25	.65	- 4.48
	3) C-O1e	occul-te	near .50	.64	3.77	.63	3.55
	4) S-O1e	jus-tement	near .50	.56	n.s.	.52	n.s.
	5) S-O2e	as-tre	near .50	.68	4.58	.69	4.79
Geminate	1) GC	vil-légiature	near .50	.69	6.68	.70	7.30
	2) GSv	cuil-lère	near .50	.72	7.63	.68	5.22
Ambiguous							
S-cluster	1) N-S	e-scalier	near .50	.14	-29.87	.17	-22.03
	2) C-S	ob-struer	near .50	.85	24.19	.85	23.55
	3) O-S	p-sychologue	near .50	.01	-111.85	0	*
	4) VS-O1	aus-tère	near .50	.80	21.60	.79	16.46
	5) VS-O2	as-treindre	near .50	.86	18.00	.68	6.76
	6) CS-O1	obs-cur	near .50	.32	- 5.72	.27	- 6.67
	7) CS-O2	abs-traction	near .50	.27	- 5.87	.31	- 4.75
Aspirated-h	1) H-N	nih-ilisme	near .50	.01	-235.27	.01	-195.01
	2) N-H	ni-hilisme	near .50	.97	65.17	.97	53.56
Letter Cluster	1) OV	entho-usiasme	near 0	.01	3.76	.03	6.44
	2) NV	océa-n	near 0	.0005	n.s.	.003	2.34
	3) CC	éb-louir	near 0	.01	4.77	.01	3.91
	4) Sv	o-uate	near 0	.04	4.27	.03	5.90

All t-values are significant to α / K, unless marked n.s; * SD=0, t-value cannot be computed; DFw=99, DFp=98; N=nucleus, C=coda, O=onset, Sv=semivowel, O1e=single onset before a mute-e, O2e=complex onset before a mute-e, S=letter 's', GC=geminate consonant, GSv=geminate consonant within a semivowel, VS='s' preceded by a vowel, CS='s' preceded by a consonant, H=letter 'h', OV=oral vowel, NV=nasal vowel, CC=consonant cluster.

(2) nucleus-coda (e.g, 'épe-rvier' [sparrowhawk]). The proportion of cuts was not expected to be significantly different from zero in each case.

A second line of interest in our investigation focused on optional and ambiguous segmentation. We hypothesized that skilled readers of French would be collectively ambivalent regarding the possibility of segmentation in each type of syllabic environment associated with these two categories. Therefore, the benchmark criterion was set at chance-level (i.e., with a probability of .50). A second set of hypotheses, conditional upon the rejection of the main hypothesis of ambivalence / non-differentiation, was proposed for certain types of syllabic environments (i.e., mute-e, geminates, s-clusters, and aspirated-h).

Three types of syllabic environments were considered in the optional segmentation category (a) semivowel, (b) mute-e, and (c) geminate consonants. Semivowels are phonological units that assume a double identity, behaving at times like vowels and at other times like consonants. These segments can take on one of three different forms, which are closely related to high vowels (i.e., /i/, /u/, and /y/): the phoneme /j/ as in 'calcium' [calcium], the phoneme /ɥ/ as in 'huissier' [bailiff], and the phoneme /w/ as in 'ouaouaron' [bullfrog]. What characterizes semivowels in terms of syllabification is that they (as opposed to high vowels) cannot stand alone as a nucleus. Furthermore, there is the potential for free variation between semivowels and their corresponding high vowels in semivowel-nucleus sequences (i.e., a given word may be phonetically realized in two different ways without resulting in a change in meaning; e.g., 'muette' [mute] → /myεt/ or /mɥεt/). In contrast, this alternation is not exhibited by nucleus-semivowel sequences, which should be divided in situations where the semivowel (acting as the onset) precedes a pronounced vowel (e.g., 'piller' [to rob]: /pi-je/). We examined two types of syllabic environments in which a semivowel was present: (1) semivowel-nucleus (e.g., 'balanci-er'[pendulum]), and (2) nucleus-semivowel (e.g., 'poitrail' [chest]). However, the focus of the analysis was placed on the former.

The second type of optional segmentation grouped together five cases of mute-e environments: (1) nucleus-single onset + e (e.g.,'grou-pement' [grouping], (2) nucleus-double onset + e (e.g., encom-brement [obstacle]), (3) coda-single onset + e (e.g., occul-te [occult]), (4) s-single onset + e (e.g., 'jus-tement' [justly]), and (5) s-double onset + e (e.g., 'as-tre' [star]). We were interested in finding out whether participants in the written syllabification task would use a phonetic or graphemic strategy to parse the letter strings. In French, there exist some guidelines concerning the realization of the letter 'e' in speech. The general rule-of-thumb states that /e/ is more likely to be deleted the fewer the consonants preceding it (Valdman, 1976). In order to test for this possibility, we predicted that the proportion of cuts may be lesser for syllabic environments formed by a mute-e that is preceded by a single rather than complex onset (i.e., Cases 1 vs. 2 and 4 vs. 5). We were also interested in determining whether the sonority level of a segment preceding the onset (i.e., nucleus, coda, and 's') would influence syllabification behavior. Thus, a lower proportion of cuts was predicted for syllabic environments in which the left boundary element was high rather than low in sonority (i.e., Cases 1 vs. 3). Although Case 4 was also lower in sonority than Case 1, we did not predict a significant difference between the two, given that s-clusters are equally likely to have the 's' parsed with the onset or the coda; note that this analysis uniquely involved single onset cases, since there was no counterpart for Case 3 (i.e., coda-double onset + mute-e).

The third type of optional segmentation involved geminate consonants occurring in two types of syllabic environments: (1) regular geminate consonants (e.g., 'vil-légiature' [holiday]), and (2) geminate consonants within a semivowel (e.g., cuil-lère [spoon]). Based on the written syllabification rules prescribed by Grévisse (1964), one would expect geminate consonants to be divided. However, participants may also exercise their option to parse letter strings phonetically; in such a case, both geminate consonants would be assigned to the onset position, given the 2 : 1 grapheme-to-phoneme association (Warnant, 1988). In the event that the hypothesis of ambivalence / non-differentiation is rejected, we predicted that participants would rely on a graphemic parsing strategy (i.e., the proportion of cuts would not differ significantly from an expected probability of one if geminate consonants are invariably divided). With respect to the second case involving a semivowel, there is no existing data upon which to base a conditional hypothesis. Therefore, the following perspective was adopted: Skilled readers of French were not expected to divide semivowels, given that these represent integral units (i.e., the proportion of cuts should not differ significantly from zero).

For ambiguous segmentation, two types of syllabic environments were studied: (a) s-clusters, and (b) aspirated-h. With respect to the first type of environment, seven cases of s-clusters were included in the analyses: (1) nucleus-s (e.g., 'e-scalier' [staircase]), (2) coda-s (e.g., 'ob-struer' [to obstruct]), (3) onset-s (e.g., 'p-sychologue' [psychologist]), (4) nucleus + s-single onset (e.g., 'aus-tère' [austere], (5) nucleus + s-double onset (e.g., 'as-treindre' [to oblige]), (6) coda + s-single onset (e.g., 'obs-cur' [obscur]), and (7) coda + s-double onset (e.g., 'obs-truer' [to obstruct]). In keeping with the view that 's' can be assigned equivocally to either an onset or coda position, we predicted that the proportion of cuts overall would not differ significantly from .50. In a different set of analyses, including the first three cases, we investigated whether or not syllabification behavior is influenced by the sonority of a segment preceding the 's'. Based on the sonority principle, a lesser proportion of cuts was predicted for Cases 1 and 3 compared to Case 2. The reasoning goes as follows: 's' offers a gradual decline in sonority from the nucleus to the coda in Case 1 and a potential increase in sonority from the onset to the nucleus in Case 3, whereas, the presence of a coda in Case 2 already provides a decrease in sonority, which may increase the likelihood of parsing 's' with the onset.

Another set of analyses, including the last four cases, manipulated the sonority of a segment preceding the s-cluster (i.e., vowel vs. consonant) in conjunction with the complexity of the onset (i.e., single vs. double). Predictions were based on prescribed syllabification rules for French (Grévisse, 1964) and findings from a previous study by Treiman et al. (1992); first, when 's' is preceded by a vowel and followed by a single consonant (Case 4), the probability that 's' will be assigned to the coda is on average .75 (i.e, Treiman et. al., 1992); when 's' is preceded by a consonant and followed by one (Case 6) or two (Case 7) consonants, this probability falls to .50 (i.e, Grévisse, 1964). The case which theoretically remains unknown is when the 's' is preceded by a vowel and followed by a complex onset (Case 5). If sonority prevails over onset complexity, then the proportion of cuts between 's' and the following onset is expected to be higher for cases where 's' is preceded by a vowel rather than a consonant (Cases 4 and 5 vs. 6 and 7). If both sonority and onset complexity play a role in the syllabification of s-clusters, then the proportion of cuts is expected to differ between Cases 4 and 5, but not between Cases 6 and 7. However, the direction of the predicted effect, relative to onset complexity, was not determined a priori.

The second category of ambiguous segmentation compared responses to two types of aspirated-h environments: (1) h-nucleus (e.g., 'nih-ilisme' [nihilism]), and (2) nucleus-h (e.g., 'ni-hilisme' [nihilism]). From a linguistic perspective, the letter 'h' invariably occupies an onset position, although it has no correspondence at the phonetic level. The behavioral data supporting this claim comes from the rules of liaison in French (e.g., Grévisse, 1964; Valdman, 1976). However, it is unknown whether the same outcome will be observed for syllabification in the context of isolated words or pseudowords and in situations other than those in which 'h' occupies a word-initial position. If the hypothesis of ambivalence / non-differentiation is rejected, then the proportion of cuts is predicted not to differ significantly from a probability of zero or one for Cases 1 and 2, respectively. These predictions are consistent with the idea that native speakers of French are sensitive to the underlying structure of the language.

The final category of segmentation in the framework included four types of letter cluster errors: (1) oral vowel group (e.g., 'entho-usiasme' [enthusiasm]), (2) nasal vowel group (e.g., 'océa-n'[ocean]), (3) consonant cluster group (e.g., 'éb-louir' [to dazzle]), and (4) semivowel group (e.g., 'o-uate' [wadding]). Overall, we predicted that the proportion of cuts would not differ significantly from a probability of zero for all four types of clusters, since skilled readers have presumably mastered grapheme-to-phoneme correspondence rules.

In addition to the set of hypotheses derived from the five categories of segmentation in the framework, we wanted to find out how lexical status might influence syllabification. With this goal in mind, parallel lists of word and pseudoword stimuli were prepared. Each pseudoword was constructed by modifying a corresponding base word from the list of lexical items, without changing its underlying structure. For example, one or two segments in word-initial positions were replaced by segments that belonged to the same linguistic category, in order to remove any obvious resemblance to real words. We hypothesized that spelling-to-sound correspondences may represent a sufficient condition for syllabification, in which case it was expected that both kinds of stimuli would yield a similar pattern of responses. Alternatively, a different pattern of segmentation may arise from the effects of lexical factors; for example, morphological influences may come into play for the syllabification of real words (e.g., Smith and Pitt, 1999), since polymorphemic and monomorphemic stimuli of variable lengths were used in this series of experiments; for pseudoword stimuli, lexical influences may arise if participants were to make use, either consciously or not (e.g., Baron, 1979; Brooks, 1978), of an analogy-based strategy.

Overview of the Experiments

The objectives of the present study were to develop a framework for investigating written syllabification and to test this framework against responses to different kinds of syllabic environments. The term syllabic environment was coined to express all real and potential cuts that can be made within a letter string. Native speakers of French were presented with a list of either real words (Experiment 1) or their pseudoword counterparts (Experiment 2), in the context of a paper-and-pencil syllabification task. The data were coded and then tabulated for analysis across five broad categories of segmentation. The unit of analysis was the grapheme forming a break point and the dependent variable was the probability of introducing syllabic breaks within the letter strings. In addition to studying segmentation behavior using an objective syllabification task, a self-report test was included at the end of the experiment, which queried participants as to their strategy for identifying syllabic boundaries in print.

Experiments 1 and 2

Method

Participants. The first group of participants (presented with real words) included 100 undergraduate students (74 women and 26 men; M = 20 years) from the University of Ottawa. All were native speakers of French, with English as a second language (with the exception of one monolingual French speaker). The second group of participants (presented with pseudowords), included 99 participants (64 women and 35 men; M = 21 years) drawn from the same population.

Material. The material included a list of 248 French words and a list of 248 pseudowords, that matched the syllabic structure of real word stimuli in the first list. Each list was presented in a distinct booklet that had the following layout: the first two pages included the title page and instructions; the next four pages contained word (Experiment 1) or pseudoword (Experiment 2) stimuli, that were printed double-spaced, across three columns, and in black lowercase lettering (12 point font, Times New Roman); and the last three pages contained the self-assessment portion of the questionnaire, as well as, a general information sheet pertaining to demographic variables. In addition, a group-based consent form was distributed for participants to sign during the experiment.

The real word stimuli were drawn from Mandalex, a lexical database containing over 54,000 French words (Desrochers, 1995), and the selection process was guided by the detailed framework described in the introduction. Briefly, the main dimensions of the framework included five broad categories of segmentation: mandatory, illegitimate, optional, ambiguous, and letter cluster. A primary distinction was drawn between mandatory (inter-syllabic) and illegitimate (intra-syllabic) segmentation. Another distinction was made between optional (categorical or probabilistic rules) and ambiguous (unspecified or arbitrary rules) segmentation to achieve a finer-grained analysis at the segmental level. The final category, letter cluster segmentation (i.e., grapho-phonological errors), was required to capture all erroneous syllabification responses. Each cell within the framework contained information on the type of syllabic environment and the corresponding serial position in the letter string; for example, the word 're-pos' [rest] is shown here with a parsing between nucleus and onset constituents in the second serial position.

A corresponding list of pseudowords was created by pooling together lists of words that were modified independently by three researchers, whose native language was French. The following criteria were used to construct pseudoword stimuli, in keeping with the aim of preserving the syllabic structure of their real word counterparts from Experiment 1. First, letter substitutions were made, generally by using letters that belonged to the same linguistic category (i.e., liquid, nasal, obstruent). Second, modifications usually involved the stem and, on occasion, other parts of the word, in order to reduce the degree of similarity with existing words; according to Taft (1979), words are accessed via their root morphemes after the prefix has been stripped off. Third, the number of changes was generally limited to one or two letter substitutions. For example, the words 'destruction' [destruction] and 'anguille' [eel] were transformed into the pseudowords 'pestriction' and 'onguille'.

Procedure. A group study was undertaken in several introductory-level Psychology classes. Participation was voluntary and no form of remuneration or course credit was received. A common consent form was circulated throughout the experimental session, which lasted approximately 45 minutes. Each participant received a booklet divided into four sections: instructions, syllabification task, self-assessment form, and general information sheet. Participants were instructed to insert a forward slash to indicate the location of syllabic boundaries found within the letter strings. The model shown to participants in Experiment 1 was a syllabified version of the word 'CA/NA/DA', whereas in Experiment 2, a modified version of this word 'RATADA' was presented in unsyllabified form, in order to avoid bias. The experimenter provided oral instructions, which were supported by visual aids. Participants were asked to follow the order of presentation in the booklet and specifically instructed not to modify their answers after completing each section. At the end of the session, participants were debriefed and thanked for their efforts.

Results and Discussion

The results will first be presented and discussed for the objective data set, followed by the subjective data set (i.e., written syllabification task and self-report test, respectively). The former is subdivided into five sections, that correspond to each of the five broad categories of segmentation in the framework, and further subdivided into two subsections, pertaining to word (Experiment 1) and pseudoword (Experiment 2) stimuli.

Objective Data. For each category of segmentation, two main sets of analyses were conducted: (a) a series of one-sample t-tests, which compared the probability of segmentation for each type of syllabic environment (observed) to a probabilistic criterion value (expected) set to zero, one, or .50 (i.e., included in Table 3 along with associated t-values for each comparison); and (b) a combination of analyses, including 1-way and 2-way ANOVAs comparing the proportion of cuts for various types of syllabic environments across different serial positions in the letter strings, as well as, multiple pairwise comparisons. Serial position was included solely in the ANOVAs related to mandatory and illegitimate segmentation. The alpha level for multiple comparisons was set hypothesiswise, in order to control the risk of committing a Type 1 error (i.e., Bonferroni's method: α / K, where $\alpha = .05$ and K = number of comparisons; Kennedy and Bush, 1985). The conceptual unit defining each family of comparisons was based on the various categories and sub-categories of segmentation in the framework: mandatory, illegitimate, letter cluster, semivowel, mute-e, geminate, s-clusters, and aspirated-h.

Mandatory Segmentation. The first set of analyses with real words revealed significant differences between observed and expected probabilities of segmentation for each type of syllabic environment (Table 3). In the second set of analyses, a 3 (syllabic environment: N-O, C-O, N-N) X 8 (serial position) ANOVA was carried out on the proportion of cuts (Figure 1); a mean substitution was performed for the C-O environment in position 1-2, in order to compensate for a lack of entries.[7] Significant main effects of syllabic environment, $F(2,198) = 34.99$, $MSe = .0931$, and serial position, $F(7,693) = 12.51$, $MSe = .0088$, were observed, as well as, an interaction between these variables, $F(14,1386) = 21.08$, $MSe = .0076$. Post-hoc analyses revealed that the proportion of cuts was significantly different for each type of syllabic environment (all $ps<.001$) and are presented here in decreasing order of accuracy: C-O (M = .95), N-N (M = .88), and N-O (M = .82). Overall, the highest proportion of responses across serial positions in the letter string were observed for positions 2-3 and 8-9 (M = .91 in both cases), whereas the remainder ranged from M = .75 to M = 1.00. In terms of the interaction, the pattern of responses for both C-O and N-N environments was fairly consistent across serial positions, compared to the more variable pattern associated with the N-O environment. Two notable departures from the mean were observed in the latter for position 2-3 (where N-O did not differ significantly from either N-N or C-O, $p>.678$ and $p>.999$, respectively) and position 8-9

[7] The data were initially analyzed as an incomplete factorial model. Based on the pattern of missing data and a strategy proposed by Milliken & Johnson (1984), separate ANOVAs were run on two sub-designs, which were complete with respect to one of the two factors of interest: first subdesign → 3 (syllabic environment) X 7 (serial position); second subdesign → 2 (syllabic structure) X 8 (serial position). Justification for reporting the results of an analysis based on a full factorial model stems from the high degree of similarity between the results from the analysis of each subdesign and the full factorial model.

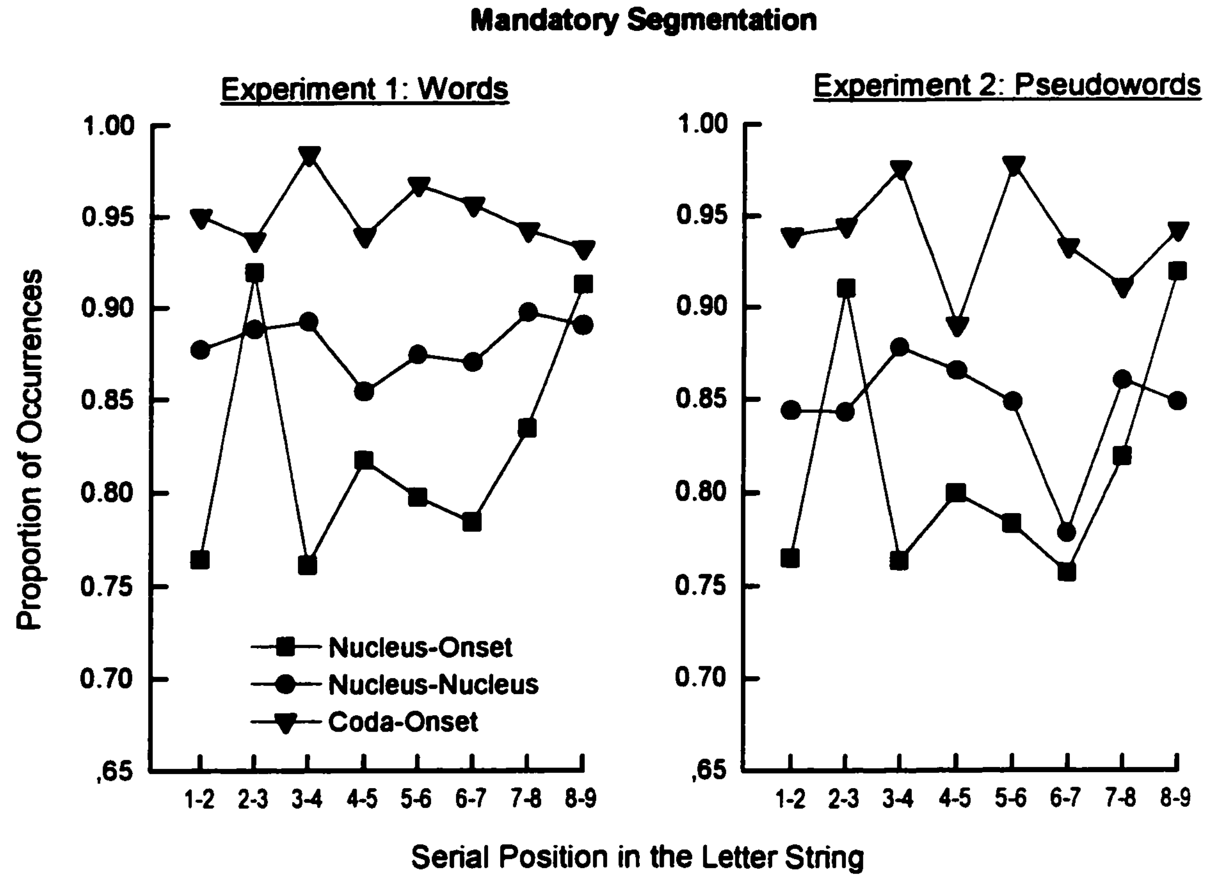

Figure 1. Proportion of occurrences for mandatory segmentation as a function of syllabic environment and serial position in real words and pseudowords.

(where no significant differences between the three environments were found, all ps>.093).

For pseudoword stimuli, significant differences were also detected between observed and expected probabilities of segmentation for each type of syllabic environment (Table 3). In addition, a 2-way ANOVA revealed significant main effects of syllabic environment, $F(2,196) = 29.07$, $MSe = .1150$, and serial position, $F(7,686) = 20.30$, $MSe = .0103$, as well as their interaction, $F(14,1372) = 22.26$, $MSe = .0087$. The proportion of cuts associated with each type of syllabic environment followed a similar trend as in Experiment 1, with the highest level of accuracy observed for the C-O environment, except that the difference between N-N and N-O environments was not significant ($p>.162$): C-O (M = .94), N-N (M = .85), and N-O (M = .81). Overall, the highest proportion of responses across serial positions in the letter strings was associated with positions 2-3 and 8-9 (M = .90 in both cases), whereas the remainder ranged from M = .82 to M = .87. Although the variability of responses across serial positions appeared to be somewhat greater for pseudowords than real words, the overall pattern of responses was quite similar. Again, marked departures from the mean were observed for the N-O environment in positions 2-3 and 8-9 (where N-O did not differ significantly from N-N and C-O, $p>.599$ and $p>.991$, respectively).

