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STATEMENT OF INTEGRITY

I hereby declare having conducted this academic work with integrity. I confirm that I have not used plagiarism or any form of undue use of information or falsification of results along the process leading to its elaboration.

I further declare that I have fully acknowledged the Code of Ethical Conduct of the University of Minho.

O papel da sílaba no reconhecimento visual de palavras do Português Europeu: Evidência comportamental e eletrofisiológica

Resumo

Várias investigações comportamentais e eletrofisiológicos observaram evidências robustas quanto à importância da sílaba como unidade de acesso lexical no reconhecimento visual de palavras. No entanto, o facto de que em tarefas de decisão lexical com priming mascarado, efeitos silábicos foram observados para palavras com uma estrutura silábica de consoante-vogal (CV), mas não com estrutura silábica de consonante-vogal-consonante (CVC) – o chamado *efeito de estrutura silábica* – tem sido negligenciado ainda que ponha em causa a importância da sílaba. Neste trabalho, investigamos o papel da sílaba no reconhecimento visual de palavras do Português-Europeu (PE) com leitores em desenvolvimento (i.e., alunos do terceiro e quinto ano) e leitores proficientes, assim como as potenciais causas para o efeito de estrutura silábica. Deste modo, no Artigo 1 realizamos uma tarefa de decisão lexical com paradigma de priming mascarado onde a congruência entre primes pseudopalavras e targets palavras e pseudopalavras com estrutura CV e CVC, foi manipulada gerando uma condição de congruência (e.g., ru.mis-RU.MOR), uma de incongruência (e.g., rum.pa-RU.MOR), e uma não-relacionada (e.g., ca.fas-RU.MOR). No Artigo 2 uma manipulação semelhante foi utilizada para estudar o efeito silábico e o efeito de estrutura silábica em leitores iniciantes e intermédios, usado o paradigma de priming de sandwich combinado com a tarefa go/no-go. Nos Artigos 3 e 4 duas explicações para o efeito de estrutura foram investigadas: a maior complexidade de sílabas CVC, e a vizinhança silábica mais densa de palavras CV respetivamente. No Artigo 3 replicamos o paradigma do Artigo 1, mas com durações de priming maiores de 67 e 82 ms em vez de 50 ms, e no Artigo 4, palavras CV e CVC foram controladas quanto ao número de vizinhos silábicos. Finalmente no Artigo 5 investigamos o efeito de estrutura silábica através do uso de potenciais de eventos relacionados (PER) combinado com um paradigma de congruência de cores onde palavras CV e dois tipos de CVC, aquelas com correspondência fonológica e ortográfica, CVC_{O+P+}, e aquelas sem CVC_{O+P-}, apareciam segmentadas de acordo com a sua sílaba (e.g., zebra), ou não (e.g., zebra). Os nossos resultados mostram evidência de uma ativação precoce da sílaba para leitores em desenvolvimento e proficientes. Foram também observados efeitos silábicos para palavras CV e CVC com leitores em desenvolvimento, e em leitores proficientes, os resultados dos PERs mostraram efeitos silábicos para targets CV, CVC_{O+P+}, e CVC_{O+P-}, sugerindo uma ativação silábica que precede a ativação lexical e que é conduzida pela ortografia.

Palavras-chave: eletrofisiologia, leitura, estrutura silábica, priming mascarado, sílaba

The role of the syllable at early stages of visual word recognition in European Portuguese: Behavioral and electrophysiological evidence

Abstract

Throughout the years many behavioral and electrophysiological studies have found reliable evidence of the syllable acting as an access unit for visual word recognition. Nevertheless, the fact that masked priming lexical decision tasks showed that syllable effects only occurred for words with a consonant-vowel (CV) but not for with a consonant-vowel-consonant (CVC) first-syllable structure – the so-called *syllable structure effect* – has long been overlooked, even though it puts into question the importance of the syllable. In this work, we investigated the role of the syllable in the visual word recognition of European-Portuguese (EP) words with developing (third- and fifth- grade students) and adult expert readers, as well as the potential causes for the syllable structure effect. Thus, in Paper 1 we conducted a masked priming lexical decision task where the syllable congruency between pseudoword primes and CV and CVC words and pseudoword targets was manipulated giving rise to a syllable-congruent (e.g., ru.mis-RU.MOR [rumor]), syllable-incongruent (e.g., rum.pa-RU.MOR), and unrelated condition (e.g., ca.fas-RU.MOR), to investigate the emergence of syllable effects and of the syllable structure effect in EP. In Paper 2 we employed a similar manipulation to investigate syllable effects and the syllable structure effect with EP beginning and intermediate readers, though we have opted to use the sandwich masked priming combined with a go/no-go lexical decision task. In Paper 3, and Paper 4, two potential accounts for the syllable structure effect were investigated, the greater syllable complexity of CVC syllables, and the denser syllabic neighborhood of CV words, respectively. In Paper 3 we replicated the paradigm employed in Paper 1 but using longer prime durations of 67 and 82 ms instead of 50 ms, and in Paper 4 we have matched CV and CVC on their number of syllabic neighbors. Finally in Paper 5, we investigated the syllable structure effect using event-related potentials (ERPs), combined with a color-congruency paradigm where CV, and two types of CVC words, those with a phonological (P) and orthographic (O) match CVC_{O+P+}, and those with a P and O mismatch, CVC_{O+P-} appeared segmented according to their syllable boundary (e.g., zebra [zebra]) or not (e.g., zebra). Our results suggest evidence of an early syllable activation for expert and intermediate readers. Furthermore, with developing readers syllable effects were found with CV and CVC words alike, and with expert readers, ERP data showed syllable effects for CV, CVC_{O+P+}, and CVC_{O+P-} words, and suggested that syllable activation occurs prior to lexical activation and is driven by orthographic information.