The striking similarity in the pattern of segmentation for real word and pseudoword stimuli[8] implies a common process underlying syllabification behavior. Participants in each experiment appear to have relied on their knowledge of spelling-to-sound correspondences in order to segment letter strings. Another key finding relates to the significant differences between observed and expected probabilities of segmentation (t-tests) and among various types of syllabic environments (ANOVA). A priori, no differences were expected among syllabic environments, which were predicted to attain near-perfect accuracy levels. Although the highest proportion of cuts observed for the C-O environment was relatively close to the probabilistic criterion value of one (but significantly different from this criterion), this was not the case for N-N and N-O environments (in Experiment 1 the probability of segmentation between the two latter environments differed significantly from each other). This outcome suggests two things. First, skilled readers appeared to be operating with the legality principle in mind and perhaps the

[8] A between-subjects design was chosen to avoid bias in the pseudoword syllabification task, even though the internal validity is typically less than for a within-subjects design.

sonority principle as well, when parsing letter strings into syllables. By this view, medial consonant sequences are quickly identified and assessed in terms of cohesiveness (Grévisse, 1964). Second, the lower proportion of cuts in N-N and N-O environments implies that there are other determining factors involved in deciding to syllabify vocalic and consonant-vowel sequences. This point will be taken up in later sections dealing with optional and letter cluster segmentation.

Illegitimate Segmentation. The first set of analyses with real words revealed significant differences between the probability of segmentation in each type of syllabic environment and a criterion value of zero (Table 3). Nevertheless, the level of accuracy in each case was reasonably high (i.e., above 90%). The second set of analyses entailed a 2 (syllabic environment: O-N, N-C) X 8 (serial position) ANOVA performed on the proportion of incorrect cuts (Figure 2). The results showed small but significant main effects of syllabic environment, $F(1,99) = 9.99$, $MSe = .0059$, and serial position, $F(1,693) = 13.14$, $MSe = .0014$, as well as their interaction, $F(7,693) = 17.79$, $MSe = .0013$. The proportion of cuts overall was slightly higher for N-C than O-N environments ($M = .03$ and $M = .01$, respectively). A non-monotonic decrease in the proportion of cuts was observed from the first to the last serial position ($M = .02$ and $M = .01$, respectively). The interaction effect revealed that significant differences between the proportion of cuts to O-N and N-C environments were isolated to initial serial positions (i.e., positions 1-2, 3-4, and 4-5: differences of .04, .04, and .02, respectively; all other $ps > .999$).

For pseudoword stimuli, significant differences between observed and expected segmentation probabilities associated with each type of syllabic environment were observed (Table 3). As in Experiment 1, a 2-way ANOVA revealed significant main effects of syllabic environment, $F(1,98) = 3.99$, $MSe = .0058$, and serial position, $F(7,686) = 19.56$, $MSe = .0016$, as well as their interaction, $F(7,686) = 27.25$, $MSe = .0015$. Again, the proportion of cuts was highest for the N-C than O-N environment ($M = .03$ vs. $M = .02$, respectively; $p < .048$). Across serial positions, the proportion of cuts decreased non-monotonically from the first to the last serial position ($M = .02$ vs. $M = .01$, respectively). In terms of the interaction effect, post-hoc analyses revealed that the proportion of cuts for both types of syllabic environments generally

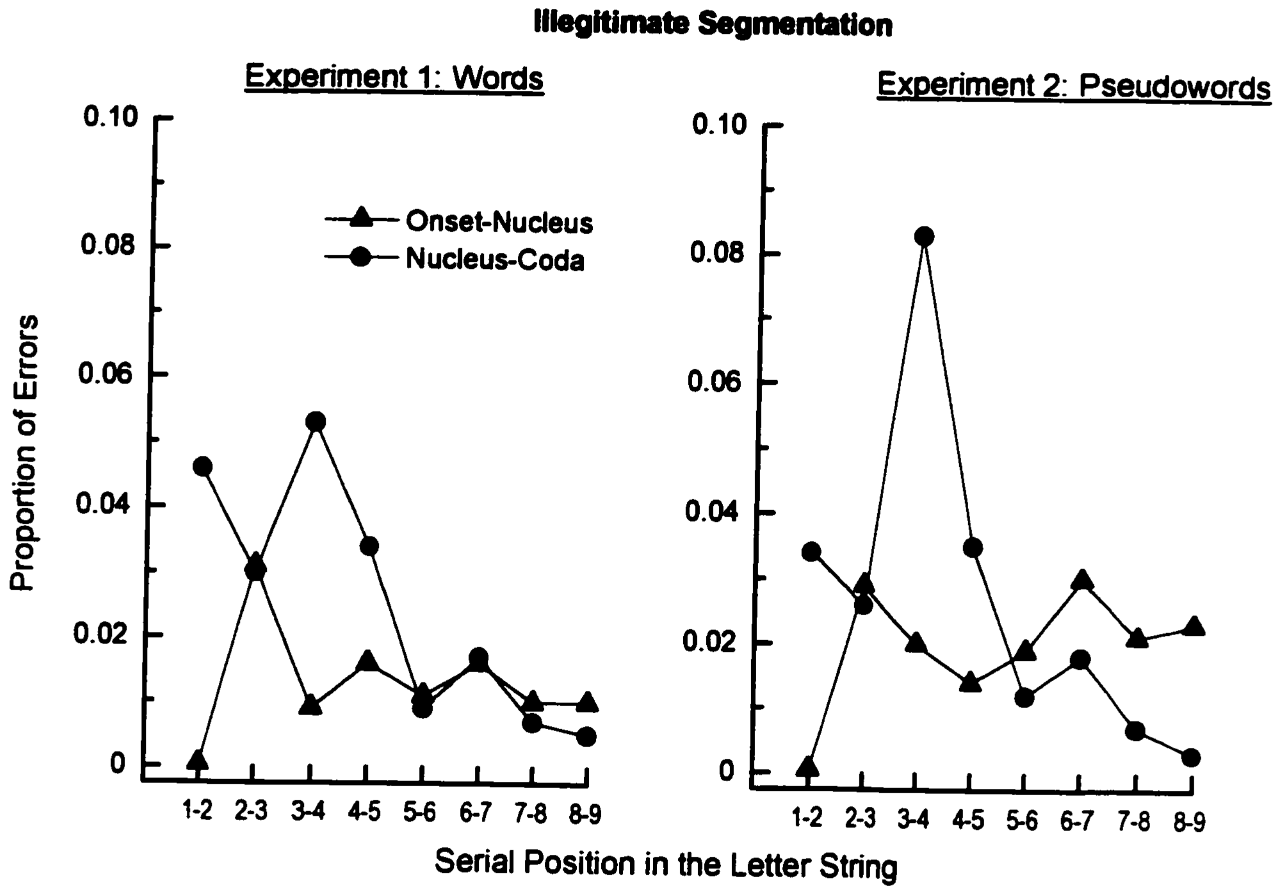

Figure 2. Proportion of occurrences for illegitimate segmentation as a function of syllabic environment and serial position in real words and pseudowords.

differed in the first than last four serial positions (i.e., positions 1-2, 3-4, and 4-5: differences of .03, .06, and .02, respectively; all other ps>.356, except in position 8-9 where p<.041).

The pattern of responses for both word and pseudoword stimuli was again very similar. Although observed and expected probabilities of segmentation did differ significantly, the proportion of incorrect cuts was reasonably low (i.e., below 10%). In both experiments, the proportion of cuts for initial serial positions was slightly greater for N-C than O-N environments. The main difference in results between experiments was a somewhat greater proportion of cuts for the N-C environment in position 3-4 for Experiment 2 compared to Experiment 1 (i.e., .05 vs. .08, respectively). At the risk of over-interpreting the difference between N-C and O-N environments, these results may be attributed to statistical differences underlying the degree of affinity between syllabic constituents. To be more specific, a study by Kessler and Treiman (1997) found that probabilistic combinations govern the association of various rime constituents (i.e., nucleus and coda), whereas onset and nucleus combinations are statistically random (i.e., non-probabilistic). The implication of these results for the present study is that readers may be less likely to view any association between syllabic boundary elements in O-N than N-C environments (i.e., at least those with higher probabilities of association between rime elements) and, consequently, are less likely to consider parsing in the former.

Optional Segmentation. Table 3 reveals the proportion of cuts for three types of optional syllabic environments: semivowel, mute-e and geminate consonants. For semivowel environments within real words, the first set of analyses revealed a significant difference between the observed probability of segmentation and a probabilistic criterion value set at .50 (i.e., expected value according to chance), in the case of N-Sv, but not Sv-N environments. Moreover, a paired comparison confirmed that the proportion of cuts was significantly greater for the latter than the former (M = .46 vs. .04, respectively; $t(99, .05) = -15.30$). Similarly, the results for pseudowords showed a significant difference between observed and expected probabilities for N-Sv but not Sv-N environments (Table 3). Again, the proportion of cuts was significantly greater for the latter than the former (M = .51 vs. M = .06, respectively; $t(98, .05) = -17.27$).

Overall, the pattern of responses for real words and pseudowords was identical. In accordance with the hypothesis of ambivalence / non-differentiation and the principle of free variation between semivowels and high vowels, the proportion of cuts for the Sv-N environment did not differ significantly from chance-level. As for the N-Sv environment, where free variation was not a factor, the semivowel was typically left unparsed (i.e., the only entry in the N-Sv analysis occurred word-finally: poitrai̲l̲ [chest]).

For mute-e environments, the first set of analyses with real words revealed significant differences between the probability of segmentation observed in four out of the five types of syllabic environments (the exception being S-O1e) and an expected value of .50 (Table 3). In the second set of analyses, a 1-way ANOVA (5 levels) showed significant differences between the means associated with various mute-e environments, $\underline{F}(4, 396) = 44.50$, $\underline{MSe} = .0328$. Post-hoc analyses (Tukey's HSD) revealed a significantly lower proportion of cuts for single than complex onset cases within nucleus-onset sequences (N-O1e vs. NO-2e: M = .39, M = .66, $\underline{p}<.000017$), and s-onset sequences (S-O1e vs. S-O2e: M = .56, M = .68, $\underline{p}<.00004$). In terms of the sonority effect, a significantly lower proportion of cuts was observed in cases where the left boundary element was high (vowel) rather than low (consonant) in sonority; this result was applicable to cases that either did or did not from a sonority gradient (N-O1e vs. C-O1e: .39 vs. .64; N-O1e vs. SO1e: M = .39 vs. .56; $\underline{p}<.000017$).

For pseudowords (mute-e environment), the first set of analyses again revealed significant differences between observed and expected probabilities of segmentation in four out of the five types of syllabic environments (Table 3). A 1-way ANOVA (5 levels) showed significant differences between the means associated with various mute-e environments, $\underline{F}(4, 392) = 44.38$, $\underline{MSe} = .0314$. Post-hoc analyses (Tukey's HSD) revealed a significantly lower proportion of cuts for single than complex onset cases, with both nucleus-onset sequences (N-O1e vs. NO-2e: : M = .39 vs. .65, $\underline{p}<.000017$) and s-onset sequences (S-O1e vs. S-O2e: M = .52 vs. .69, $\underline{p}<.00007$). For pairwise comparisons between nucleus-onset and coda-onset sequences, a significantly lower proportion of cuts was observed in cases where the left boundary element was high rather than low in sonority, regardless of whether or not these formed a sonority gradient (NO1e vs. CO1e: M = .39 vs. .63, $\underline{p}<.000017$; N-O1e vs. SO1e: M = .39 vs. .52; $\underline{p}<.000022$).

The general pattern of responses for word and pseudoword stimuli was fairly similar. Onset complexity influenced syllabification responses for nucleus-onset and s-onset cases. The greater tendency to omit parsing in single than double onset cases in a mute-e environment supports the notion that the number of consonants preceding a mute-e is inversely proportional to the probability of segmentation. Furthermore, it suggests that participants relied on a pronunciation-based strategy to determine the location of syllabic boundaries within letter strings. The sonority of the segment preceding the onset in mute-e environments also had a determining effect on syllabification behavior; when the left boundary element was high in sonority the tendency was to omit segmentation. Although there was no difference predicted a priori, between nucleus-onset and s-onset cases (due to the equivocal assignment of 's' to an onset or coda position), such a difference was observed in both experiments. Thus, onset complexity and the sonority of a segment immediately preceding the onset within a mute-e environment had determining effects on syllabification.

For geminate consonants, the first set of analyses with real words revealed significant differences in the observed probability of segmentation, for both regular and semivowel environments, compared to the expected probability of .50 (Table 3). In the second set of analyses, a paired comparison revealed that the proportion of cuts did not differ significantly between both types of syllabic environments ($M = .69$, $M = .72$ for GC and GSv, respectively; $p > .05$). For pseudowords, the difference between observed and expected probabilities was again significant for both regular and semivowel environments (Table 3). In addition, a paired comparison showed that the proportion of cuts between the two syllabic environments was not significantly different ($M = .70$, $M = .68$ for GC and GSv, respectively; $p > .23$). The pattern of results for words and pseudowords was almost identical and revealed that spelling had a strong influence over syllabification, irrespective of whether or not geminate consonants belonged to a cohesive unit (i.e., semivowel). This outcome supports the idea that participants generalized the rule for dividing between two consonants in French (Grévisse, 1964) to the majority of cases that include geminate consonants (i.e., regular or semivowel environments).

Ambiguous Segmentation. Table 3 reveals the proportion of cuts for two types of ambiguous syllabic environments: s-clusters and aspirated-h. For s-clusters, the first set of analyses involving real words revealed significant differences between observed probabilities of segmentation and a criterion set at .50, for all seven types of syllabic environments (Table 3). Although the overall proportion of cuts was close to .50 (i.e., M=.47), individual cases varied considerably. To gain further insight, a 1-way ANOVA was carried out on the proportion of responses using the first three cases (N-S, C-S, and O-S). A significant effect for the sonority of the segment preceding the 's' was observed, $\underline{F}(2, 198) = 1637.40$, $\underline{MSe} = .0125$. Post-hoc comparisons (Tukey's HSD) revealed a significantly lower proportion of cuts in cases where the ideal sonority profile was achieved with the 's' (N-S and O-S: M = .14, M = .01), compared to the case where a sonority plateau or reversal was created (C-S: M = .85; both $\underline{p}<.000022$). A significant difference in the proportion of cuts was also observed for N-S and O-S environments (M = .14, M = .01, respectively, $\underline{p}<.000022$). The results of a 2-way ANOVA that included Cases 4 through 7 (VS-O1, VS-O2, CS-O1, CS-O2), revealed a significant main effect of sonority, $\underline{F}(1, 99) = 320.73$, $\underline{MSe} = .0903$, but not onset complexity ($\underline{p}>.85$), as well as, a significant interaction between both variables, $\underline{F}(1, 99) = 9.88$, $\underline{MSe} = .0318$. The results showed that syllabic boundaries preceded by a vocalic rather than consonantal segment were associated with a higher proportion of cuts between 's' and the following onset (.83 vs. .30, respectively). In terms of the interaction, post-hoc analyses (Tukey HSD) did not reveal any significant differences between Cases 4 and 5 (M = .80, M = .86, respectively, $\underline{p}>.14$), nor between Cases 6 and 7 (M = .32, M = .27, respectively; $\underline{p}>.24$). A significant difference between the former two cases (i.e., Cases 4 vs. 5) had been expected, based on the behavioral findings from Treiman et al. (1992).

For pseudoword stimuli, the first set of analyses for s-clusters revealed significant differences between observed and expected probabilities of segmentation, for six out of the seven syllabic environments (the exception being O-S; Table 3). As in Experiment 1, a significant effect of sonority was observed in a 1-way ANOVA, which included the first three cases (N-S, C-S, O-S), $\underline{F}(2, 196) = 1599.82$, $\underline{MSe} = .0126$. Post-hoc comparisons (Tukey's HSD) revealed a significantly higher proportion of cuts for Case 2 vs. Case 1 (M = .85, M = .17, respectively; $\underline{p}<.000022$) and Case 2 vs. 3 (M = .85, M = 0, respectively; $\underline{p}<.000022$). The results of a 2-way ANOVA, which included Cases 4 through 7 (VS-O1, VS-O2, CS-O1, CS-O2), revealed significant main effects of sonority, $\underline{F}(1, 98) = 232.43$, $\underline{MSe} = .0841$, but not onset complexity,

$p > .04$, in addition to a significant interaction between both variables, $F(1, 98) = 13.76$, MSe = .0382. As in Experiment 1, the presence of a vocalic segment preceding the s-onset boundary lead to a greater proportion of cuts than for s-onset boundaries preceded by a consonant (M = .73 vs. .29, respectively). Likewise, the main effect of onset complexity was not significant (single vs. complex onset: M = .53 vs. .49, respectively; $p > .04$). With respect to the interaction effect, post-hoc comparisons (Tukey's HSD) revealed a significant difference between Cases 4 and 5 (M = .79 vs. .68, $p < .002088$), but not between Cases 6 and 7 (M = .27 vs. .31, respectively; $p > .66$).

The overall pattern of responses for word and pseudoword stimuli with respect to s-clusters was fairly similar. Subsequent analyses revealed that the observed probability of segmentation associated with various types of s-cluster environments did not conform to expectations. Based on French rules of syllabification (Grévisse, 1964), it was predicted that assignment of 's' to either the onset or coda position would be equivocal. Instead, the syllabification of s-onset boundaries varied according to the sonority of the segment immediately preceding the 's'. However, onset complexity did not appear to be a determining factor. With respect to the sonority effect, previous research by Treiman et al. (1992) supports the view that s-clusters do not form legal onsets (i.e., 's' is extra-syllabic). A possible limitation to the generalization of their findings concerns the structural properties of the stimuli, all of which were nonwords that contained s-clusters preceded by a vocalic segment (e.g., 'nus-peem'). The findings of the present study suggest that the assignment of 's' to an onset or coda position does not represent an entirely arbitrary process; however, the findings do not imply that s-clusters should not be viewed as extra-syllabic segments. Specifically, there is a greater likelihood of parsing 's' with the coda when the preceding segment is high rather than low in sonority, because the 's' offers a gradual decline in sonority. With respect to onset complexity, the proportion of cuts before a single or complex onset did not differ significantly. Nevertheless, this finding should not be viewed as conclusive evidence against the possible effects of onset complexity on syllabification, given the low number of entries for CS-O1 (n = 4) and CS-O2 (n = 2) environments. The interaction between sonority and onset complexity was significant for both words and pseudowords, although specific predictions were met only in the case of pseudowords (i.e., significant difference observed between VS-O1 and VS-O2 but not between

CS-O1 and CS-O2). Moreover, the proportion of cuts was much lower than the expected probability of .50 for consonant + s-onset cases (based on Grévisse, 1964), whereas vowel + s-onset cases were fairly close to the expected probability of .75 (based on the results of Treiman et al., 1992 for English). In sum, we may conclude that the sonority of a segment preceding an s-onset boundary influenced syllabification and that further research is needed in order to determine the effects of onset complexity on s-cluster syllabification.

For aspirated-h environments, the first set of analyses with real words revealed significant differences between observed probabilities of segmentation and a criterion set at .50, for both H-N and N-H environments (Table 3). In the second set of analyses, a paired comparison showed a significant difference between the proportion of cuts in both types of syllabic environments (.01 vs. 97, respectively; $\underline{t}(99, .05) = -115.72$). For pseudowords, the difference between observed and expected probabilities of segmentation was significant for both H-N and N-H environments (Table 3). A paired comparison confirmed that the proportion of cuts in each case was significantly different (.01 vs. .97, respectively; $\underline{t}(98, .05) = -93.20$). In linguistic theory, the assignment of 'h' to an onset position is not a controversial matter. In contrast, from a psychological perspective, the fact that this segment is not realized at a phonetic level raises the possibility that skilled readers of French may treat written words presented in isolation differently than they would in continuous speech. However, this hypothesis can be rejected based on the finding that 'h' was almost invariably assigned to an onset position in both H-N and N-H environments. The implication of this finding is that skilled readers rely on the underlying structure of the language to syllabify letter strings.

Letter Cluster Segmentation. The first set of analyses with real words revealed small but significant differences between the observed probabilities of segmentation and a probabilistic criterion value set at zero, for three out of the four types of letter clusters (i.e., the exception being NV; Table 3). In the second set of analyses, a significant effect of cluster type was observed in a 1-way ANOVA (4 levels), $\underline{F}(3,297) = 12.75$, $\underline{MSe} = .0025$. Post-hoc analyses (Tukey's HSD) revealed that the proportion of cuts for semivowel clusters (M = .04) was significantly greater than for any other cluster type (i.e., OV, NV, and CC: M = .01, .0005, and .01, respectively). For pseudoword stimuli, differences between observed and expected probabilities of segmentation were significant for all four types of letter clusters (Table 3). Again, the omnibus F was significant in a 1-way ANOVA, $\underline{F}(3,294) = 7.59$, $\underline{MSe} = .0026$. Post-hoc analyses (Tukey's HSD) revealed a significantly lower proportion of cuts for nasal vowel clusters (M=.003) than any other cluster type (i.e., OV, CC, and Sv: M = .03, .01, and .03, respectively). The pattern of responses for real words and pseudowords differed somewhat. However, given that this difference was extremely small and the proportion of cuts for various cluster types was fairly low (i.e., below .05), we may conclude that the data support the hypothesis that native speakers of French do not segment cohesive letter clusters.[9]

Subjective Data. After completing the syllabification task, participants in each experiment assessed their own performance in terms of a seven-point Likert-type scale. A score of one represented the lowest perceived accuracy rating, whereas a score of seven corresponded to the highest rating. A t-test for independent samples revealed a small but significantly higher degree of certainty ($\underline{t}(196) = 2.28$, $\underline{p} < .02$) for the syllabification of real words than pseudowords (Experiment 1 vs. 2: M = 4.52 vs. 4.13, SD = 1.21 vs. 1.18). Levene's test for the homogeneity of variances was not significant ($\underline{p} > .46$), indicating that the variability of responses was essentially equivalent in each group. Data were also collected about the number of hours spent reading in French, on a weekly basis. Estimates based on self-report for each group revealed similar descriptive statistics: total reading time was, on average, 13 hours and ranged from 1 to 60 hours per week (Experiment 1 vs. 2: M = 12.81 vs. 13.83, SD = 10.91 vs. 11.67, MD = 9.5 for both). Moreover, the difference in total reading time between both groups was not significant, $\underline{t}(194) = -.63$, $\underline{p} > .51$.

Syllabification strategies reported by participants were tabulated in terms of frequencies for three categories of responses: nonlexical, lexical, and other (Table 4). Nonlexical responses included the use of a pronunciation-based strategy (i.e., unspecified, finger taps) or syllabification rules (i.e., geminate consonants, mute-e, semivowels, aspirated-h, open syllabification, or unspecified parsing rules). Lexical responses included influences due to morphology (i.e., recognition of internal words, affixes) or the use of an analogy-based strategy (for pseudowords). The third category grouped together miscellaneous responses including a

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[9] An arcsine transformation was performed on the proportion of errors for letter cluster segmentation.

Table 4

<u>Frequency as a function of the type of syllabification strategy reported by participants in experiments 1 and 2</u>

Strategy		Percentages (%) Experiment 1	Experiment 2
Nonlexical			
	Pronunciation	80	83
	Syllabification Rules	69	52
Lexical			
	Morphology	6	3
	Analogy	n/a	6
Other			
	Hyphenation	4	0
	Don't Know	2	0

Note: Multiple responses per respondent were possible hyphenation strategy used for syllabifying words at the end of a line of print and non-specific answers. The number of blank answer sheets (self-report task) was fairly low in each group (Experiment 1 vs. 2: 10% vs. 7%). The most frequently cited strategy was the pronunciation of letter strings (80 and 83 citations, respectively), followed by a prescribed rule for dividing geminate consonants (24 and 25 citations, respectively). All other syllabification strategies were applied less than 10% of the time. In sum, these data corroborate the findings from the objective data set, suggesting that participants relied upon simple heuristics to perform the syllabification task and made use of orthographic and phonological knowledge.

Conclusion

Two experiments examined the syllabification responses given by native speakers of French for various types of syllabic environments, that were categorized according to a framework including five broad categories of segmentation: mandatory, illegitimate, optional, ambiguous, and letter cluster. The clearest outcomes were predicted for mandatory, illegitimate, and letter cluster segmentation, where it was generally assumed that skilled readers would be able to judge the legitimacy of syllabic or non-syllabic boundaries with near-perfect accuracy. However, the results showed significant deviations for each type of syllabic environment compared to a criterion (t-test), as well as, a significant degree of variability between these environments (ANOVA); the largest deviations were observed in the case of mandatory segmentation. As for optional and ambiguous segmentation, the pattern of responses did not generally conform to the pattern of results based on the hypothesis of ambivalence / non-differentiation. Perhaps the most obvious finding was the striking similarity between the pattern of responses for word and pseudoword syllabification, which has strong implications for a common process underlying segmentation behavior. Finally, the results of the subjective data analysis suggested that participants relied on simple heuristics to parse the letter strings and that spelling-to-sound translation was omnipresent throughout both experiments. The specific results for each category of segmentation will be reviewed below to highlight their theoretical implications, following a discussion on lexicality effects and various types of syllabification strategies.

Lexicality did not have a noticeable influence over syllabification in this untimed task; the pattern of responses in Experiments 1 and 2 was nearly identical (i.e., correlation of r = .99). The implication is that spelling-to-sound translation underlies parsing behavior for both real word and pseudoword stimuli (the latter of which have no representation in memory). However, spelling-to-sound translation is not the only mechanism available for reading pseudowords. It has been argued that an analogy-based strategy could also be used (e.g., Glushko, 1979) and that spelling-to-sound translation is not necessarily restricted to the grapheme-phoneme level. Applying this logic to the present study, it is fair to question whether or not the pseudowords in Experiment 2 were sufficiently differentiated from their real word counterparts in Experiment 1. Previous research has tended to quantify the perception of wordlikeness in one of two ways, either by counting the number of real words that a fictitious word resembles or by measuring a nonwords's degree of conformity to the phonotactic rules of a given language (Frisch, Large, and Pisoni, 2000). With respect to the first method, it is reasonable to assume that a fair number of participants (i.e., at least 10%) in Experiment 2 would cite the use of an analogy-based strategy. This was not the case (see Table 4). From a structural standpoint, pseudowords (as opposed to nonwords) are made up of legal graphemic or phonemic sequences (Brown and Hildum, 1956). Therefore, we may conclude that the majority of participants did not consciously make use of analogies to real words when parsing pseudowords. Instead, participants relied on their knowledge of phonotactic constraints, thereby demonstrating a sensitivity to the underlying structure of the language.

The range of syllabification strategies reported by participants was rather limited. Apart from spelling-to-sound translation (which was cited by at least 80% of participants in each sample), knowledge of syllabification rules (in particular a rule for parsing geminate consonants) was cited by 69% and 52% of the sample in Experiments 1 and 2, respectively. The low number of citations for morphological influences (i.e., Experiments 1 and 2: 6% and 3%, respectively) further corroborates the claim that the vast majority of letter strings were processed through spelling-to-sound translation (i.e., without access to a word's meaning). According to Taft (1979), words are accessed via their root morpheme, after a preliminary step involving prefix stripping. In all fairness, the vast majority of the stimuli in the present study were not prefixed. Moreover, a deliberate action was taken to modify the beginnings of words to create pseudowords that had minimal visual similarity to real words. Nevertheless, this issue may be of interest for future investigations into the matter. To reiterate the key finding, participants relied on simple heuristics to parse letter strings: a pronunciation-based strategy and the detection of particular spelling patterns (i.e., geminate consonants).

Mandatory segmentation, as the term implies, represents required parsing in three types of syllabic environments (N-O, C-O, and N-N). No differences were expected, a priori, among these environments. However, the outcome was of a different sort. Specifically, the proportion of cuts in each of the three environments differed, to varying degrees, from the expected value of one. The fact that syllabification in these environments is less straightforward than previously assumed, implies that there may be more than one determining factor. Past research has highlighted the role of legality and sonority on syllabification decisions (e.g., Treiman and Danis, 1988; Treiman and Zukowski, 1990). By far the easiest choice, for deciding upon the location of a syllabic boundary, involved the separation of consonant pairs (C-O), relative to vocalic (N-N) and vowel-consonant (N-O) sequences. The implication of this finding is that participants operated with the legality principle in mind; participants assessed the cohesiveness of consonant sequences in terms of legitimate onsets. It may also reflect the influence of sonority, whereby adjacent segments that have a lesser sonority differential provide more salient cues for syllabification. From a different perspective, it might have seemed more fitting if N-O environments had turned out to be the easiest to syllabify, given the regularity of syllabic structure in French. However, one crucial point to bear in mind is that N-O environments include more than simple vowel-consonant sequences, they also represent sequences that contain complex onsets (e.g., V-CC). Onset complexity could explain why segmentation decisions for the N-O environment were the most difficult of the three. With respect to N-N environments, the proportion of cuts was mid-range between C-O and N-O environments (in Experiment 2 the difference between the last two cases was not statistically reliable). What this suggests for situations in which parsing was omitted for N-N environments is that adjacent nuclei from separate syllables were sometimes treated as part of the same syllable; we will elaborate on this point in a subsequent section dealing with optional segmentation (i.e., semivowels). To summarize, behavioral evidence showed that readers elect, on occasion, to omit mandatory segmentation and that different types of syllabic environments are not treated equally.

Slight discrepancies between observed and expected probabilities of segmentation were found with illegitimate segmentation. Specifically, the proportion of cuts (i.e., errors of commission) differed significantly from zero in both O-N and N-C environments, although they remained below 10% across all serial positions in the letter strings. Moreover, a significantly greater proportion of cuts was observed for the latter than the former (i.e., Experiments 1 and 2: .02 and .01 difference, respectively). Some caution is necessary in interpreting these results given the magnitude of this difference and the low proportion of (incorrect) cuts associated with illegitimate segmentation. One way to explain this difference is based on the results of Kessler and Treiman (1997) who examined the probability of co-occurrence between onset-vowel and vowel-coda pairs in English monosyllables. They showed that the pairing of onset-vowel sequences was statistically random, whereas vowel-coda combinations were governed by probabilistic constraints. Assuming these findings generalize to polysyllabic French words, the implication for the present results is that syllabic constituents within O-N environments share less affinity (leading to a lower proportion of cuts) than those in N-C environments. Similarly, one can interpret this finding based on the results from various language processing experiments (e.g., Bowey, 1990; Mackay, 1970; Treiman, 1983) that also support the onset-rime view. For example, in a lexical decision task by Treiman and Chafetz (1987), native speakers of English were able to identify the lexical status of letter strings more quickly when the integrity of the rime was preserved, that is, when the marker was placed between the onset and the rime (e.g., cr//isp vs. cri//sp). Similarly, in the present study, parsing within a N-C environment disrupts the integrity of the rime unit, but respects the onset-rime division in an O-N environment. Overall, however, we conclude that skilled readers generally avoided all types of inter-syllabic breaks.

Optional segmentation responses were analyzed according to three types of syllabic environments: semivowels, mute-e, and geminate consonants. For semivowel environments, the focus of the investigation was on Sv-N cases, where there exists a possibility for free variation between semivowels and their corresponding high vowels. The observed probability of segmentation did not differ significantly from a criterion value of .50 (i.e., expected value based on chance) for Sv-N environments in Experiments 1 and 2. The fact that readers discriminated between two alternative phonetic realizations of a letter string in a written syllabification task is significant. It might otherwise have been possible to think that readers operated on a more abstract phonological representation of the stimuli.

With respect to mute-e environments (i.e., N-O1e, N-O2e, C-O1e, S-O1e, S-O2e), it was once again evident that readers operated on a phonological representation of the letter strings. In accordance with guidelines for the pronunciation of a mute-e in speech (Valdman, 1976), the behavioral data showed that readers tended to omit the segmentation of syllabic boundaries in mute-e environments, when there were fewer consonants preceding a mute-e (i.e., lower proportion of cuts for single than complex onsets preceding a mute-e). In addition, the sonority of a segment immediately preceding the onset in a mute-e environment also influenced syllabification; the proportion of cuts was lower when the segment preceding the onset was high rather than low in sonority (i.e., vowel vs. consonant, respectively).

For geminate consonants, readers adopted a graphemic parsing strategy and typically opted to separate regular geminate consonants. Nevertheless, the proportion of cuts was greater than anticipated (Experiments 1 and 2: .69 and .70, respectively), based on findings from Treiman and Danis (1988; .45 for English words with second-syllable stress). This discrepancy may be attributed to differences between oral and written syllabification tasks, and / or between French and English syllabification. To elaborate on the latter point, it is possible that the same behavior observed in each language may be attributable to different causes. According to some sources (e.g., Kahn, 1976), ambisyllabicity is thought to be prevalent in English, but not in French. Thus, it would seem that French readers were able to base their decisions more reliably on their knowledge of written syllabification rules (i.e., rule for dividing geminate consonants). Contrary to expectations, geminates within semivowel environments were just as likely to be divided as regular geminates, although semivowels represent cohesive units. One way to view this outcome is to consider the possibility that skilled readers were not able to clearly discern the boundaries for the semivowel /j/, which can take on three different forms (i.e., 'cuillère' [spoon], 'entrebâillement' [half-open door]; 'calcium' [calcium]). However, the subjective data set supports a different interpretation; specifically, participants may have generalized the parsing rule for geminates in a regular environment to geminates in a semivowel environment. Hence, in the context of a written syllabification task, French readers choose to divide geminate consonants in the vast majority of cases, regardless of whether they appear in regular or semivowel environments.

Ambiguous segmentation included s-cluster and aspirated-h environments. With respect to the former, the data showed that the sonority of a segment immediately preceding the 's' is a strong determinant of syllabification. In keeping with the set of predictions that was conditional upon the rejection of the ambivalence / non-differentiation hypothesis, cases in which a sonority gradient was present (N-S), instead of a sonority plateau (C-S), were much less likely to incur parsing. Onset complexity did not appear to be a determining factor. Nevertheless, as predicted, onset complexity interacted with sonority. Specifically, when a vocalic segment preceded the s-onset boundary, the proportion of cuts for single and complex onset cases differed significantly (Experiment 2 only), whereas no such difference was found in cases where the preceding segment was a consonant. A caveat to bear in mind at this point concerns the relatively low number of entries in the database for testing the onset complexity hypothesis. Consequently, this issue must be left for future research to replicate. For present purposes, these data offer a different perspective from that of Treiman et al. (1992), who investigated the legality of s-clusters. In their study, a vocalic segment always preceded an s-cluster and the tendency was to assign the 's' to a coda instead of an onset position. The present findings do not imply that s-clusters should be viewed as legal onsets. However, they do indicate that the sonority of a preceding segment carries at least as much weight as the segment following the 's' for syllabification decisions involving s-clusters.

For syllabic environments involving an aspirated-h, the pattern of results was quite clear: participants invariably assigned the 'h' to an onset position for both H-N and N-H environments (i.e., the proportion of cuts in each case was close to zero and one, respectively). This may not come as a surprise to most linguists, however, from a psychological perspective the rules of liaison which are apparent in speech (e.g., 'les_héros' is pronounced without a liaison /le'ero/) are lost when written words are presented in isolation. The present findings clearly showed that skilled readers have internalized the structure of their native language such that, even with pseudoword stimuli there is no ambiguity in assigning the 'h' to an onset position.

Finally, with respect to letter cluster segmentation, the proportion of cuts was not expected to differ significantly from a criterion value of zero. Although there were some significant differences between the proportion of cuts for certain cluster types in each experiment, these differences were quite small. Moreover, the overall proportion of cuts for non-syllabic errors was fairly low. Research on word recognition processes has shown that readers are able to quickly and accurately identify vocalic or consonant sequences that form cohesive clusters, during early acquisition stages (e.g., Laberge and Samuels, 1974; Ans, Carbonnel, and Valdois, 1998). The findings of the present study are generally in line with these predictions.

In summary, this research addressed the need to capture behavioral evidence about written syllabification in a comprehensive format. The framework that was developed is universally applicable to different alphabetic languages (subject to some language-specific modifications). It enables the analysis of segmentation responses across different types of syllabic environments and serial positions in a letter string. As stated previously, research in the area of written syllabification is quite sparse and has tended to focus on pointed issues. The intent of this tool is to allow researchers to identify potential relationships between different types of syllabic environments and to further cross-linguistic research in the area of written syllabification.

Chapter 3

Syllabic Boundary Verification in French Print Using a Timed Task

Abstract

Three experiments addressed the issues of syllabic boundary identification and syllabic mediation in reading French print. In a timed verification task, native speakers of French decided upon the adequacy of a proposed syllabic boundary within trisyllabic stimuli, that contained either a single medial consonant (e.g., CV.CV.CV) or medial consonant pair (e.g., CVC.CV.CV). For syllabic boundary decisions, processing latencies (and error proportions in Experiment 1) increased with the left-to-right serial position of a proposed boundary. The presence of a medial consonant pair, either at the beginning (Experiment 1) or in the middle of the word (Experiment 2), increased response latencies and error proportions. These effects remained whether the stimuli ended with a mute-e or voiced phoneme (Experiment 3). Response latencies and error proportions for non-syllabic boundary decisions generally decreased towards the end of words, except when stimuli ended in a voiced phoneme (Experiment 3). Coupled with a reliable word-frequency effect, the location-specific effect of syllabic structure is most consistent with the idea that syllabic structure effects were lexically derived and inconsistent with the notion of syllables-as-access codes. Implications for the role of syllable-sized units in reading are discussed.

Introduction

The ability to discriminate syllabic boundaries is an important component of the reading process, not only during acquisition but for skilled reading as well. Over the last three decades, a considerable body of evidence has accrued in favor of syllables as functional units in the processing of both print and speech (e.g., Spoehr and Smith, 1973; Bowey, 1990; Prinzmetal, Treiman, and Rho, 1986; Treiman and Chafetz, 1987; Taft and Radeau, 1995; Ferrand, Segui, and Humphreys, 1997). In a syllable-timed language such as French, it has been demonstrated that native speakers can use a syllabified code when performing various speech perception, speech production, and silent reading tasks (e.g., Mehler, Dommergues, Frauenfelder, and Segui, 1981; Peretz, Lussier, and Béland, 1998; Colé, Magnan, and Grainger, 1999).

The appeal to the syllable comes from the proposition that any sequence of sounds produced by native speakers of any language can be conveniently parsed into segmental groupings. A rule-like procedure appears to underlie the way in which these groupings are formed. Although grammarians have outlined written syllabification rules (e.g., Grévisse, 1964), which are partially based on phonotactic rules and behavioral observation, there exists no unequivocal and comprehensive set of rules that can be used in any given language. Thus, there is a need to study the cognitive mechanism by which syllabic boundaries are perceived in print and the influence of syllabic structure on written language processing. We argue here that this investigation should be language specific, since every language is assumed to have its own set of phonotactic constraints specifying which phonemes may occur at the beginning, in the middle, and at the end of syllables (e.g., Roach, 1992). Moreover, given that the conditions which favor the syllable as a segmental unit are present in the structure of lexical stimuli this implies, conversely, that lexical identification could be carried out through syllabic segmentation. This paper focused on the syllabic structure of French and also looked at the role of syllables in lexical identification during on-line processing.

The Role of Syllabic Structure in Syllabic Boundary Identification

Syllables are defined as phonological units consisting of three basic constituents: (a) an initial consonant group called the onset, (b) a vocalic group called the nucleus, and (c) a final consonant group called the coda (e.g., Giegerich, 1992). To illustrate, the onset, nucleus, and coda positions in the first syllable of the French word 'sur.pris' [surprised] are occupied by the following phonemes, / s /, / y /, and / r /, respectively. The only obligatory element within a syllable is the nucleus. Moreover, there is evidence that the syllable is not merely a linear string of phonemes, but a hierarchical structure with an intermediate level between the phoneme and the syllable. This hierarchical structure refers to two different levels of structure: the onset and rime units, at the higher level, and the nucleus and coda elements which make up the rime, at the lower level (e.g., Fowler, Treiman, and Gross, 1993). These structural properties are assumed to be involved in several phenomena observed in the processing of spoken and printed words (e.g., Fromkin, 1973; Mackay, 1970; Treiman, 1983, 1984). Mehler et al. (1981) provided direct evidence for the role of syllables in the segmentation of spoken words. Native speakers of French had to detect a visually-presented CV or CVC target from the structure of spoken words. The target provided either a perfect match or a non-match with the word-initial syllable. The results revealed faster response times for target sequences that matched the word-initial syllable (Experiment 1) or corresponding rime unit (Experiment 2) of spoken words, than those that did not.

The problem of identifying syllabic boundaries revolves around the status of inter-vocalic consonants, since the vowel can take on a single value, that of the nucleus. The outstanding issue is how these medial consonants are assigned to the onset or coda position of adjacent syllables. Treiman and Chafetz (1987) sought relevant evidence for the English language. Reasoning that phonological processes are necessarily involved in reading, since the primary function of the alphabet is to represent speech sounds (e.g., Diringer, 1968), they used two kinds of printed word recognition tasks: anagram and lexical decision. In both tasks, discontinuities were inserted into letter strings, with the intent of dividing syllabic units on critical trials. In the first task, words were identified more quickly from an array of fragments when the stimuli were parsed between the onset and the rime (e.g., FL_OST_ANK_TR), than within these subsyllabic units. In the second task, stimuli with a CCVCC structure were presented with a break either before or after the vowel. The results showed that participants were faster at identifying the lexical status of stimuli with prevocalic breaks, that preserved the integrity of the rime (e.g., cr//isp vs. cri//sp).

These findings converge with those of Treiman and Danis (1988) who targeted the initial VCV sequence of polysyllabic word pairs, which differed on a number of phonological and orthographic dimensions including: stress pattern, sonority, vowel length, spelling, and bigram frequencies. The influence of these variables over syllabification decisions was investigated both in oral and written contexts. An oral word game required participants to reverse the order of pronunciation for the first syllable and remainder of a word (e.g., 'snowman' → 'man_snow'), whereas, a written syllabification task elicited a choice between two parsing alternatives (e.g., 'pro/per' vs. 'prop/er'). The overall pattern of results in each task was highly similar. Most notably, in words that carried second-syllable stress, the general tendency was to assign a medial consonant to the onset position of the second syllable (e.g., 'pro/pel'), whereas for words that received first-syllable stress, no reliable preference was observed between onset and coda positions (e.g., 'pro/per' vs. 'prop/er'). In the oral task, ambisyllabic responses were observed when a medial consonant: (a) appeared in words that received first-syllable rather than second-syllable stress, (b) had a double (i.e., geminate) consonant spelling (e.g., 'com/mand'), (c) were high in sonority (liquid or nasal vs. obstruent), or (d) were preceded by a short vowel (in words that carried first-syllable stress only). According to Seidenberg's (1987) bigram frequency hypothesis, letter pairs forming an inter-syllabic boundary should be of a lower frequency than those occurring intra-syllabically. By this view, syllables are not real psychological units, since they can be accounted for by knowledge about the distribution of letter patterns in the language. This hypothesis, however, was not supported by Treiman and Danis' (1988) data.

Following Treiman and Danis (1988), Treiman and Zukowski (1990) targeted medial consonants within the VCCV sequence of polysyllabic words. For the written syllabification task, words were typed on a sheet of paper and presented along with three syllabification alternatives (e.g., 'a-tlases', 'at-lases', and 'atl-ases'). Each word was read aloud by the experimenter and used in a sentence beforehand. Participants were then instructed to "circle the syllabification that corresponded to how they would divide the word at the end of a line of print"

(Treiman and Zukowski, 1990, p. 68). The main findings were that medial consonant pairs were almost invariably separated when constraints imposed by phonotactic legality were violated (e.g., in 'at-lases', /tl/ is not a legal CC sequence at the beginning or end of words and consequently syllables), and as a general rule, when the stress fell on the syllable following a medial consonant pair (e.g., 'pon-toon'). In addition, legal CC sequences that showed a steady rise in sonority toward the nucleus were assigned to the onset position and not separated, whereas /st/-clusters forming a sonority plateau or reversal were divided (e.g., 'Ma-drid' vs. 'es-tate'). One implication of these results for the discrimination of syllabic boundaries in print is that there exists a core set of syllabification principles (i.e., legality, sonority, and stress) underlying segmentation behavior. A second implication is that a clear understanding of these principles will ensure proper controls for studies investigating the role of syllables in on-line reading tasks.

The present study extends previous research by Treiman and her colleagues (i.e., Treiman and Danis, 1988; Treiman and Zukowski, 1990) to an on-line written syllabification task conducted with native speakers of French. We used trisyllabic stimuli that contained either a single medial consonant (CV.CV.CV) or medial consonant pair (CVC.CV.CV or CV.CVC.CV) to investigate the role of syllabic structure in the identification of syllabic boundaries in printed words. Our procedure differed from Treiman's written task in two important ways: first, our task was computer-controlled and timed; and secondly, the parsing alternatives for each word were shown on different randomized trials. Controlling the timing aspect was crucial given that our aim was two-fold: (a) to investigate the influence of syllabic structure on syllabification decisions, and (b) to explore the role that syllables play in visual word recognition (VWR). We examined the relative processing time for stimuli with a regular CV-type structure and those that contained a CVC syllable (e.g., CV.CV.CV vs. CVC.CV.CV). According to the syllabification rules of French (e.g., Grévisse, 1964), a single medial consonant is indisputably assigned to the onset position of stimuli with a recurrent CV structure and fixed stress assignment. Moreover, the CV pattern is highly regular in French; an estimated 55% of French words have a CV structure, in comparison to only 17% of words that have a CVC structure (e.g., Valdman, 1976; Dauer, 1983). In order to make decisions for stimuli with a medial consonant pair as simple as possible, the stimulus selection criteria included words that could be divided on the basis of: (a) legality - since the stimuli contained medial consonant pairs that are illegal in word-initial positions (but not always in word-final positions; however, word-final stress in French would mitigate this effect by attracting the second consonant of such pairs); (b) sonority – since the stimuli contained medial consonant pairs that represented either a sonority reversal or plateau; and (c) stress – since stress assignment in French is fixed. Thus, we predicted faster and more accurate responses for syllabic boundary decisions involving two CV syllables rather than consecutive CVC and CV syllables.

In the aforementioned studies by Treiman and her colleagues, participants were given instructions that either explicitly (i.e., written task) or implicitly (i.e., word games) referred to the concept of syllables. One ambiguity concerning the set of instructions for the written task is that mixed reference was made to the concepts of syllabification and hyphenation. Therefore, it is possible that the results stemmed from one or both of the following sources: (a) direct activation of the concept of syllables, and / or (b) task demands (i.e., verifying the location of a hyphen for words appearing at the end of a line of print). Furthermore, although Treiman used the words 'syllabification' and 'hyphenation' somewhat interchangeably in her instructions, it is possible to consider hyphenation as an implicit syllabification task. The present study was focused solely on written syllabification and manipulated instructions along an explicit / implicit dimension. Prescribed rules applying to either a hyphenation or syllabification task may yield a different pattern of segmentation responses. On a pragmatic level, the hyphenation task could tap into a different knowledge base or one that only partially overlaps with syllabification. A possible outcome which fits with this scenario is that 'No' responses in the hyphenation condition may yield corresponding 'Yes' responses in the syllabification condition, if there are only two letters shown at the beginning or end of a line of print (e.g., 'repti/le' [reptile]). Thus, more errors and possibly higher response times were expected in the hyphenation than syllabification condition, for stimuli that contained either a single medial consonant or medial consonant pair.

Syllabic Mediation and Syllable-as-Access-Code

The concept of syllable implies more than a mere constituent unit of word structure. It has been proposed that (low-frequency) visual words are parsed into syllables which, in turn, serve as access codes in reading (Bowey, 1990, 1993; Colé et al., 1999). Bowey hypothesized that naming times for low-frequency monosyllabic words would be reduced if the rime or onset was previewed, compared to an unprimed condition. In the first study, stronger facilitation effects were observed for rime-primed stimuli (e.g. 'ail' → 'hail') than those in which the three-letter prime did not correspond to the rime unit (e.g., 'ray' → 'pray'). Similarly, greater facilitation effects were observed for stimuli with a two-letter prime that corresponded to the onset in the experimental condition (e.g., 'br' → 'brand'), compared to stimuli with a single onset followed by a nucleus in the control condition (e.g., 'bi' → 'birch'). The second study confirmed that the locus of the differential rime-priming effect was not based at the articulation stage; orthographic primes (sharing both the rime's spelling and pronunciation; e.g., 'ack' → 'tack') produced greater facilitation effects than phonological primes (sharing the rime's pronunciation but not its spelling; e.g., 'erf' → 'turf'). Taken together, the results of these studies support the view that orthographic onsets and rimes serve as functional units in reading.

Colé et al. (1999) used a visual version of the syllable monitoring task. As in the original study by Mehler et al. (1981), participants were instructed to indicate whether or not a target letter sequence (CV or CVC syllable) was present at the beginning of written words (e.g., 'pa' in 'paroi' [partition] versus 'parfum' [perfume]). Word frequency was also manipulated in order to determine whether high- and low-frequency words differentially influenced the syllabic structure effect. The results showed an interaction between target syllable and carrier word for skilled adult readers, in the case of low-frequency words, but not with high-frequency words. This three-way interaction supports the view that skilled readers of French relied on a syllabified code to mediate lexical identification in the case of low-frequency words, whereas high-frequency words were processed via a whole-word orthographic code.

As in the syllable monitoring task by Colé et al. (1999), word frequency was also manipulated in the present SBV task. From the standpoint of dual-route models (e.g., Coltheart, 1978), letter strings are processed via a lexical (holistic) mechanism, which operates in parallel with a non-lexical (sequential) mechanism. It is generally assumed that the output from the non-lexical route is delayed relative to that of the more direct orthographic route. Hence, in the case of low-frequency words, it is sometimes possible for the former to produce its output ahead of the latter, due to the extra processing time required for low-frequency words. In French, results from the visual monitoring task (Colé et al., 1999) conform with this view, insofar as high- and low-frequency words are processed differently. However, the results differ with respect to the grain-size of units used during sublexical processing (i.e., syllabic units vs. grapheme-to-phoneme correspondences or GPCs). Therefore, if stimuli with a CC structure are more difficult to process than those with a C structure, faster responses and less errors were expected for low-frequency stimuli with a C than CC structure.

In order to test the syllable-as-access-code hypothesis using the SBV task, we manipulated the left-to-right serial position of proposed syllabic boundary markers within the letter strings. Marker positions for syllabic segmentation occurred either early or late in words that included a single medial consonant (CV.1CV.2CV) or medial consonant pair (CVC.1CV.2CV or CV.1CVC.2CV). Non-syllabic breaks in the next serial position served as a control condition (CV.C1V.C2V and CVC.C1V.C2V or CV.C1VC.C2V). The rationale for manipulating the serial position of a syllabic boundary marker was two-fold: (1) to determine whether the pattern of results conformed to serial or holistic processing of the letter strings, and (2) in the event of serial-based processing, whether or not, the mechanism generalizes to both syllabic boundary positions. From a dual-route perspective (Coltheart, 1978), a serial processing effect would indicate the use of a sublexical processing strategy, which operates strictly at the level of graphemes and phonemes (i.e., phonemic hypothesis). Alternatively, a sublexical account is also proposed in the Multiple-Trace model (i.e., Ans, et al., 1998), except that syllables become the primary parsing unit (i.e., syllabic mediation hypothesis). Along similar lines, Taft and Forster (1976) claimed that a reiterative search through the lexicon ensues up to the boundary of a word-initial syllable, in order to locate an access code for the retrieval of lexical representations. For example, with 'candle' a cumulative search in memory would involve the following letter groupings 'c-ca-can-cand' until a match is found for a syllabic unit; in French, this unit corresponds to a word's phonological-first syllable (e.g., 'chandelle' [candle] → 'c-ch-cha-chan'; Taft and Radeau, 1995). We predicted faster, but not necessarily more accurate, responses for early than late marker positions, if a left-to-right processing mechanism operated on the letter strings and syllabic structure had no influence on performance.

Overview of the Experiments

An on-line written syllabification task was used to examine the role of syllabic structure in the discrimination of syllabic boundaries and the role of syllables for printed word recognition in French. In all three experiments, syllabic structure (single medial consonant vs. medial consonant pair) and word frequency (high vs. low) were manipulated, as well as, the serial position of a syllabic boundary marker (early vs. late in the letter string). In addition, Experiment 1 manipulated instruction type according to the degree of explicitness in referring to the concept of syllables (syllabification vs. hyphenation task) and Experiment 3 manipulated the phonetic quality of a word's final phoneme (mute-e vs. voiced phoneme). If syllabic structure plays a determining role in the identification of syllabic boundaries, response latencies and possibly error proportions are expected to be greater for decisions involving adjacent CV and CVC syllables than two CV syllables. As per the role of syllables in lexical identification, holistic and serial-based processing strategies were predicted for high- and low-frequency words, respectively. Finally, with respect to serial processing, decisions should be faster and possibly more accurate for early than late marker positions if the letter strings are scanned from left to right.

Experiment 1

Method

Participants. The participants were 48 undergraduate students (40 women and 8 men; mean age = 23) enrolled at the University of Ottawa, Canada. All volunteers were native speakers of French, with English as a second language. None reported a history of reading difficulties.

Materials and Equipment. The lexical material included a practice list (n = 48) and an experimental list (n = 144) containing polysyllabic French words. The stimulus list formed a 2 X 2 design, with word frequency (high vs. low) and syllabic structure (single medial consonant:

CV.CV.CV vs. medial consonant pair: CVC.CV.CV) as variables, and 36 stimuli in each of the four cells of the design. All words were selected from the Mandalex database (i.e., Desrochers, 1995). The frequency estimates (i.e., Imbs, 1971) of high-frequency items ranged from 3.8 to 154 and 3.8 to 153.7 occurrences per million for stimuli with a C (M = 23.8, SD = 30.5) or CC (M = 23.8, SD = 30.3) structure, respectively. The frequency estimates of low-frequency words ranged from .08 to 3.5 and .12 to 3.6 occurrences per million for stimuli with a C (M = 1.3, SD = 1) or CC (M = 1.3, SD = 1) structure, respectively.

A PC-compatible ACER 486-33 MHz computer was used to display the stimuli which appeared on an ACER SVGA video monitor in white lowercase lettering against a black background. Each stimulus was presented a total of four times with a marker (forward slash) inserted in one of four consecutive locations within a word, for a total of 576 experimental trials (144 stimuli X 4 marker positions). The first marker position was located after the first syllable with the next three positions numbered consecutively as follows: CV1.C2V3.C4V for stimuli with a C structure and CVC1.C2V3.C4V for stimuli with a CC structure; positions 1 and 3 refer to syllabic segmentation, whereas positions 2 and 4 represent non-syllabic segmentation. MEL software (Micro Experimental Lab, version 2.0; Schneider, Rodgers, Maciejczyk, Zuccolotto, and St. James, 1995) was used to control the timing, sequencing of stimuli presentation, and recording of responses. Participants indicated their responses using a MEL response-box (Model 200A); the outer left and right keys corresponded to 'Yes' and 'No' answers for half of the participants in each condition and to the reverse association for the other half. Cue cards, placed just below and on either side of the monitor, indicated the proper hand-response association.

Procedure. Testing was carried out individually in a quiet room. Participants were assigned to one of two conditions and asked to decide, whether or not, a marker appearing within a letter string coincided with the proper location for a hyphen, when dividing a word at the end of a line of print (condition 1), or for a syllabic boundary (condition 2). They were instructed to respond as quickly as possible while maintaining an error rate below 10%. The sequence of events for any given trial unfolded in the following manner: (1) a prompt 'Prêt?' [Ready] appeared at the center of the screen, (2) the initiation of each trial was triggered manually by the participant, (3) a fixation point (plus sign) appeared at the center of the screen for 500 ms, and

(4) a stimulus appeared in its place and remained in view until the participant's response was recorded. The same list of stimuli was presented in a uniquely randomized order for each participant. No feedback on the speed or accuracy of responses was provided.

Results and Discussion

A series of ANOVA's were performed on mean correct response latencies and mean error proportions, separately for syllabic and non-syllabic segmentation, with both subjects (Fs) and items (Fi) as units of analysis. The response time distribution was truncated at a lower threshold of 150 ms and an upper threshold of 4000 ms. An arcsine transformation was applied to the error data in order to reduce the probability of observing spurious effects (Myers, 1979). In the analysis by subjects, instruction type (hyphenation vs. syllabification) was declared as a between-subjects factor, whereas word frequency (high vs. low), syllabic structure (single medial consonant vs. medial consonant pair) and marker position (early vs. late in the word) were declared as within-subjects factors. In the analysis by items, syllabic structure and word frequency were treated as between-items, whereas marker position and instruction type were treated as within-items. In the analysis by subjects (Fs), the design was a 2 (instruction type) X 4 (syllabic structure / marker position) X 2 (word frequency), whereas in the analysis by items, two separate analyses of a 2 X 2 X 2 design were run in which either marker position (Fi1) or syllabic structure (Fi2) was a confounded variable. The results of the analysis by items are presented only when they are also significant in the analysis by subjects. Subject means are presented in the figures and discussed in the text. The critical alpha level of the statistical test reported as significant was .05 and post-hoc analyses were carried out using Tukey's HSD method.

<u>Syllabic Segmentation</u>. The ANOVA on response times (Figure 3: panels A and B) showed significant main effects of the combined syllabic structure / marker position variable and word frequency. However, the main effect of instruction type was not significant. Response times were faster for syllabic boundary decisions involving a C than CC structure (831 vs. 934 ms), $Fs(3,138) = 24.59$, $MSe = 22323$, $Fi1(1,140) = 144.46$, $MSe=5289$, and for high- than low-frequency words (869 vs. 895 ms), $Fs(1,46) = 9.55$, $MSe = 6436$, $Fi1(1,140) = 8.72$, $MSe = 5289$,

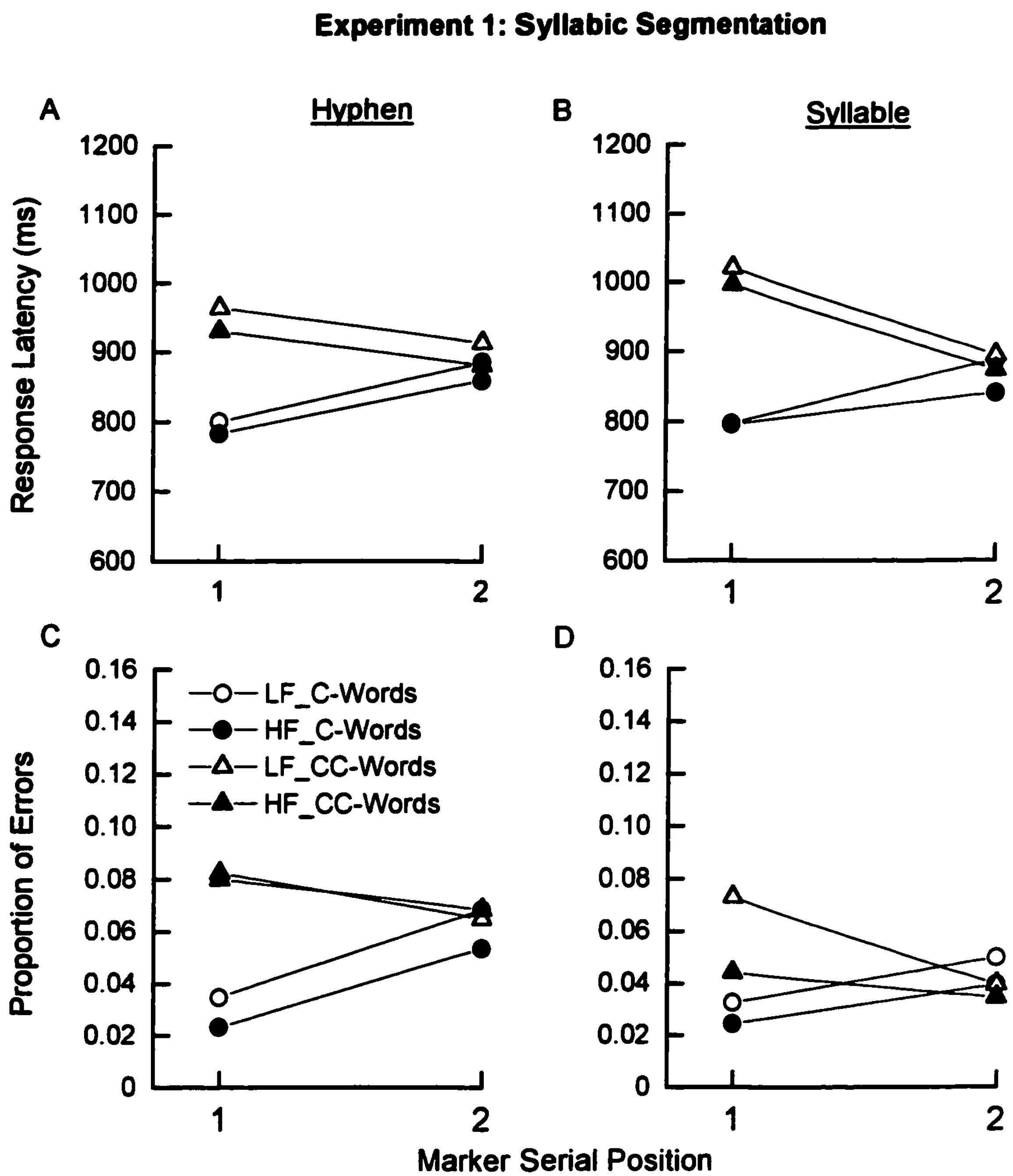

Figure 3. Response latency and proportion of errors in syllabic segmentation, as a function of marker position, syllabic structure, and word frequency, for hyphenation and syllabification instructions.

$\underline{F}i2$ (1,142) = 4.08, $\underline{MSe}$ = 4410. A post-hoc analysis revealed a location-specific effect of syllabic structure in the critical marker position (i.e, 183 ms RT-advantage for stimuli with a C than CC structure in the first marker position; second position: 22 ms, n.s.). Furthermore, response times increased significantly from the first to the second marker position for stimuli with a C structure (794 vs. 868 ms), while stimuli with a CC structure showed a corresponding decrease that was also significant (977 vs. 890 ms).

The ANOVA on error proportions (Figure 3: panels C and D) replicated the main effect of the combined syllabic structure / marker position variable. However, the main effects of word frequency and instruction type were not significant. Overall, responses were more accurate for stimuli with a C than CC structure (.04 vs. .06), $\underline{F}s(3,138) = 4.26$, $\underline{MSe}$ = .0524, $\underline{F}i1(1,140)$ = 36.37, $\underline{MSe}$ = .0167. A post-hoc analysis revealed a location-specific effect of syllabic structure in the critical marker position (i.e., .04 error-advantage for stimuli with a C than CC structure in the first marker position; position 2: .01, n.s.). Moreover, response accuracy was significantly greater for stimuli with a C structure in the first than second marker position (.03 vs. .05), while stimuli with a CC structure showed a non-significant difference in response accuracy for the corresponding marker positions (.07 vs. .06, n.s.).

As predicted, syllabic boundary decisions were facilitated in the context of a single medial consonant, relative to a medial consonant pair occurring early in the word. In addition, only a main effect of word frequency (speed data only) was observed and, contrary to expectations, this variable did not modulate the syllabic structure effect. The absence of an interaction between word frequency and syllabic structure / marker position is incompatible with the notion that low-frequency stimuli were processed via a syllabified code, while high-frequency stimuli were processed via a whole-word orthographic code. Instead, this finding suggests that a common mechanism underlies the processing of both types of stimuli in the SBV task. At this point, the pattern of results is compatible with three possible scenarios: (1) scenario one - letter strings are processed holistically, which implies access to lexical entries (i.e., a word-frequency effect is to be expected but not a serial-processing effect, based on Coltheart, 1978); (2) scenario two - letter strings are parsed, from left-to-right, up to the first syllabic boundary and the word-initial syllable serves as a retrieval cue for a word's lexical representation (i.e., syllable-as-access-code hypothesis); and (3) scenario three – a serial-based segmentation mechanism operates over entire letter strings and a syllabified code is used to retrieve the lexical representation of corresponding words (i.e., syllabic mediation hypothesis). Lastly, the pattern of responses in the hyphenation and syllabification tasks was highly similar, which suggests the use of a common parsing mechanism in both conditions. Thus, instruction type was not manipulated in subsequent experiments.

Non-syllabic Segmentation. The ANOVA on response times (Figure 4: panels A and B) revealed significant main effects of the combined syllabic structure / marker position variable and word-frequency, as well as, a higher-order interaction involving all three variables. As in the syllabic segmentation data, the main effect of instruction type was not significant. Response times were significantly lower for high- than low-frequency words (915 vs. 930 ms) in the analysis by subjects only, $F_s(1,46) = 4.75$, $MSe = 4344$. Post-hoc analyses revealed that response times decreased significantly, from the first to the second marker position, both for stimuli with a C or CC structure (1012 vs. 817 ms and 1025 vs. 835 ms, respectively), $F_s(3,138) = 55.57$, $MSe = 21546$, $F_{i1}(1,140) = 4.86$, $MSe = 10362$, $F_{i2}(1,142) = 688.81$, $MSe = 7770$, and no significant differences were observed between each type of stimuli in either marker position. The 3-way interaction was significant in the analysis by subjects only, $F_s(3,138) = 3.95$, $MSe = 2586$. Although the pattern of responses was similar in both conditions, response latencies were highest in the first marker position for the syllabification condition, compared to the hyphenation condition in both the first or second marker positions, barring two exceptions (i.e., no significant difference observed between low-frequency stimuli with a CC structure in the hyphenation condition and high-frequency stimuli with a C structure in the syllabification condition, with respect to the first marker position; and a significant difference was observed between low-frequency stimuli with a CC structure in the syllabification condition and high-frequency stimuli with a C structure in the hyphenation condition).

The ANOVA on error proportions (Figure 4: panels C and D) revealed one significant main effect for the combined syllabic structure / marker position variable $F_s(3, 138) = 19.06$, $MSe = .0308$, $F_{i1}(1,140) = 8.14$, $MSe = .01788$, $F_{i2}(1,142) = 96.84$, $MSe = .0019$. A post-hoc analysis revealed a significant increase in response accuracy, from the first to the second marker position, for stimuli with either a C or CC structure (.07 vs. .04 and .05 vs. .03, respectively).

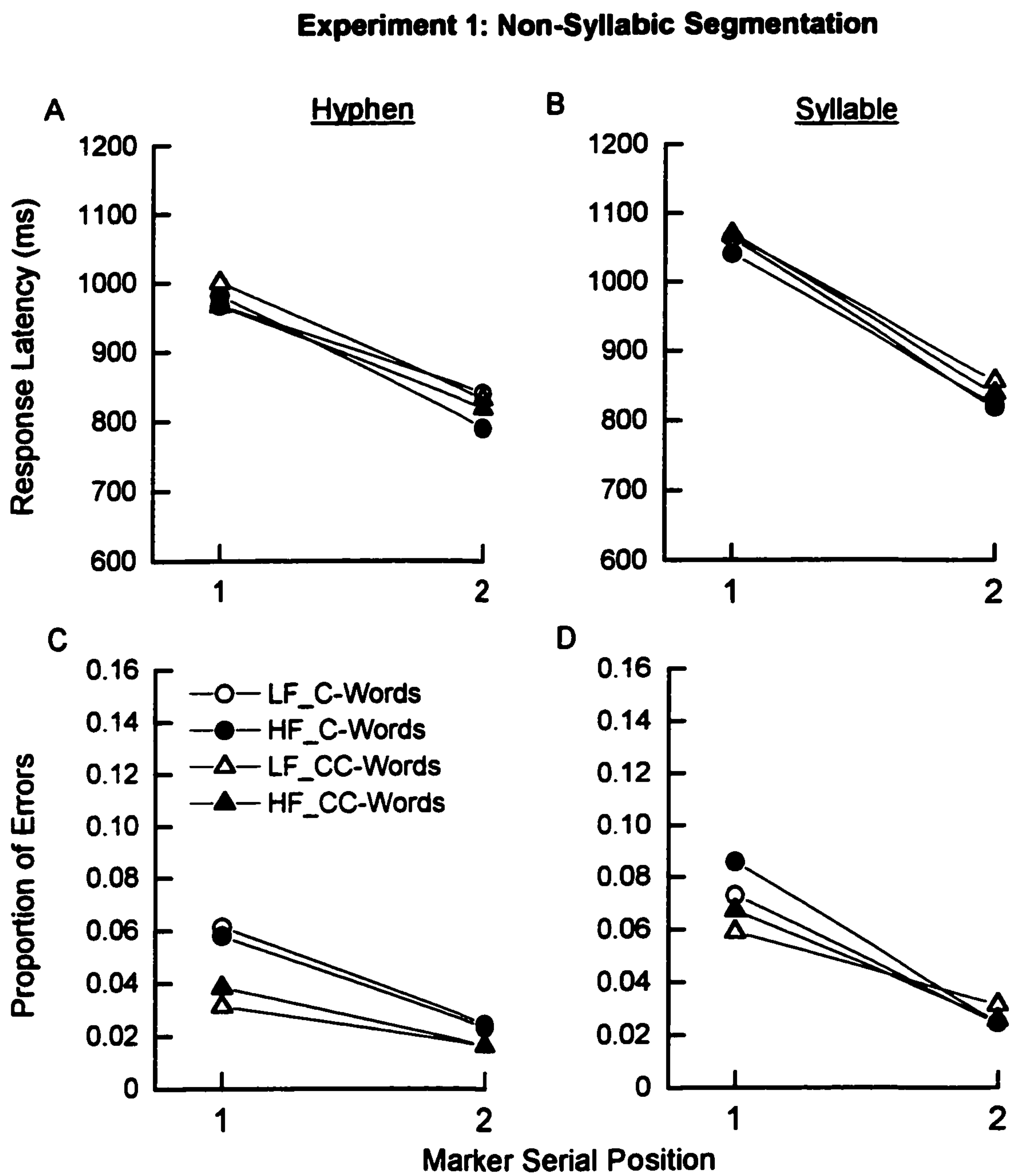

Figure 4. Response latency and proportion of errors in non-syllabic segmentation, as a function of marker position, syllabic structure, and word frequency, for hyphenation and syllabification instructions.

Moreover, response accuracy differed for both types of stimuli in the first marker position only (i.e., less errors for stimuli with a CC than C structure: difference of .02).

For non-syllabic segmentation, marker position was the main variable operating on performance. Responses were slower and less accurate in the first than second marker position. This finding markedly contrasts the pattern which can be anticipated from a left-to-right serial processing strategy (i.e., increase in response times and error proportions towards the end of words). However, this discrepancy may be merely apparent and can be explained on the basis of a task-specific strategy that may have emerged as a result of the consistent pairing between a negative response and the word-final marker placement (e.g., 'décid/é' = 'No' response). More specifically, participants appear to have been biased towards an automatic 'No' response when only one letter appeared after the marker, thus leading to an increase in response speed and accuracy. Other variables only had moderate effects on response times in the subjects analysis (i.e., a small but significant effect of word frequency and a 3-way syllabic structure / marker position X word frequency X instruction type interaction).

Taken together the findings of the first experiment provide support for the importance of syllabic structure in the discrimination of syllabic boundaries in print and for syllabic mediation in VWR. The goal of Experiment 2 was to extend the location-specific effect of syllabic structure to the second marker position, using two types of stimuli that contrasted C and CC structures later in the word (e.g., CV.CV.CV vs. CV.CVC.CV). This manipulation effectively tests the syllable-as-access-code hypothesis. According to Taft (1979), the search for an access code proceeds via a reiterative left-to-right mechanism, that operates up to the location of the first syllabic boundary. Should this hypothesis hold true, in the case of the SBV task, response times and error proportions should not differ between stimuli with a C or CC structure that occurs later in the letter string. Alternatively, lexical retrieval may operate via a fully syllabified representation of the letter string (i.e., syllabic mediation hypothesis), in which case, a location-specific effect of syllabic structure is to be expected at the critical marker position (i.e., late in the word).

Experiment 2

Method

Participants. The participants were 24 undergraduates (19 women and 5 men; mean age = 21) from the University of Ottawa, with similar characteristics as the sample in Experiment 1.

Materials and Equipment. The materials and equipment were similar to Experiment 1, except for the location of a CC structure at the boundary between the second and third syllables, instead of the boundary between the first and second syllable. The list of stimuli included 124 trisyllabic French words in a 2 X 2 design, with word frequency (high vs. low) and syllabic structure (single medial consonant: CV.CV.CV vs. medial consonant pair: CV.CVC.CV) as variables, and 31 items in each of the 4 cells of a completely within-subjects design. The word-frequency estimates (Imbs, 1971) of high-frequency items ranged from 4.46 to 153.96 and 3.65 to 203.69 occurrences per million, for stimuli with a C (M = 25.57, SD = 32.41) or CC (M = 25.56, SD = 40.29) structure, respectively. The word-frequency estimates of low-frequency items ranged from .25 to 3.48 and .38 to 2.68 occurrences per million, for stimuli with a C (M = 1.33, SD = .98) or CC (M = 1.22, SD = .66) structure, respectively. For syllabic (i.e., positions 1 and 3) and non-syllabic segmentation (i.e., positions 2 and 4), the corresponding marker positions were: $CV_1.C_2V_3.C_4V$, for stimuli with a C structure, and $CV_1.C_2VC_3.C_4V$, for stimuli with a CC structure.

Procedure. The procedure was identical to that of the syllabification condition in Experiment 1.

Results and Discussion

The analysis by subjects was a completely within-subjects design. In the analysis by items, marker position was included as a within-items variable, while syllabic structure and word frequency were manipulated between-items.

Syllabic Segmentation. The ANOVA on response times (Figure 5: panel A) revealed significant main effects of the combined syllabic structure / marker position variable and word frequency. Overall, response times were faster for syllabic boundary decisions involving a C than CC structure (695 vs. 880 ms), $F_s(3, 69) = 33.49$, $MSe = 19593$, $F_{i1}(1,120) = 25.76$, $MSe = 3138$, $F_{i2}(1,122) = 281.51$, $MSe = 4984$, and for high- than low-frequency stimuli in the subjects analysis only (779 vs. 796 ms), $F_s(1,23) = 6.14$, $MSe = 2242$. A post-hoc analysis revealed a location-specific effect of syllabic structure in the critical marker position (i.e., 116 ms RT-advantage for stimuli with a C than CC structure in the second marker position; first position: 2 ms, n.s.). In addition, both types of stimuli showed a significant increase in response times from the first to the second marker position (696 vs. 822 ms and 694 vs. 938 ms, respectively).

The ANOVA on error proportions (Figure 5: panel C) revealed significant main effects for the combined syllabic structure / marker position variable and word frequency, as well as, a 2-way interaction between these variables. Overall, response accuracy was greater for stimuli with a C than CC structure (.01 vs. .10), $F_s(3,69) = 11.43$, $MSe = .0127$, $F_{i1}(1,118) = 20.42$, $MSe = .0015$, $F_{i2}(1,120) = 132.61$, $MSe = .0033$, and for high- than low-frequency stimuli (.05 vs. .07), $F_s(1,23) = 8.07$, $MSe = .0013$, $F_{i1}(1,118) = 4.63$, $MSe = .0015$, $F_{i2}(1,120) = 4.30$, $MSe = .0037$. Post-hoc analyses revealed a location-specific effect of syllabic structure in the critical marker position (i.e., .06 error-advantage for stimuli with a C than CC structure in the second marker position; position 1: .01, n.s.). Furthermore, response accuracy was significantly greater, in the first than second marker position, for stimuli with a CC structure (.02 vs. .13 ms), while stimuli with a C structure showed a corresponding non-significant trend in the same direction (.01 vs. .07 ms). In terms of the interaction, subsequent analyses revealed that responses to high- and low-frequency stimuli with a CC structure differed significantly in the second marker position (i.e., .11 vs. .15, respectively).

The key finding in Experiment 2 was a replication of the location-specific effect of syllabic structure in the critical marker position (i.e., late in the word). This finding considerably weakens the syllable-as-access-code hypothesis, which assigns a functional role to the word-initial syllable in VWR. By this view, performance should not have been influenced by syllabic patterns contrasted late in the word. In addition, a main effect of word frequency was observed in the speed (subjects analysis only) and error (subjects and items analyses) data, as well as, an

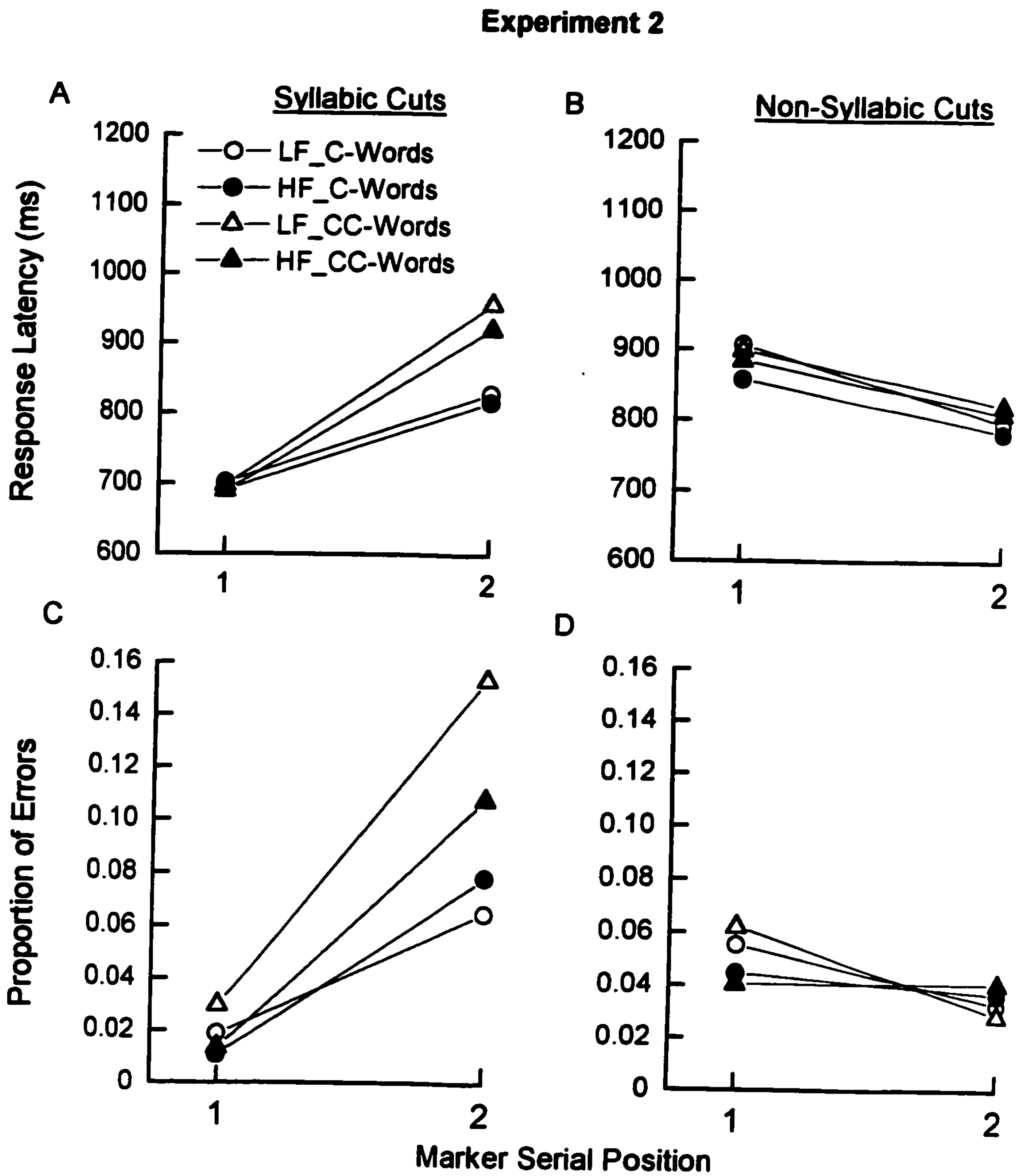

Figure 5. Response latency and proportion of errors as a function of marker position, syllabic structure, and word frequency, for syllabic and non-syllabic segmentation responses.

interaction between syllabic structure / marker position and word frequency (error data only). However, the pattern of results for the interaction was not compatible with the notion of separate mechanisms for the processing of high- and low-frequency stimuli (i.e., holistic vs. serial processing, respectively), since both types of stimuli shared a similar overall pattern. More importantly, from a dual-route perspective (i.e., Coltheart, 1978), the simultaneous observation of serial processing and word-frequency effects creates an apparent paradox. In this model, the lexical (whole-word code) and non-lexical (GPC) mechanisms compete to produce an output and a word-frequency effect is only expected when the lexical mechanism prevails. Therefore, the presence of a word-frequency effect in the SBV task carries with it the implication that the syllabic structure effect was lexically derived, whereas the evidence of serial processing implies the use of assembled phonology. However, this is not the only way to frame the problem. We shall elaborate on other possibilities in the general discussion, once the robustness of the serial-processing effect has been investigated in Experiment 3.

Non-syllabic Segmentation. The ANOVA on response times (Figure 5: panel B) revealed a significant main effect for the combined syllabic structure / marker position variable, $F_s(3,69) = 6.18$, $MSe = 19767$, $F_{i2}(1,122) = 114.41$, $MSe = 2355$. A post-hoc analysis revealed a significant decrease in response times, from the first to the second marker position, for stimuli with either a C or CC structure (881 vs. 788 ms and 891 vs. 814 ms, respectively). No significant differences were observed between types of stimuli at either marker location. The error data (Figure 5: panel D) did not reveal any significant effects from the first to the second marker position, for stimuli with either a C or CC structure. As in Experiment 1, the apparent contradiction between the pattern of results anticipated from a left-to-right serial processing mechanism and the observed pattern of results may be attributed to a task-specific strategy.

The goal of Experiment 3 was to determine whether or not the elevation in response times, observed in the syllabic segmentation data, was due to the effect of a left-to-right serial-based processing mechanism or, alternatively, to the presence of a mute-e in the final phoneme position (e.g., 'caba/n(e)' [shack]). A post-hoc examination of each list of stimuli in the first two experiments revealed a disproportionately high ratio of stimuli ending in a mute-e versus a voiced phoneme (i.e., ratios of 5 : 1 and 6 : 1 for Experiments 1 and 2, respectively). Previous research on memory processes in reading (i.e., Peretz et al., 1998) suggests that native speakers of French process visual stimuli using a phonological code. To explain briefly, Peretz et al. (1998) developed a stem completion task in which participants were asked to memorize a list of written words that contained a mute-e, such as 'cal(e)pin' [notebook]; afterwards, they were presented with either a CV or CVC stem to perform a cued-recall task of stimuli from the original list. The results showed that mute-e words were more often elicited by a CVC stem that matched the phonological-first syllable in a word (CVC.CV) than a CV stem that matched a word-initial orthographic syllable (CV.CV.CV). Although the possibility exists that the use of a phonological code in this task was linked to the oral response modality, the authors interpreted these results as support for the syllabified code hypothesis (i.e., syllabic mediation hypothesis). Returning to the SBV task, the crucial point is that orthographic and phonological parsing strategies may conflict during the processing of stimuli ending in a mute-e; this would lead to an increase in response times and possibly error proportions, for stimuli ending in a mute-e than voiced phoneme. Alternatively, if the elevation in response times is due to a serial-based (left-to-right) processing mechanism, then the pattern of responses for stimuli ending in a mute-e or voiced phoneme are not expected to differ significantly in the syllabic segmentation data.

Experiment 3

Method

Participants. The participants were 24 undergraduates (20 women and 4 men; mean age = 26), from the University of Ottawa, with similar characteristics as those in Experiments 1 and 2.

Materials and Equipment. The materials and equipment were similar to those in Experiment 1, except for the final phoneme manipulation. A total of 144 trisyllabic French words were included in a 2 X 2 X 2 within-subjects design, with word frequency (high vs. low), syllabic structure (CV.CV.CV. vs. CVC.CV.CV), and final phoneme (mute-e vs. voiced phoneme) as variables, and 18 items in each of the six cells of a completely within-subjects design. Due to constraints imposed on stimulus selection, half of the stimuli in the voiced phoneme condition had a 1 : 1 letter-to-phoneme association in the final vocalic position (e.g., 'cultivé' [cultivated]), whereas the other half had a corresponding 2 : 1 association (e.g., 'mesurer' [to measure]; note that the common vocalic cluster 'er' was used for consistency). The word-frequency estimates (Imbs, 1971) of high-frequency items ending with a mute-e ranged from 10.04 to 76.53 and 4.46 to 64.02 occurrences per million, for stimuli with a C ($M = 25.78$, $SD = 18.28$) or CC ($M = 25.81$, $SD = 18.72$) structure, respectively; for items ending in a voiced phoneme these estimates ranged from 6.16 to 78.79 and 4.80 to 84.36, for stimuli with a C ($M = 25.80$, $SD = 19.11$) or CC ($M = 25.81$, $SD = 19.64$) structure, respectively. The word-frequency estimates of low-frequency items ending in a mute-e ranged from .38 to 2.68 and .63 to 2.89 occurrences per million, for stimuli with a C ($M = 1.48$, $SD = 1.48$) or CC ($M = 1.49$, $SD = .65$) structure, respectively; for items ending in a voiced phoneme these estimates ranged from .12 to 2.97 and .51 to 2.76, for stimuli with a C ($M = 1.48$, $SD = .78$) or CC ($M = 1.50$, $SD = .65$) structure, respectively.

Procedure. The procedure was identical to that of Experiment 2.

Results and Discussion

In the analysis by subjects, syllabic structure, marker position, word frequency, and final phoneme were treated within-subjects, whereas in the analysis by items, marker position was treated within-items, while the remaining variables were treated between-items.

Syllabic Segmentation. The ANOVA on response times (Figure 6: panels A and B) replicated both main effects of the combined syllabic structure / marker position variable and word frequency found in Experiment 1. In addition, these variables were involved in a 2-way interaction. Most importantly, the final phoneme manipulation did not have a significant effect on response latency. Overall, response times were faster for stimuli with a C than CC structure (883 vs. 1064 ms), $F_s(3,69) = 11.75$, $MSe = 122109$, $F_{i1}(1,136) = 131.30$, $MSe = 8976$, $F_{i2}(1,140) = 11.52$, $MSe=13578$, and for high-frequency than low-frequency stimuli (957 vs. 991 ms), $F_s(1,23) = 7.65$, $MSe = 14041$, $F_{i1}(1,136) = 4.49$, $MSe=8976$. A post-hoc analysis revealed

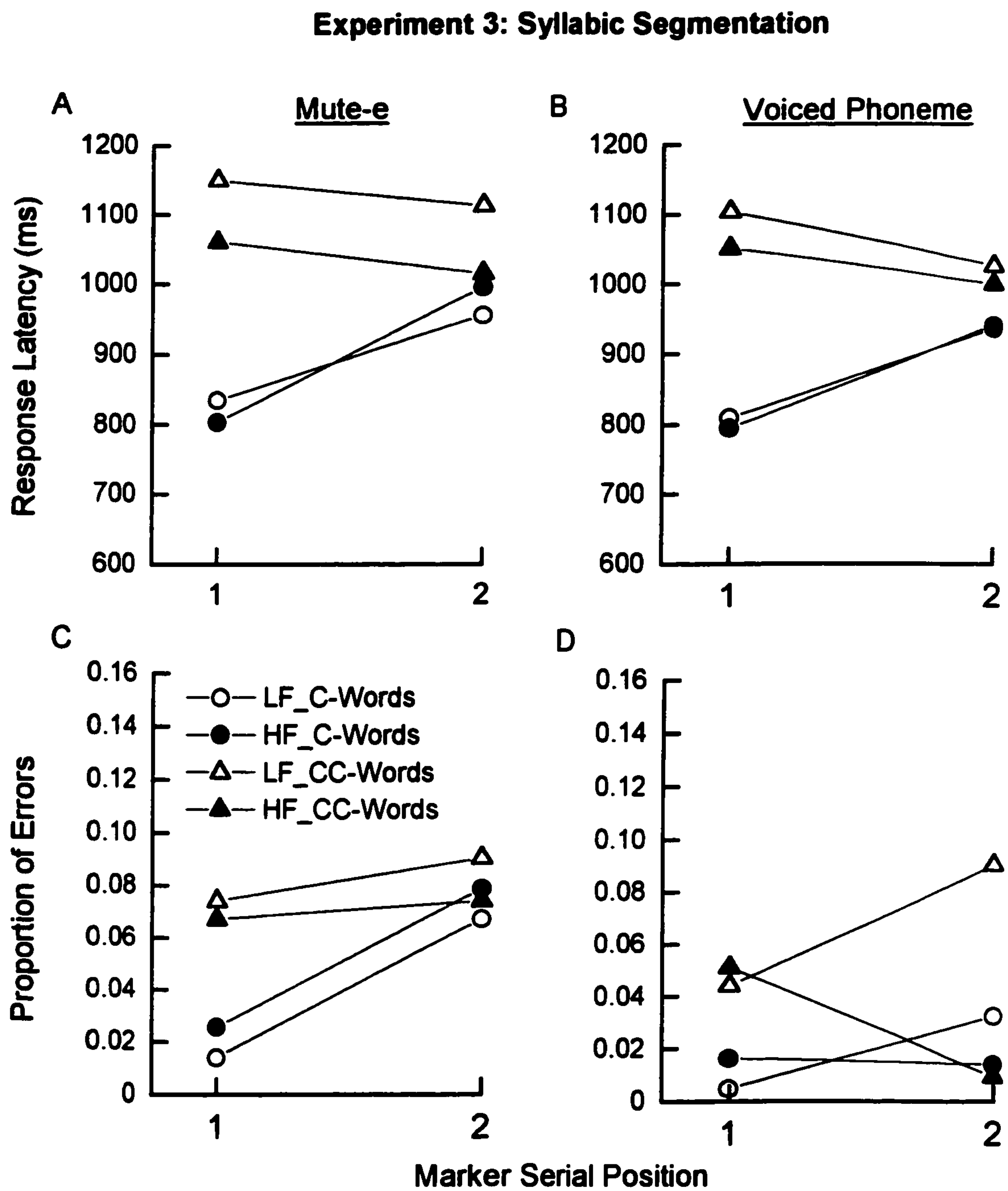

Figure 6. Response latency and proportion of errors in syllabic segmentation, as a function of marker position, syllabic structure, and word frequency, for stimuli in the mute-e and voiced phoneme conditions.

a location-specific effect of syllabic structure in the critical marker position (i.e., 281 ms RT-advantage for stimuli with a C than CC structure in the first marker position; second position: 81 ms, n.s.). Moreover, the typical rise in response times, from the first to the second marker position, was observed for stimuli with a C structure (810 vs. 957 ms), while the corresponding descending trend observed for stimuli with a CC structure did not reach significance (1091 vs. 1038 ms). In terms of the interaction, $F_s(3,69) = 4.73$, $MSe = 9136$, $F_{i1}(1,136) = 4.35$, $MSe = 8976$, response times differed for low- and high-frequency stimuli with a CC structure in both marker positions (1126 vs. 1055 ms and 1068 vs. 1007 ms, respectively), but did not differ significantly for stimuli with a C structure.

The ANOVA on error proportions (Figure 6: panels C and D) revealed a similar pattern of results as the speed data. Both main effects and the interaction were replicated for the combined syllabic structure / marker position variable and word frequency. In addition, significant 2-way, mute-e X word frequency interaction, and 3-way, mute-e X word frequency X syllabic structure / marker position interaction, were observed. Overall, response accuracy was greater for stimuli with a C than CC structure (.03 vs. .06), $F_s(3,69)=3.31$, $MSe=.0163$, $F_{i1}(1,136)=9.20$, $MSe=.0048$, $F_{i2}(1,140)=4.19$, $MSe=.0098$, and for high-frequency than low-frequency stimuli in the analysis by subjects only (.04 vs. .05), $F_s(1,23)=7.30$, $MSe=.0014$. Post-hoc analyses revealed no significant differences between stimuli with a C or CC structure, in either marker position and, despite a visible trend in this direction, the decrease in response accuracy, from the first to second marker position, was not significant for both types of stimuli. In terms of the 2-way mute-e X word frequency interaction, subsequent analyses showed a significantly greater response accuracy for low-frequency stimuli in the voiced phoneme condition (.04), compared to either high-frequency or low-frequency stimuli in the mute-e condition (both .06); likewise, responses were most accurate for high-frequency stimuli in the voiced phoneme condition (.02), compared to all other data points. The 3-way interaction was due to a lower response accuracy for stimuli in the mute-e than voiced phoneme condition, in the second marker position (for all data points except low-frequency stimuli with a CC structure).

The location-specific effect of syllabic structure observed in Experiment 1 was replicated in the syllabic segmentation data (speed data only). The main effect of word frequency was also replicated in both the speed (subjects and items analyses) and error (subjects analysis) data;

however, in contrast to Experiment 1, the word-frequency effect was restricted to stimuli with a CC structure. Importantly, the final phoneme manipulation did not have a significant effect on syllabic segmentation, since response times increased, from the first to the second marker position, for stimuli with a C structure in both the mute-e and voiced phoneme conditions. Therefore, we may conclude that the elevation in response times, observed for stimuli with a C structure, was not due to a conflict between orthographic and phonological parsing strategies. This outcome strengthens the claim for a serial-based mechanism that operates, from left-to-right, over letter strings.

Non-syllabic Segmentation. The ANOVA on response times (Figure 7: panels A and B) revealed significant main effects for the combined syllabic structure / marker position variable, word frequency, and final phoneme, as well as, a 2-way final phoneme X syllabic structure / marker position interaction. Overall, response times were significantly lower for: stimuli with a C than CC structure (1000 vs. 1039 ms), $F_s(3,69) = 6.27$, $MSe = 36438$, $F_{i1}(1,136) = 9.21$, $MSe = 5931$, $F_{i2}(1,140) = 32.25$, $MSe = 11813$; high- than low-frequency stimuli (997 vs. 1041 ms), $F_s(1,23) = 14.62$, $MSe = 12676$, $F_{i1}(1,136) = 11.71$, $MSe = 5931$, $F_{i2}(1,140) = 11.12$, $MSe = 12500$; and stimuli ending in a mute-e than voiced phoneme (989 vs. 1050 ms), $F_s(1,23) = 13.40$, $MSe = 27061$, $F_{i1}(1,136) = 22.93$, $MSe = 5931$, $F_{i2}(1,140) = 21.76$, $MSe = 12500$.
Post-hoc analyses revealed a significant decrease in response times, from the first to the second marker position, for stimuli with a CC structure only (1084 vs. 993 ms; stimuli with a C structure: 1027 vs. 973 ms, n.s.). In terms of the 2-way interaction, $F_s(3,69) = 15.58$, $MSe = 17255$, $F_{i2}(1,140) = 49.38$, $MSe = 11813$, response times associated with the following data points differed significantly from each other: (a) faster response times corresponding to the second marker position of stimuli with a C or CC structure from the mute-e condition, compared to all data points in the voiced phoneme condition; (b) slower response times for stimuli with a C or CC structure from the mute-e condition in the first than second marker position; and (c) faster response times in the first marker position of stimuli with a C than CC structure from the voiced phoneme condition.

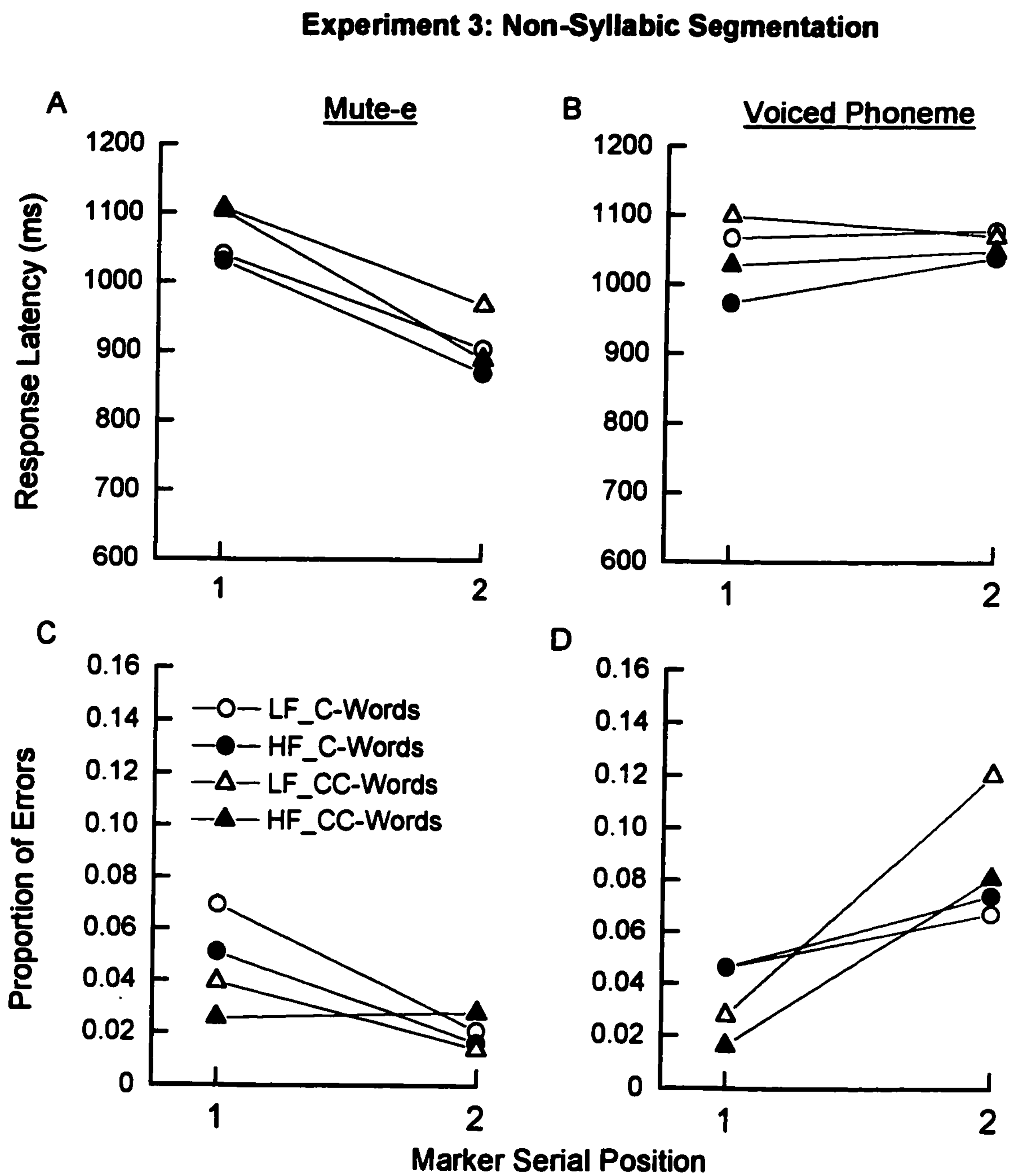

Figure 7. Response latency and proportion of errors in non-syllabic segmentation, as a function of marker position, syllabic structure, and word frequency, for stimuli in the mute-e and voiced phoneme conditions

The ANOVA on error proportions (Figure 7: panels C and D) showed significant main effects of the combined syllabic structure / marker position variable and final phoneme, in addition to a significant 2-way interaction between these variables. Overall, response accuracy was significantly greater for stimuli with a CC than C structure, in the subjects analysis only (.04 vs. .05), $\underline{F}s(3,69) = 4.55$, $\underline{MSe} = .0046$, and for stimuli ending in a mute-e than voiced phoneme (.03 vs. .06), $\underline{F}s(1,23) = 7.52$, $\underline{MSe} = .0097$, $\underline{F}i1(1,136) = 21.62$, $\underline{MSe} = .0261$, $\underline{F}i2(1,140) = 21.29$, $\underline{MSe} = .0024$. Post-hoc analyses revealed a significant decrease in response accuracy, from the first to the second marker position, for stimuli with a CC structure (.03 vs. .06), while stimuli with a C structure showed a non-significant decrease in the opposite direction (.05 vs. .04, n.s.). Furthermore, response accuracy was greater in the first marker position for stimuli with a CC than C structure (.03 vs. .05). In terms of the 2-way interaction, $\underline{F}s(3,69) = 6.27$, $\underline{MSe} = .0086$, $\underline{F}i2(1,140) = 36.31$, $\underline{MSe} = .003$, subsequent analyses revealed that response accuracy differed significantly between stimuli in the voiced phoneme condition that have a CC structure in the second marker position and the following data points: mute-e stimuli with a C or CC structure in the second marker position, mute-e stimuli with a CC structure, and stimuli in the voiced phoneme condition that have a C structure in the first marker position.

The final phoneme manipulation had a significant effect on non-syllabic segmentation. Response times and error proportions increased in the second marker position for the voiced phoneme condition, relative to the mute-e condition. With respect to the mute-e condition, the pattern of results generally conformed to that of Experiment 1 (i.e., increase in speed and accuracy of responses toward the end of words). This outcome fits with the idea that participants decided upon the legitimacy of proposed boundaries by applying the following rule: if the marker immediately precedes the final letter in a word, then the response is negative (e.g., 'décid/é' [decided]). It is easy to see how this strategy becomes counter-productive when there are two letters instead of one appearing after the word-final marker (e.g., 'retir/er' [to withdraw]), thus leading to an increase in response times and errors. Nevertheless, the key finding from the non-syllabic segmentation data was that the pattern of results for stimuli in the mute-e condition essentially mirrored that of Experiment 1.

Conclusion

The present study investigated the role of syllabic structure in the discrimination of syllabic boundaries for printed words and the role of syllables during VWR. In all three experiments, the syllabic segmentation data revealed a location-specific effect of syllabic structure, whereby faster responses and fewer errors were observed for syllabic boundary decisions involving stimuli with a C rather than a CC structure in the critical marker position. This pattern held for syllabic boundaries that occurred early (Experiments 1 and 3) or late (Experiment 2) within trisyllabic letter strings. Moreover, a robust serial-processing effect, which operates from left-to-right in the letter string, was observed on response times for stimuli with a C structure (and for stimuli with a CC structure in Experiment 2). Word frequency also influenced performance, with faster and more accurate responses for high- than low-frequency stimuli (Experiment 1: speed data only). However, contrary to expectations, word frequency did not differentially influence the pattern of responses for stimuli with a C or CC structure. Also, no significant differences were observed between implicit (hyphenation) and explicit syllabification tasks, based on the instruction type manipulation in Experiment 1. For non-syllabic segmentation, the main variable operating on performance was marker position; in contrast to the syllabic segmentation data, response times and error proportions were greater for word-initial than word-final decisions (Experiment 3: mute-e condition only). Lastly, the final phoneme manipulation in Experiment 3 had a significant effect on non-syllabic segmentation; response times and error proportions associated with the second marker position were significantly greater for stimuli in the voiced phoneme than mute-e condition. The implications of these findings are discussed separately below with respect to the issues of syllabic boundary identification and syllabic mediation.

Syllabic structure is a determining factor in both the explicit and implicit identification of syllabic boundaries. In Experiment 1, the type of instructions given to participants differed according to the degree of explicitness in referring to the concept of syllables. The pattern of responses in the hyphenation (implicit syllabification) and syllabification tasks were expected to differ, if the parsing mechanism in the former relied on particular rules that apply uniquely to hyphenation (e.g., choosing not to separate one or two letters from the remainder of the word).

Instead, the decision to divide a word at the end of a line of print was based on the presence of a legitimate syllabic boundary. This outcome does not come as much of a surprise, since the vast majority of hyphenation cuts in French words match syllabic boundaries. Nevertheless, this finding resolves the concern, which arose from a previous study (Treiman and Danis, 1988; written syllabification task), about whether or not the combined effects of task requirements (i.e., hyphenating a word at the end of a line of print) and instructions (i.e., syllabifying words) were responsible for producing the observed pattern of results. This was not the case. Thus, we may conclude that a common parsing mechanism subtends both explicit and implicit syllabification behavior in the SBV task. The implication of these results for written syllabification behavior is that the way in which people apply their knowledge of syllabification in metalinguistic tasks does not vary according to, whether or not, explicit reference is made to the concept of syllables in the instructions.

With respect to the syllabic structure effect itself, the findings of the present study showed that the presence of a medial consonant pair, occurring early or late in the letter string, had measurable effects on decisions concerning the legitimacy of proposed boundaries. In French, the assignment of a single medial consonant to the onset position in stimuli with a C structure is relatively straightforward (given the regularity of the CV-type syllable), in comparison to stimuli with a CC structure. Moreover, the latter may require additional processing time in order to determine, whether or not, such consonant sequences form cohesive units (e.g., rt- in 'par.tage' [share] vs. tr- in 'ma.trice' [matrix]). The stimulus selection criteria were intended to reduce this extra decision time to a minimum, by choosing to include only stimuli with consonant sequences that formed a sonority plateau or reversal. However, before accepting this explanation it is worth exploring some alternative interpretations of the syllabic structure effect (i.e., faster processing times incurred by stimuli with a C than CC structure in critical marker positions).

First, syllabic structure was not the only differentiating feature between stimuli with a C or CC structure; length was also a factor. Therefore, it is possible to argue that processing times were longer for the latter because there was always one additional letter to process than in the former (e.g., 'rep/tile' [reptile] vs. 'ca/bane' [shack]). However, it should be noted that the first syllabic boundary marker was purposefully inserted after the initial syllable for two reasons: (1)

to ensure that the marker's serial position in the letter string was not confounded with the correct response; and (2) to preserve the integrity of the first syllable, in order to properly test the syllable-as-access-code hypothesis. Although length may have had some influence on syllabification decisions, this factor alone cannot account for the data, given the magnitude of the location-specific effect of syllabic structure observed in the syllabic segmentation data (i.e., Experiments 1 to 3: 183 ms, 116 ms, and 281 ms). Moreover, if length was truly a determining factor in the SBV task, one would have expected longer responses for stimuli with a CC than C structure in both marker positions; this was not the case.

A second possible interpretation for the location-specific effect of syllabic structure concerns the salience of a word's orthographic properties during early processing of the letter string. It could be argued that medial consonant pairs created an irregularity in an otherwise recurrent consonant-vowel sequence in the SBV task. To make this argument, we need to posit that the orthographic structure of the stimuli is available in the early stages of perceptual processing (i.e., consonant-vowel discrimination) and then categorized into higher-order units that correspond to the orthographic equivalents of syllables. This proposal resembles the concept of 'reading units' discovered by Prinzmetal et al. (1986; 1991), using an illusory conjunctions task. This type of explanation is not mutually exclusive with the idea that stimuli with a CC structure required extra processing time in order to determine the legality of a proposed syllabic boundary. For instance, readers may first identify vocalic elements in a letter string and then assign consonants to form higher-order units (i.e., syllables), based on the legality principle. However, to give substance to this combined scenario, it is necessary to specify the mechanism by which this structural information is recovered. This point leads us to the second issue of interest, concerning the potential role that syllables play in the process of lexical identification.

The issue of syllabic mediation was initially framed in terms of three models. The first model (i.e., Taft and Forster, 1976), which assigned a special status to word-initial syllables, can be rejected on the grounds that the location-specific effect of syllabic structure was extended to the second marker position in Experiment 2. Likewise, the dual-route model (Coltheart, 1978) cannot provide an adequate account of the data, due to the paradox created by the simultaneous observation of serial-based processing (non-lexical) and a word-frequency effect (lexical). Moreover, a spelling-to-sound strategy, based on grapheme-to-phoneme conversion, does not seem likely in light of the findings in Experiment 3, which support an orthographic parsing strategy. The robustness of the left-to-right serial processing effect was supported by the outcome of the final phoneme manipulation in Experiment 3. Specifically, it was reasoned that syllabic boundaries preceding a mute-e may require extra processing time, if the presence of a silent letter engenders a conflict between orthographic and phonological parsing strategies. However, this was not the case. Although final phoneme did bear an influence over non-syllabic segmentation, this effect can be attributed to a specific task-based strategy (i.e., bias towards 'No' responses in the word-final marker position for non-syllabic segmentation). The third model (Ans et al., 1998), also falls short of providing a compelling account of the data. The foremost appeal of the computational Multiple-Trace model consists of a serial tagging mechanism by which syllabic boundaries are identified, in addition to the fact that it has been tested with polysyllabic French stimuli. However, the processing assumptions of this model are such that holistic processing is the default strategy for any kind of letter string; only after this strategy fails will sequential processing be attempted on a syllable-by-syllable basis. The likelihood that a word will be processed holistically, increases with its lexical frequency. During initial encounters, both word and segment traces are created in episodic memory while the stimuli are read in the analytic mode. Words are read globally after a pre-determined number of encounters. In the present series of experiments, it could be argued that many low-frequency and some high-frequency stimuli may be considered as intermediate frequency items. Stimulus frequencies (which ranged on average from 5.15 to 121.13 and .29 to 3.07 occurrences per million for high- and low-frequency items, respectively) were mostly outside the likely range for analytic processing to occur, even 25% of the time. Therefore, to provide an effective test of the predictions based on the Multiple-Trace model, it would be necessary to adjust the parameters of stimulus selection according to the range of frequencies that correspond to analytic processing (i.e., .04 to 5.36 occurrences per million). Any firm conclusions regarding the ability of this model to explain the syllabic structure effects found in the SBV task cannot be drawn without further experimentation.

A different model, that provides a better fit for the data at present, is a computational model called LEX (i.e., Kwantes and Mewhort, 1999). This model can simulate syllabic effects without the need for positing a level of representation for syllables or spelling-to-sound correspondence rules. In the LEX model, parallel encoding of a letter string creates an orthographic representation of the stimulus which is then subjected to processing via a serial-based mechanism, that enables the retrieval of appropriate lexical entries from the lexicon (i.e., words sharing one or more letters in common with the stimulus). Sampling of the lexicon occurs by iteration, whereby cohorts of lexical candidates are identified and contribute to the formation of a second orthographic representation (i.e., through a blending of traces activated in the lexicon). The probability that a word will be sampled during the retrieval process is proportional to its printed frequency. The end of this process is marked by a lexical check being performed by the system to ensure an exact match between both orthographic representations; typically, this is the point at which a word's phonological representation becomes available, even though it is retrieved in parallel with the orthographic information.

Framing the results of the SBV task using the LEX model, syllabic structure effects emerge as a consequence of the complex pattern of correlations between spelling, pronunciation, and meaning that is stored in the lexicon. Furthermore, because lexical identification per se is assumed to reflect an entirely serial-based process, the simultaneous presence of a word-frequency effect and serial-based processing can be readily explained. In support of their claim against the necessity for a subword level of representation beyond letters and phonemes, Kwantes and Mewhort (1999) showed that LEX could replicate syllabic effects that were observed in a lexical decision study by Taft and Forster (1976), even though this model does not posit a level of representation for syllables. In the original study, native speakers of English categorized nonwords faster when the initial sequence of letters provided an exact match for a syllable-like structure called the Basic Orthographic Syllable Structure or BOSS, presumably because this unit represents an access code. However, Kwantes and Mewhort (1999) argued that LEX could simulate these results, by virtue of the fact that the lexicon contained more words with BOSS- than non-BOSS beginnings.

We may apply a similar logic in the present study, albeit with some degree of caution, given that the LEX model was not developed for the purpose of explaining syllabification behavior, but rather reading aloud (this statement is equally applicable to the other models considered here). More specifically, the syllabic structure effect could be explained based on knowledge of the distributional properties of French. Yet, the claim we make is more farreaching than this, since a regular CV structure occurring at any point in the letter string should lead to faster processing times than a CVC structure. With respect to the mechanism for identifying syllabic boundaries in print, it follows from the LEX model that words with a regular CV structure are more likely to be sampled from the lexicon than those with a less prevalent CVC structure. Thus, when the correct lexical entry has been identified, by reference to its orthographic properties, then the stored syllabification of a word becomes available. In other words, the mechanism for syllabic boundary identification is based on frequency and comes into play at a post-identification stage.

It should be noted that the issues surrounding representation and sensitivity to the lexical properties of words have also been raised by PDP theorists. To reiterate briefly, this theory holds that syllabic boundaries emerge as a consequence of the distribution of letter patterns in a language and simply coincide with a particular pattern called a bigram trough (i.e., lower bigram frequencies between than within syllables). However, the present data do not support the bigram trough hypothesis (Seidenberg, 1987). Table 5 shows the frequencies of (inter-syllabic) bigrams that occur in the first and second syllabic marker positions, as well as, intra-syllabic bigrams (i.e., labeled as 'pre' and 'post'). In all three experiments, post-hoc analyses (i.e., 1-way ANOVA with 3 levels) including stimuli with either a C or CC structure clearly did not exhibit the frequency pattern predicted by the bigram trough hypothesis, in either marker position. In fact, bigram frequencies associated with inter-syllabic boundaries were higher (and in some cases equal) to that of intra-syllabic boundaries.

In comparison to the aforementioned scenario, the case for syllabic mediation is relatively weak. Nevertheless, some evidence can be garnered in support of this view, which presupposes the existence of a level of representation for syllables and places the locus of syllabic structure effects at a retrieval i.e., (pre-identification) stage. The notion of orthographic syllables is congruent with such a view. In the words of Taft (1991; cited in Colé et al., 1999), "Orthographic syllables are hypothetical sublexical orthographic codes acting as an intermediate code between letter representations (or visual features) and whole-word orthographic representations" (p.523). This claim is made possible in light of the fact that word frequency did not differentially influence the processing of stimuli with a C or CC structure in the SBV task. In the visual monitoring study by Colé et al. (1999), the syllabic structure effect was observed for

Table 5

Positional bigram frequencies for syllabic segmentation responses: Post-hoc analyses

Sample Stimuli	Marker Position 1			Marker Position 2		
	Pre	Pos1	Post	Pre	Pos2	Post
Experiment 1						
CVC_1CV_2CV	873	555*	500*	500*	502*	703
CV_1CV_2CV	675	886	526*	526*	689	951
All Stimuli	774	720	513*	513*	596*	827
Experiment 2						
CV_1CVC_2CV	606*	932	1102	626	1021	557*
CV_1CV_2CV	700*	1098	780	780*	780*	1299
All Stimuli	653*	1015	941	703*	901	928
Experiment 3						
CVC_1CV_2Ce	710	610*	641	641*	633*	1270
CV_1CV_2Ce	501	494	356*	356*	1131	1314
Overall Mute-e	605	552	498*	499*	882*	1292
CVC_1CV_2CV	781	216*	278	278*	339*	112
CV_1CV_2CV	1124	404	319*	319	403	99*
Overall Voiced Phoneme	952	310	299*	300	368	105*

* An asterix marks the lowest bigram frequency for each letter pair surrounding a syllabic boundary

low-frequency words only, while high-frequency words were processed holistically. Although we have described the reasons why the locus of the syllabic structure effect is likely to be lexically derived (i.e., main effect of word frequency; orthographic parsing strategy in the third experiment), it is possible that future research may uncover evidence providing stronger support for the syllabic mediation hypothesis. For instance, it is possible that syllabic boundaries are identified at an early processing stage, but that responses are generated only after lexical identification has taken place.

To this end, future studies aimed at targeting the locus of the syllabic structure effect could manipulate response time intervals. In the current study participants were simply encouraged to respond as quickly and accurately as possible. Although there was no evidence of a speed-accuracy trade-off, the average response times were quite long (i.e., close to 1000 ms). If response times were shortened, this would force participants to provide a judgement based on a partial analysis of the letter string. Another fruitful approach would be to contrast responses to pseudowords and their real word counterparts. In the former case, no word- frequency effect would be anticipated since pseudowords, by definition, have no representation in the lexicon. Thus, syllabic boundary decisions would have to be based entirely on non-lexical knowledge (e.g., phonotactic rules, syllabification rules, spelling-to-sound conversion rules). In sum, it would be useful to determine, whether or not, the syllabic structure effect remains when response deadline is manipulated or pseudowords are used as stimuli in the SBV task.

We have presented an account of how the mechanism underlying syllabic boundary identification could operate in the SBV task with respect to two key issues, set forth at the outset of this study. First, the structural properties of words influence syllabic boundary decisions, whereby extra processing time is required to determine the legality of medial consonant pairs, relative to single medial consonants. Second, the notion of syllables-as-access-codes in French was not supported in the context of the SBV task. The present findings can be adequately interpreted in the absence of a theory on syllables. However, we wish to express a more cautious view regarding the possibility of syllabic mediation in French, given the wealth of research that converges on the notion of syllables as functional units in reading. On this final note, additional research is needed to address issues raised in the context of the SBV task.

Chapter 4

General Discussion

This program of research sought an answer to the following question: What is the nature of the mechanism underlying French readers' ability to identify syllabic boundaries in print? Two complementary approaches were taken to shed some light on this problem: first, we examined how the structural properties of syllables influence syllabification decisions; and second, we explored the relationship between syllabic structure and the issue of syllabic mediation in VWR. In the first study, the realm of all possible environments in which syllabic boundaries can be identified was mapped out for any given letter string. This framework enabled the collection of valuable data on the probability of segmentation, across various types of syllabic environments. In the second study, stimuli with specific syllabic patterns were contrasted in an on-line metalinguistic task (i.e., syllable boundary verification task or SBV). A summary of the findings for each study will first be presented and interpreted in the context of past literature, followed by an account of the implications of these findings, and finally, a brief discussion concerning the limitations and possible future directions of this research.

Study 1

Overview of the Results

In the first study, five sets of hypotheses were derived from the main categories of segmentation outlined in the framework: (1) mandatory, (2) illegitimate, (3) optional, (4) ambiguous, and (5) letter cluster. A primary distinction between mandatory and illegitimate segmentation was drawn, based on the notion that parsing between syllables represents a correct response, whereas parsing within a syllable is incorrect. A secondary distinction was made between optional and ambiguous segmentation, in order to contrast syllabification rules of a categorical or probabilistic nature with those that are either arbitrary or unspecified, respectively. A general hypothesis predicted that the expected probability of segmentation should be near chance-level, if skilled readers of French remained collectively ambivalent towards syllabification in various types of optional and ambiguous environments and failed to differentiate among these. A secondary set of hypotheses, conditional upon the rejection of the ambivalence / non-differentiation hypothesis, was devised for optional and ambiguous segmentation. Lastly, with respect to letter cluster segmentation (i.e., non-syllabic errors), no parsing was expected within these cohesive letter groups (i.e., oral vowel, nasal vowel, consonant cluster, and semivowel).

Ten key findings emerged from the first study. First, lexicality was not a determining factor in the written syllabification task, since the pattern of segmentation for word and pseudoword stimuli was virtually identical. Second, the level of accuracy for mandatory segmentation was less than expected and varied significantly among the three types of syllabic environments (i.e., nucleus-coda, nucleus-nucleus, and coda-onset). Third, the level of accuracy for illegitimate segmentation differed somewhat from expectations and varied significantly (although within a very small interval) between both types of syllabic environments (i.e., onset-nucleus and nucleus-coda). Fourth, with respect to optional and ambiguous segmentation, the findings did not generally support the hypothesis of ambivalence / non-differentiation, although finer-grained hypotheses were supported. Fifth, the principle of free variation modulated the pattern of responses for optional segmentation within a semivowel environment. Six, onset complexity and sonority influenced the optional pattern of segmentation in a mute-e environment; parsing tended to be omitted at syllabic boundaries preceding a mute-e, when this segment followed a single rather than a complex onset (e.g., 'grou-p(e)ment' vs. 'encom-br(e)ment'), as well as, when the left-boundary element was high rather than low in sonority (e.g., 'grou-p(e)ment' vs. 'occul-t(e)'). Seven, geminate consonants were typically divided regardless of, whether or not, they belonged to a semivowel. Eight, contrary to expectations, the syllabification of s-clusters did not reflect an entirely arbitrary process, since the sonority of a segment preceding the 's' had an influence over syllabification; although, onset complexity appeared to have little effect. Nine, sensitivity to the underlying structure of the language was apparent for ambiguous segmentation in an aspirated-h environment; this segment was invariably parsed with the onset in two types of syllabic environments (i.e., nucleus-h and h-nucleus). Ten, there was a general tendency to avoid segmentation within all types of cohesive letter clusters (i.e., oral vowel, nasal vowel, semivowel and consonant groups).

Discussion of the Findings

These findings enrich our understanding of the process underlying written syllabification behavior on many levels. At a high level, the present findings strongly suggest a common process underlying the syllabification of word and pseudoword stimuli. More specifically, both orthographic and phonological factors had an influence over written syllabification, although the relative importance of each is somewhat difficult to gauge in this untimed task. In Experiments 1 and 2, spelling-to-sound translation was the most frequently reported syllabification strategy (i.e., cited by over three quarters of participants in each sample). Spelling was another major determinant of syllabification; almost one quarter of participants from each sample cited a rule for dividing geminate consonants, which corroborated the finding from the written syllabification task, where geminates were separated in the majority of cases. With these simple heuristics in mind, participants were able to syllabify any type of letter string; although, confidence ratings were slightly greater for real word than pseudoword stimuli.

With respect to mandatory segmentation, the findings revealed that even skilled readers will omit parsing approximately one out of ten times (i.e., Experiments 1 and 2: M=.88 and .87). More importantly, the variable probability of segmentation, associated with different types of syllabic environments, raises a number of questions. First, what makes the coda-onset environment a more likely candidate for segmentation, than either a nucleus-nucleus or nucleus-onset environment? Second, what are the implications of these findings for written language processing? A coda-onset environment represents a syllabic boundary within a medial consonant sequence. In order to apply the graphemic parsing rules of French (Grévisse, 1964), a reader would first have to assess the cohesiveness of medial consonants. The cohesiveness of a medial pair could be assessed in terms of: (a) whether it forms a legal sequence in syllable-initial or syllable-final positions (legality principle), and / or (b) the relative sonority of its segments (sonority principle).

As for the lower probabilities of segmentation associated with the two remaining syllabic environments, one could argue that syllabification decisions should be easiest for a nucleus-onset environment, due to the regularity of syllabic structure in French (i.e., CV structure predominantly; Valdman, 1976). However, characterizing this type of syllabic environment in terms of a simple vowel-consonant sequence is misleading, because it overshadows the potential effects of onset complexity (e.g., 'toni-truant' [resounding]) or of particular types of segments that may be harder to syllabify than others (e.g., semivowels 'pi-ller' [to loot]). Moreover, it could also be argued that the most difficult environment to syllabify should be nucleus-nucleus, because of the reduced sonority differential between boundary elements, compared to those in a nucleus-onset environment (and in some coda-onset environments). Nevertheless, although a sonority gradient may help to discriminate the boundary between syllables, it is not the sole determinant of syllabification.

The observation that various types of syllabic environments, requiring mandatory segmentation, lead to different probabilities of segmentation, has potential implications for written language processing. It suggests that not all spelling patterns (either consonant or vowel sequences) are discriminated equally well, even though they are over-learned by skilled readers. In particular, the Multiple-Trace model (i.e., Ans et al., 1998) assumes that an alignment mechanism targets the initial vocalic sequence (e.g., eau, ain, en) in a letter string, a process that is said to "take place after early perceptual analysis at a stage at which graphemic units can be extracted" (p.683). This assumption implies that cohesive vocalic clusters can be discriminated from vowel sequences that contain adjacent nuclei belonging to separate syllables ('ch<u>au</u>-dron' [cauldron] vs. 'm<u>é-an</u>dre' [meander]). The model, however, does not make any specific claims pertaining to the discrimination of consonant sequences. This may be acceptable when the stimulus is encoded as a whole, however during analytic processing, the discrimination of cohesive and non-cohesive medial consonant sequences is essential. Otherwise, the segmentation mechanism will fail to correctly identify the location of the first syllabic boundary. At this point, the present findings suggest that various types of medial consonant sequences, present at syllabic boundaries, may lead to response time differences in a VWR task.

For illegitimate segmentation, the data indicated a significant difference in the probability of segmentation for nucleus-coda and onset-nucleus environments, although the overall proportion of cuts was fairly low in each experiment (i.e., Experiments 1 and 2: range of .01 to .03 and .01 to .02, respectively). At the risk of over-interpreting these results, one could explain the findings on the basis of the onset-rime view and the notion of phonotactic constraints within the rime. A study by Kessler and Treiman (1997) found that probabilistic constraints governed the combination of vowel-consonant sequences (i.e., rime) in English monosyllables, whereas the combination of onset-vowel sequences (i.e., body) was statistically random. The present findings obtained with French polysyllabic stimuli are compatible with this explanation. In the context of a syllabification task, parsing may be less likely at the onset-rime boundary than at any point within the rime, because segments bear less affinity to each other in the former than the latter (i.e., at least compared to rime constituents that have a high frequency of co-occurrence). Another possible interpretation of these results is based on the bigram trough hypothesis (Seidenberg, 1987). Although bigram frequencies were not taken into account in this study, they may have been a contributing factor in the written syllabification task. Typically, this factor alone would not be sufficient to account for syllabic effects. Given that the magnitude of the effect was relatively small in the illegitimate segmentation data, no attempt was made to determine the degree to which syllabic structure effects could be attributed to the bigram trough hypothesis over and above the explanation based on the onset-rime view.

The pattern of responses for optional segmentation in different types of syllabic environments (i.e., semivowel, mute-e, and geminate consonants) suggests that participants applied syllabification principles based on a phonological representation of the letter strings. The probability of segmentation in a semivowel-nucleus environment was close to .50; this suggests that the principle of free variation was operating on the letter string (i.e., phonetic alternation between semivowels and their corresponding high vowels, without resulting in a change in meaning).

Likewise, the probability of voicing a mute-e is tied to the speech code. According to Valdman (1976): the fewer the consonants preceding a mute-e, the greater the likelihood that this segment will not be realized in speech. By extension, for the syllabification of printed stimuli, the syllabic boundary preceding a mute-e becomes optional as well (e.g., 'grou-p(e)ment' [grouping]). Similar findings were obtained by Peretz et al. (1998) using a different methodology. The results from their stem completion task revealed that mute-e words (memorized during a training phase) were more often elicited by CVC than CV stems (e.g., 'cal-(e)pin' [notebook]), suggesting that participants relied on a phonological code to parse letter strings. The present findings are significant in that a written syllabification task, which required a manual output rather than an oral response, also suggests the use of a phonological code / parsing strategy. Thus, input and response modalities are not necessarily linked.

In contrast to other types of optional segmentation environments, the pattern of results for the syllabification of geminate consonants suggests the use of a graphemic parsing strategy. Had a phonetic parsing strategy been in effect, geminates should have been parsed with the onset, given their 2 : 1 grapheme-to-phoneme association. The present findings converge with those from an English study on oral and written syllabification (i.e., Treiman and Danis, 1988). In the oral task, geminate consonants were frequently divided (i.e., probability of .45 for words with second-syllable stress in Experiment 1; e.g., 'com-mand', 'comm-and' or 'co-mmand'). In the written task, participants performed near chance-level when instructed to assign geminates to either the onset or coda position (e.g., 'co-mmand' vs. 'comm-and'). Moreover, anecdotal evidence collected during debriefing revealed that participants applied a prescribed rule for the separation of geminates. The explanation of these findings, based on a graphemic parsing strategy, does not necessarily conflict with the previous suggestion from other types of optional environments for a phonological encoding strategy, if it is assumed that a graphemic parsing strategy was triggered by the recognition of a specific spelling pattern (i.e., geminates) during phonological encoding of the letter strings.

For ambiguous segmentation in the context of s-clusters, the present findings go beyond what has been explored in the literature. Past research (e.g., Treiman et al., 1992) has focused on the issue of sonority gradients within s-clusters, solely from the perspective of segments that follow the 's', not those which precede it. The present findings indicate that assignment of 's' to an onset or coda position does not reflect an entirely arbitrary process, as has been suggested by previous research and French syllabification rules (i.e., Grévisse, 1964). Specifically, 's' has a greater propensity to be parsed with the coda than the onset, when the preceding segment is high rather than low in sonority (e.g., 'cris-tal' [crystal] vs. 'ob-stacle' [obstacle]).

The approach taken by Treiman et al. (1992) on the study of s-cluster syllabification was driven by a different research question: Should s-clusters be viewed as true onsets? In order to test this hypothesis, three types of nonwords were presented in a written syllabification task: (a) s + stop (e.g., nus-peem), (b) s + sonorant (e.g., nus-leem), and (c) obstruent + sonorant (e.g., nuf-leem) sequences. The results showed that s-clusters, regardless of their sonority profile, were syllabified differently from non-s-clusters, the latter of which formed a sonority gradient and were most often parsed with the onset. Similar findings arose in the context of an oral syllabification task with real words (i.e., Treiman and Danis, 1988; Treiman and Zukowski; 1990). Thus, Treiman and her collaborators concluded that s-clusters do not form legal onsets.

Although the present findings do not call into question the conclusion reached by Treiman et al. (1992), they do offer a new perspective on the syllabification of s-clusters in print. More specifically, s-cluster syllabification is influenced by the sonority of a segment preceding the 's' and possibly onset complexity as well. However, the present data are insufficient to provide any definitive answers on the latter (i.e., given the low number of corresponding entries). These findings also underscore the importance of comparing theoretically-derived probabilities of segmentation against behavioral data; for s-clusters preceded by a consonant, the observed probability of segmentation was much lower than expected (i.e., .32 vs. .50, respectively). In sum, s-cluster syllabification does not reflect an arbitrary process.

The pattern of responses for ambiguous segmentation in the context of aspirated-h environments showed that skilled readers of French are sensitive to the underlying structure of their native language. This finding is important for two reasons. First, it establishes that the mechanism underlying the segmentation of letter strings does not depend entirely on cues present in the acoustic signal. Instead, it indicates that processing of letter strings occurred at a deeper more abstract phonological level. Second, it establishes a link between segmentation data obtained with isolated words and reading aloud of connected text, since the prediction that aspirated-h should be assigned to the onset was derived from the rules of liaison in French (e.g., 'les_hé-ros' [the heros]). This kind of data is essential for any future research attempting to bridge the gap between theories of phonological encoding in speech (e.g., Levelt, 1989) and VWR theories.

The framework used to analyze responses in this written syllabification task would not be complete without a final piece of evidence, letter cluster segmentation. Generally in line with expectations, the probability of segmentation for all types of letter clusters was fairly close to zero, indicating that skilled readers generally omit parsing within cohesive units. Only minor variations among different types of letter clusters were observed (i.e., semivowels in Experiment 1 and nasal vowels in Experiment 2).

Attempting to fit the findings from this study into an overall theory of syllabification is not an easy task, given that multiple sources of constraint appear to have influenced segmentation decisions. Overall, the results of the written syllabification task strongly suggest that skilled readers of French relied primarily on a pronunciation-based strategy, which was modulated by the use of specific orthographic syllabification rules (i.e., geminate parsing rule). The results also suggest that various types of medial consonant sequences, present at syllabic boundaries, may lead to latency differences in a timed task. However, it does not follow that the (non-lexical) processes involved in an untimed task will necessarily reflect those in a timed task.

Study 2

Overview of the Results

In the second study, a timed SBV task was used to investigate the issues of syllabic boundary identification and, to some extent, the issue of syllabic mediation in VWR. Trisyllabic stimuli, that contained either a single medial consonant or medial consonant pair, were presented in a mixed list with a marker inserted in one of four possible locations within a letter string, to indicate a proposed syllabic boundary (e.g., 'ca/bane', 'cab/ane', 'caba/ne', 'caban/e' [shack]). With respect to the first issue, it was hypothesized based on the regularity of syllabic structure in French (i.e., CV-type; Dauer, 1983), that responses would be faster and more accurate for syllabic boundaries formed by two CV syllables than consecutive CVC and CV syllables (e.g., 'ca/bane' vs. 'rep/tile'). This prediction was confirmed by all three experiments in this series.

Other variables, including marker serial position and word frequency, were added to the mix in order to investigate the second issue. Response times were expected to increase toward the end of words, if processing occurred via a serial-based mechanism operating, from left-to-right, over the entire letter string. The syllabic segmentation data for stimuli with a C structure (and stimuli with a CC structure in Experiment 2) conformed with this view. In addition, the presence of a word-frequency effect (speed data) indicated that lexical identification occurred during the SBV task. Taken together, the main effect of word frequency and the location-specific effect of syllabic structure support the view that lexically-derived phonology (i.e., implying a holistic processing strategy) gave rise to the syllabic structure effect, rather than assembled phonology (i.e., syllabic mediation hypothesis). The syllable-as-access-code hypothesis (e.g., Taft, 1979) was rejected on the basis that a location-specific effect for syllabic structure was extended to stimuli in Experiment 2, which contrasted C and CC structures at the second syllabic boundary.

The robustness of the serial-processing effect was put to the test in Experiment 3 by introducing a manipulation of the final phoneme. Response latencies for mute-e stimuli with a C structure were expected to increase, from left-to-right in the letter string, whereas latencies for these stimuli were not expected to differ across serial positions in the voiced phoneme condition (e.g., 'caba/n(e)' [shack] vs. 'déci/dé' [decided]), if the serial processing effect was in fact due to a conflict between phonological and orthographic parsing strategies. This hypothesis was not supported by the data, since stimuli in both conditions showed the typical rise in response times for stimuli with a C structure in the second marker position. Hence, these results were interpreted as support for a serial-based mechanism. It should be noted that the final phoneme manipulation did have a significant effect on illegitimate segmentation. Specifically, response times and error proportions decreased in word-final marker positions (as they did in Experiment 1) for stimuli in the mute-e condition, but remained equally high across both marker positions for stimuli in the voiced phoneme condition. This outcome was attributed to a task-specific strategy; participants typically parsed stimuli before the last letter, a strategy which could be applied successfully with all but a small subset of stimuli in this task (e.g., 'retir/er' [withdraw]).

Word frequency was predicted to influence syllabification decisions if lexical identification occurred while performing the SBV task. The results of the first study (i.e., untimed syllabification task) clearly showed that syllabic boundary identification need not rely on lexically-derived phonology. However, previous research on syllabic mediation in French has shown that lexical identification occurs very rapidly during the processing of a letter string, resulting in the use of a whole-word (orthographic) code for high-frequency stimuli and a syllabified (phonological) code for processing low-frequency words (i.e., Colé et al., 1999). In keeping with this view, the hypothesis set forth in the present study predicted a differential effect of word frequency on stimuli with a C or CC structure. However, contrary to expectations, the pattern of results was the same for both types of stimuli. This outcome reveals that lexical representations were accessed at some point during the processing of letter strings and that a common mechanism underlies the processing of both high- and low-frequency stimuli in the SBV task. Hence, these findings support the view that the syllabic structure effect was lexically derived and, by the same token, the view that high- and low-frequency stimuli were processed using an orthographic whole-word code.

The first experiment in this series also examined the possible effects of a contextual variable, instruction type. Specifically, two groups of participants received either syllabification or hyphenation instructions to perform the SBV task, in order to determine whether or not a different pattern of segmentation would result (i.e., for the syllabic segmentation data). This was not the case. Therefore, we surmised that a common parsing strategy was used in both the implicit (i.e., hyphenation) and explicit syllabification tasks. Moreover, these findings indicate that implicit syllabification tasks (i.e., in which no direct reference is made to the concept of syllables) lead to similar performance patterns as explicit syllabification tasks, even though the task demands may differ in each (e.g., verifying the location of a hyphen versus a syllabic boundary).

Discussion of the Findings

What do the findings from the SBV task contribute to the literature on VWR and reading? The fundamental issue we wished to address in this research was the nature of the mechanism underlying syllabic boundary identification in French print. This goal differs, in some respects, from the main focus of past research in the area, which has been geared almost exclusively towards investigating the role of word-initial syllables in retrieval processes. Nevertheless, this study was also designed to relate the present work on syllabic structure to the issue of syllabic mediation in French. In this light, the findings from the SBV task extend those of previous research to syllabic structure effects observed during VWR, across different serial positions in a letter string. To reiterate the main finding, a location-specific effect of syllabic structure which was not limited to the word-initial syllable was found in all three experiments.

The location-specific effect of syllabic structure, when interpreted in the context of an independent word-frequency effect, bears directly on the inferences that can be made about the kind of processing that occurred in the SBV task. First, the syllable-as-access-code hypothesis (e.g., Taft, 1979; Taft and Forster, 1976) can be ruled out, due to the results of Experiment 2; a location-specific effect of syllabic structure, observed at the second syllabic boundary (syllabic segmentation data), implies that a serial-based mechanism operated across the entire letter string (not just the first syllable).

Second, the results can be fitted to the phonemic hypothesis. Based on the LEX model, proposed by Kwantes and Mewhort (1999), serial processing of a letter string occurs on a letter-by-letter basis during lexical identification. In contrast, simultaneous effects of serial processing and word frequency create a paradox for the dual-route model (e.g., Coltheart's, 1978). According to the latter, letter strings are processed via lexical (orthographic whole-word code) and nonlexical (GPCs) mechanisms, although the lexical route typically yields a faster output. If one were to try to explain the findings of the SBV task in terms of a phonemic hypothesis based on GPCs (e.g., Coltheart, 1978), it could be conceived that the syllabic structure effect arose after lexical identification had taken place and was due to the difference in length between stimuli with a single medial consonant or medial consonant pair (e.g., CV.CV.CV vs. CVC.CV.CV). In this scenario, a top-down serial-processing mechanism, operating at the grapheme-phoneme level, would be responsible for the identification of syllabic boundaries. However, this explanation does not provide a satisfactory account, given the magnitude of the syllabic structure effect. If length was the only determining factor, differences in processing times between stimuli with a C or CC structure should have been relatively small, since there is only one additional letter at the critical marker position in stimuli with a CC structure. An alternative scenario for explaining syllabic structure effects within a dual-route framework would incorporate a level of representation for larger subsyllabic units (i.e., as suggested by Coltheart et al., 2001). Although this modified version of the dual-route model may become a reality in the future, the present model does not provide a satisfactory account of the mechanism used to identify syllabic boundaries in print. Therefore, for the time being, we submit that the LEX model proposed by Kwantes and Mewhort (1999), which supports the phonemic hypothesis, provides the most parsimonious account of the data. Although this model (as well as the other models considered here) was developed to account for behavior other than that related to syllabification (i.e., reading aloud), we argue that the mechanism responsible for identifying syllabic boundaries is based on the frequency of spelling patterns for words stored in memory and arises at a post-identification stage.

Third, as has already been mentioned, the results are also compatible with a syllabic mediation hypothesis, albeit to a lesser degree than the phonemic hypothesis. In the Multiple-Trace model (i.e., Ans et al., 1998), syllable-by-syllable processing of a letter string is possible only after a whole-word strategy has failed to retrieve a word's lexical representation from memory. This situation would occur primarily when processing very low-frequency words and nonwords. The stimuli in the present study were largely outside the range of frequencies for a serial-based processing of letter strings to occur. However, it could be argued that this study did not provide an adequate test of the model's analytic reading procedure, since many low-frequency and some high-frequency stimuli could be considered to be of intermediate frequency. If similar findings were eventually obtained by excluding stimuli of intermediate frequency, there exists at least one way in which the model could be adapted to account for the findings. It is possible to speculate that participants may have deliberately focused their attention to the level of subword units (i.e., syllables), in order to perform the SBV task more efficiently. Such a claim is similar to what Laberge and Samuels (1974) proposed in their model on attentional processes in reading. According to these authors, skilled reading is assumed to proceed automatically via (spelling-to-sound) translation of the largest recognizable spelling pattern (i.e., ranging from whole words to individual letters); in contrast, the analysis of letter strings on a finer-grained level requires the use of attentional processes. If the Multiple-Trace model was modified to take into account the role of attentional processes in VWR, then it may theoretically be able to account for the findings in the SBV task.

Another way to interpret these effects is to appeal to the mental syllabary hypothesis. According to this hypothesis, word-frequency and syllable-frequency effects arise at different processing stages (i.e., lexical retrieval and production, respectively). If Levelt's (1989) speech production model was extended to the reading domain, this model may identify the locus of syllabic structure effects at the production stage. However, this kind of explanation does not take into account the findings of previous research on VWR and reading in French that attribute syllabic structure effects to earlier processing stages before lexical identification has taken place (e.g., Colé et al., 1999; Peretz et al., 1998).

In this light, a Spanish study (i.e., Carreiras, Alvarez, and De Vega, 1993) found independent effects of word frequency and (positional) syllable frequency, in a series of lexical decision and naming tasks, using polysyllabic stimuli. Based on these findings, the authors argued in favor of a syllabified (phonological) code that mediates lexical retrieval in Spanish. Another interesting finding was that lexical involvement influenced the direction of the syllable frequency effect; response times were slower for stimuli that contained high- rather than low-frequency syllables, in a lexical decision task (for both words and nonwords) and in a naming task with words. The syllable frequency effect was reversed in a naming task with nonwords (i.e., high-frequency syllables led to faster response times). This pattern of results was interpreted in terms of a PDP framework, in which high-frequency syllables typically activate a larger set of lexical candidates than low-frequency syllables. Syllable frequency was not manipulated in the SBV task, however this manipulation may be a useful venue for future research to pursue. Although French and Spanish differ in terms of orthographic depth, they are both syllable-timed languages and may lead to similar outcomes.

Finally, the issue concerning the nature of the code used in the SBV task is not a trivial one. In the first study, the results strongly suggest that participants parsed the stimuli by relying on a phonological representation of the letter strings. However, in the timed verification task the case for the use of an orthographic code is much more compelling due to (a) the presence of a main effect of word frequency, and (b) the similar pattern of responses for stimuli in the mute-e and voiced phoneme conditions (i.e., syllabic segmentation data in Experiment 3).

Implications

Theory

The findings from this program of research have implications on many levels. From a theoretical standpoint, no single theory of VWR and reading can provide a complete account of the results in the untimed and timed syllabification tasks. One important caveat that researchers should bear in mind is the fact that certain computational models have only been tested with monosyllabic stimuli (e.g., Coltheart et al., 1993; 2001; Seidenberg and McClelland, 1989). This is not the case for the LEX model proposed by Kwantes and Mewhort (1999), which at present, provides the best fit for the data. In this model, there is no level of representation corresponding to syllables; syllabic effects are assumed to arise as a consequence of the pattern of correlations between orthography, phonology, and semantics that are stored in the lexicon. Although the LEX model may provide the most parsimonious account of the data, the Multiple-Trace model (i.e., Ans et al., 1998), which does include a level of representation for syllables (and has been tested with French polysyllabic words) may also do so, if it were tested with a new set of stimuli or was modified accordingly. In chorus with Coltheart et al. (2001), we believe that the optimal method for discriminating between models that provide an equally compelling account of the data, is to design subsequent research in a way that pits the predictions of each model against one another. Hence, with respect to the necessity issue for a level of representation corresponding to syllables, a more in depth investigation of this issue is required, which must be left for future research to address.

Research

From a research perspective, the methodology used in these studies introduced a new framework, as well as, significant improvements to an existing paradigm for the study of written syllabification behavior. First and foremost, the framework presented in the first study was intentionally developed as a means to further cross-linguistic research in this area. No other study to date has attempted to create a comprehensive and universal framework for the analysis of behavioral data related to written syllabification. A detailed analysis of the syllabic environments in different languages is indispensable, given that there is no reason to expect, a priori, any universals from written language processing as we do from spoken language (i.e., Coltheart et al., 2001). Second, the SBV task, which represents a computer-controlled version of the original paper-and-pencil task developed by Treiman and Zukowski's (1990), has provided a new paradigm for exploring the link between syllabic structure and the issue of syllabic mediation in VWR. To date, the latter issue has been largely investigated using a single paradigm (i.e., syllable monitoring task; e.g., Mehler et al., 1981; Colé et al., 1999). On a more detailed level, the SBV task has highlighted new dimensions of analysis, which are key to resolving the issue of syllabic mediation in printed word recognition, such as manipulating syllabic structure in different serial positions within letter strings.

Practice

The present findings also have some practical implications for the educational domain in guiding the development of pedagogical materials used to teach young children to read French. Reading development typically proceeds through three stages: logographic, alphabetic, and orthographic (e.g., Frith, 1985). When reading instruction begins, many children have already acquired a small sight vocabulary. Some degree of phonological awareness is required on the part of beginning readers before they can learn the alphabetic principle (i.e., spelling-to-sound correspondences). Liberman, Shankweiler, Fisher, and Carter (1974) showed that six-year olds who have started formal reading instruction can identify the number of segments in spoken words, whereas younger children (i.e., four- and five-year olds) are only able to identify syllable-sized units. Thus, children need to be taught the notion of breaking a syllable or word into individual segments.

Reading researchers are divided on the issue of what the appropriate size of decoding units to be used to begin reading instruction (e.g., onset-rime, Rieben and Perfetti, 1989; phoneme, Gough and Hillinger, 1980; and syllable, Rozin and Gleitman, 1977). Although the present research does not address this issue per se, the finding that certain types of constituents at syllabic boundaries posed more difficulty than others for skilled adult readers in a written syllabification task, does have some implications for the sequencing of different syllable types in beginning reading materials. In particular, syllabification within s-cluster environments can be considered more complex than that of certain mandatory environments (i.e., coda-onset) and various cluster types (i.e., oral vowel, nasal vowel, consonant cluster, and semivowel). Moreover, the former also suggests the necessity of adding new rules to the existing set of syllabification rules (e.g., a sonority rule in the case of s-clusters).

Limitations

As with any piece of research, there are unavoidable trade-offs, which impose certain limitations to the generalization of the findings and are worth a brief mention. This research examined written syllabification behavior, as it relates to native speakers of French. However, language-dominance may also be an important factor influencing the strategy used during VWR. Although the vast majority of participants in these experiments were bilingual (i.e., French with English as a second language), we did not pursue the issue of language dominance given that this was not the focus of our investigation. To do so would require a validated measure to assess the degree of bilingualism of each participant. Another potential limitation to the study is related to way in which families of comparison were defined in the second study. The alpha level was set experiment-wise for multiple comparisons within each subset of syllabic environments included in the five broad categories and sub-categories of segmentation in the framework (i.e., mandatory, illegitimate, semivowel, mute-e, geminates, s-clusters, aspirated-h, and letter clusters). It could be argued that the alpha level should have been more liberal, since this type of exploratory research can potentially lead to new avenues that may not be discovered with a criterion that is too strict. Instead, a semi-conservative criterion was chosen in order to strike a balance between statistical power and the risk of obtaining a type-1 error (i.e., incorrectly rejecting the null hypothesis). In retrospect, however, the results in most cases were highly significant, implying that the pattern of results would not have differed significantly using a more liberal criterion.

Future Research

There are many potential avenues of research generated by each series of experiments, however, given the current interest in the field on the issue of syllabic mediation in printed word recognition, this will be the focus of recommendations that follow for future investigations into the matter. One of the logical extensions of the timed verification task would be to attempt replication of the location-specific effect of syllabic structure, using nonlexical stimuli. Because pseudowords have no representation in the mental lexicon, any lexically-derived effects of syllabic structure should disappear; alternatively, if the syllabic structure effect was successfully replicated with pseudowords, this would be an important step in determining the locus of the syllabic structure effect in the SBV task. The inclusion of a syllable frequency manipulation, in addition to the manipulation of word frequency, would also be desirable, given the findings of Carreiras et al. (1993) in Spanish (i.e., independent effects of syllable frequency and word frequency for stimuli / tasks that varied according to lexical status / lexical involvement). A third manipulation, that would provide a more stringent test for this issue, would be to manipulate response deadlines in the SBV task, following stimulus presentation. If the syllabic structure effect disappeared with a more stringent response deadline, this would suggest a non-lexical locus.

Conclusion

In conclusion, this program of research contributes to the field of Psycholinguistics in two important ways. First, the present findings demonstrated how the structural properties of letter strings influenced the way native speakers of French identified syllabic boundaries during VWR, in both timed and untimed tasks. Second, this research addressed the issue of the syllable as a universal unit for language processing, since it provides a universal framework to study syllabification behavior.

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Appendix A

List of Stimuli for Study 1 - Experiment 1: Real Words

haïr
acacia
papillon
huissier
oasis
archéologue
nihilisme
calcium
carnet
enthousiasme
ponctualité
israélite
athéisme
entrebâillement
édifiant
léopard
déconcerter
obstruer
psychisme
actualité
égotisme
protozoaire
éblouissant
dissertation
kaléidoscope
espièglerie
créateur
balancier
réussir
couloir
cuillère
aérodrome
susceptible
baptismal
accentuer
extraordinaire
psaume
grenouille
marsupial
criaillerie
incoercible
influence
respectueusement
émietter
estomac
désuet
abstraction
désobéissance
destruction
impérieuse
virtualité
prière
villégiature
prouesse
éberlué
éhonté
poitrail
réellement
belvédère
historiette
aéroplane
circonscription
ellipse
aspirateur
génial
enhardir
envahisseur
verrouiller
grassouillet
obsession
ecclésiastique
ouate
réacteur
cuisson
brouhaha
éternuer
patriotisme
introspection
alias
réunir
funérailles
déesse
aïeul
ministre
trahir
marionnette
ouaouaron
dépourvu
écrevisse
diarrhée
affectueusement
accordéon
psychiatre
relief
amphithéâtre
épervier
mangeoire
introverti
annuellement
tonitruant
malléable
obséquiosité
califourchon
huitième
réapprendre
citrouille
débrouillardise
aiguille
tiédeur
préscolaire
adaptation
zoologique
cristal
apostrophe
épanouir
absolution
iode
entière
armoire
baccalauréat
obéir
arbuste
écaille
monstrueux
océan
résistance
napoléon
prospecteur
amélioration
essentiel
hiatus
théoricienne
radioactif
embarcation
arsenal
atmosphère
irréel
dépréciation
obscur
émerveiller
bouillon
faille
réagir
éblouir
européenne
feuillage
affluence
surveillance
matérialisme
psychédélique
polythéisme
jouissance
abréviation
guillemet
perspective
surréaliste
aérienne
ferroviaire
préhistoire
marseillais
atrophier
escalier
persécution
immuable
dévaluation
féerique
inapte
obstacle
linoléum
obéissance
anguille
boréal
enregistrer
gazouiller
oratoire
ruelle
prostration
inhabituel
intellectualisme
dortoir
insister
aviateur
substance
condoléances
féodal
cruellement
malséant
imperméable
glacial
figuratif
habillage
fluctuation
pancréas
impulsion
commissariat
huissier
grouillement
éolien
traverse
monarque
tortueuse
dérailleur
pléiade
alouette
psychologue
catastrophe
machiavélisme
industrialiser
rituel
aorte

brouette	accident	coordonner	perpétuel	pointilleux
calypso	ahurissement	puanteur	terrestre	échantillonnage
mystère	immersion	aérer	oisif	oeil
brusque	répertoire	altruisme	instantanéité	chaotique
guillotine	disciple	vieillot	douillette	ruisselet
inspiration	béarnais	circonstance	huileux	alcoolisme
idéaliste	suivre	instable	prestance	
houille	moitié	fusillade	jaguar	

List of Stimuli for Study 1 - Experiment 2: Pseudowords

haïm	nespactueugemont	prahir	manoléon	pidoléum
atucia	anietter	varionnelle	crospecteur	avéissande
dapillon	esturas	ouaouatau	igélioration	onguille
huiddier	bésuet	dévourlu	appontiel	soréal
oamir	ebstriction	agrevasse	hiamus	enravistrer
arphéonogue	tésopéissande	jiahrrée	phéoricielle	badouiller
pihulisme	pestriction	annectueulemont	darioactir	arotoire
taldium	impénieuse	accarpéon	emparcution	puelle
garmet	firtuanité	psyphiocre	orsenal	prostrution
enchoupiasme	priède	talief	itmosphèle	inhovituel
monctuasité	fillégiatère	onchiphéâtre	imméel	interrectuanisme
asréolite	prouenne	éfirvier	pétriciation	burtoir
othéisme	afernué	tingeoire	abscor	insispin
emprenâillement	éhonfé	incramerti	écurmeiller	oviadeur
éliviant	voitrail	orruellement	pouillon	robstance
méopard	géelletont	ponitruant	daille	gondaléantes
dégoncerler	delpédère	nolléable	déutir	téudal
abstruin	histurielle	abséquiorité	étrouir	fruellemont
psychasme	aédoplude	tadifourphon	eusotéelle	calséant
ormualité	gertonscruption	huivière	veuillade	indelméable
agotisme	illupse	réaffrondre	accluenge	cladial
protoluaire	aspinadour	pitrouille	curveillande	vicuratif
aglouissant	gurial	tévrouillarpise	satérialisme	hubillade
nissertition	enharpir	ouguille	psythudérique	plucturarion
galéiroscope	ouvahinneur	fiéteur	tolychéisme	mancréas
espièclanie	gétouiller	préscumaire	rouissande	imbirsion
tréateur	trassouillet	anipturion	atrédiation	rumméssariat
palandier	obserrion	zoomarique	guilludet	huimmier
péonnir	efflésiasmique	pristar	turspectine	trouillement
fouroir	ouade	idostrophe	murréadiste	éopien
puillède	néactour	apénouir	aériette	praberse
aénodrope	nuisson	obsélation	gerrafiaire	motarque
pusceptoble	crouhaha	iole	préhistoine	tartueuse
vaptismal	écornuer	antièle	derseillais	pédailleur
occenduer	napriotisme	artoire	icrophier	cléiade
axpriordilaire	imbrospection	toccanauréat	escutier	élouatte
psaude	olias	oméir	versacution	psychanigue
grajouille	déutir	orbaste	irruable	panastriphe
narsurial	vimérailles	igaille	pinaluarion	pachiavélisme
driaillerie	réesse	panstrueux	véerique	incustrialoser
incoardible	aïoum	acéon	inupte	rimuel
ingluende	finistre	répistande	abstocle	aorme

prouatte
tarupso
systère
crusque
guillotade
inspirumion
opéaliste
houilla

occirant
ahuvinnement
ippersion
débertoire
rusciple
méarnais
luitre
joitié

coordasser
buanveur
aéler
elcruisme
fieillot
furconstande
instacle
gusillare

pornétuel
parrestre
oisil
instouranéité
vouillette
huideux
prestande
voguar

roinpilleux
achintionnale
hail
choadique
muisselet
ircoolasme

Appendix B

List of Stimuli for Study 2 - Experiment 1

CVC.CV.CV		CV.CV.CV	
HF	LF	HF	LF
service	reptile	malade	pirate
lecture	capture	limite	tomate
formule	sardine	solide	ramure
formule	facture	régime	rigolo
culture	virgule	navire	levure
surface	tornade	volume	banane
victime	cordage	numéro	virage
parvenu	carbone	mobile	pelage
vertige	termite	retiré	salope
murmure	mordoré	façade	canari
rupture	vervure	délire	cavité
cortège	parjure	féroce	kimono
barbare	culbute	malice	pagode
cultivé	subside	cigare	canine
partage	surdité	bagage	copine
torture	parlote	narine	patère
fermeté	solfège	pilote	dédire
verdure	ductile	tenace	cirage
sordide	gargote	légume	mâture
morbide	servage	canapé	bolide
perfide	tartare	parade	barème
cascade	portage	rafale	mécano
bergère	sulfate	repère	havane
martyre	turbine	cabane	litote
forcené	berline	futile	pinède
tactile	fermage	ravagé	fédéré
bulgare	varlope	famine	pécule
bordure	gerçure	parure	pavage
mercure	perforé	lacune	nubile
marmite	bornage	reculé	galure
barbelé	torpédo	vivace	parité
fertile	voltige	gamine	ménade
servile	diptère	saturé	gavage
vermine	forçage	reposé	carabe
tartine	pergola	tapage	cubage
carnage	malvenu	satyre	rodage

List of Stimuli for Study 2 - Experiment 2

CV.CVC.CV		CV.CV.CV	
HF	LF	HF	LF
liberté	sadisme	malade	pirate
moderne	citerne	limite	tomate
réserve	juriste	régime	ramure
révolte	mégarde	solide	rigolo
faculté	modiste	volume	banane
modeste	cubisme	navire	pelage
majesté	racorni	numéro	canari
volupté	luzerne	mobile	salope
réforme	poterne	délire	kimono
tumulte	légiste	façade	pagode
céleste	cocarde	cigare	canine
superbe	bicorne	bagage	copine
robuste	copiste	narine	patère
caserne	bâtarde	pilote	dédire
lyrisme	marasme	malice	cirage
funeste	basalte	légume	mâture
caverne	nazisme	parade	bolide
divorce	lézarde	rafale	mécano
vacarme	vétuste	canapé	barème
cynisme	racisme	cabane	havane
récolte	sélecte	repère	litote
retardé	licorne	lacune	pinède
lucarne	paterne	parure	fédéré
débordé	soliste	famine	pécule
mutisme	fumiste	ravagé	pavage
taverne	fêtarde	futile	nubile
riposte	puriste	reculé	galure
néfaste	papiste	vivace	parité
bavarde	civisme	gamine	ménade
déporté	relapse	saturé	gavage
puberté	gâtisme	reposé	carabe

List of Stimuli for Study 2 - Experiment 3: Mute-e Condition

CVC.CV.CV		CV.CV.CV	
HF	LF	HF	LF
justice	bascule	misère	rapace
lecture	virgule	navire	banane
surface	tornade	police	notice
victime	carbone	menace	savate
costume	termite	mérite	limace
vertige	gymnase	remède	lavage
rupture	despote	valise	dosage
barbare	pistole	bêtise	rosace
cortège	nervure	lucide	mégère
corsage	parjure	féroce	patère
verdure	subside	malice	cavale
factice	solfège	docile	sémite
cascade	servage	bagage	médire
bergère	tartane	redire	havane
bordure	sulfure	rivage	césure
vestige	bornage	rigide	forage
mercure	carbure	sirène	bipède
reptile	diptère	rétine	pelade

List of Stimuli for Study 2 - Experiment 3: Voiced Phoneme Condition

CVC.CV.CV		CV.CV.CV	
HF	LF	HF	LF
murmurer	culbuter	retirer	végéter
respirer	capturer	diriger	libido
disparu	fortuné	figurer	mutiler
partager	parfumer	comité	dévider
terminer	surnager	mesurer	débiner
parvenu	barboter	défini	révérer
disposé	marteler	désolé	refiler
circuler	captiver	déposer	piloter
disputer	mordoré	diviser	réviser
formuler	culminer	ménager	cavité
calculer	surdité	limiter	caraco
cultivé	rescapé	défiler	délavé
fermeté	pactiser	coloré	lapider
torturer	perforé	canapé	fédéré
forcené	pergola	casino	déluré
discuté	corseté	ravagé	caméra
barbelé	tilbury	résidu	parité
gestapo	torpédo	réputé	jubilé