Keywords: masked priming, electrophysiological evidence, reading, syllable, syllable structure

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Abbreviations, Acronyms and Symbols

ANOVA - Analysis of Variance

CDP - Connectionist Dual Process

CV – Consonant-Vowel

CVC – Consonant-Vowel-Consonant

CVC_{O+P+} - Consonant-Vowel-Consonant with Phonological and Orthographic Match

CVC_{O+P-} - Consonant-Vowel-Consonant with Phonological and Orthographic Mismatch

DRC - Dual-Route Cascaded

EEG - Electroencephalogram

ERPs - Event-Related Potentials

EP - European Portuguese

IA - Interactive Activation

LDT – Lexical Decision Task

LME - Linear Mixed Effects

MROM - Multiple Read Out Model

MROM-S - Multiple Read Out Model with a Syllabic Layer

O - Orthography

P - Phonology

P-PAL - ProcuraPALavras

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General Introduction

From its early beginning Psycholinguistic studies have placed a great emphasis on the syllable with a considerable number of studies showing that this sublexical unit plays a relevant role as a functional unit for visual word recognition (e.g., Álvarez et al., 2004, 2016; Barber et al., 2004; Carreiras et al., 1993; Carreiras & Perea, 2002; Chetail & Mathey, 2009a, 2012; Conrad et al., 2006, 2008; Conrad & Jacobs, 2004; Mathey & Zagar, 2002; Perea & Carreiras, 1998). These studies, although using different techniques and paradigms, all seem to suggest that upon word presentation, readers begin decomposing letter strings into its syllabic constituents, which are then used to access information about the word in our system. In particular, the first syllable, plays a very relevant role for lexical access, acting almost as a gateway into the lexicon. Nonetheless, a curious effect has been found in some studies, particularly in those that used a masked priming paradigm. This refers to the fact that reliable syllable effects only appear to emerge for words with a CV first-syllable structure but not for those with a CVC first-syllable structure (i.e., note that C stands for "consonant" and V for "vowel"), giving rise to the so-called *syllable structure effect*. This is a puzzling result and although it has been observed in a systematic way in a number of languages, it remains poorly understood and has been largely overlooked both in empirical studies and in the current models of visual word recognition.

Indeed, likely this is owed to the fact that for many years the majority of studies on visual word recognition have focused on monosyllabic words (see Yap & Balota, 2009 and Yap & Liow, 2016 for a review), mostly because these words are simpler and easier to manipulate. This fact, however, constitutes a significant limitation since the majority of words in most languages are polysyllabic. For instance, in European Portuguese (EP) according to the ProcuraPALavras (P-PAL; Soares at al., 2014, 2018) lexical database, only 0.31% of words are monosyllabic, constituting a very small minority of the EP lexicon. Likewise, most of the earliest computational models for visual word recognition, like the Interactive Activation (IA) model (McClelland & Rumelhart, 1981), the Dual-Route Cascaded (DRC) model (Coltheart et al., 2001), the connectionist dual process (CDP) model (Zorzi et al., 1998) and its successor, the CDP+ model (Perry et al., 2007), could only simulate effects for monosyllabic words and were hence unable to accommodate the syllable effects observed in the literature such as the syllable frequency (i.e., words with high-frequent first syllables take longer to be recognized) and the syllable congruency effect (i.e., a brief prime sharing the first syllable with a target facilitates word recognition more than a prime that only shares the first three letters but not the first syllable with a target).

It is necessary for computational models not only to be able to simulate how syllable units are implemented during visual word recognition, but also to explain why while in the visual domain (reading) syllable effects tend to be observed for words with a CV first-syllable structure, but not for words with a CVC first-syllable structure, in the auditory domain (speech) such differences do not appear to exist. Furthermore, it is also necessary for subsequent studies to investigate how the psycholinguistic characteristics of languages in terms of stress, syllable complexity, and rhythm (i.e., syllable-timed versus stress-timed) can modulate those syllable effects, given that for the most part, studies in Spanish and French have dominated the investigation regarding syllable effects, especially, the syllable congruency effect. Importantly, both of these languages are syllable-timed (i.e., the intervals between syllables are maintained fairly equal during speech) and have easy-to-define syllable boundaries, unlike EP and English, which are stress-timed languages (i.e., the interval between syllables is not constant during speech with stressed syllables being prolonged, while unstress syllables are shortened) with fuzzier syllable boundaries and a greater variety of permissible syllable structures.

The primary goal of this dissertation is to investigate, for the first time, syllable effects during the visual word recognition of polysyllabic EP words, and, critically, to study if the syllable structure effect, observed in masked priming lexical decision studies, might emerge in this language, not only in mature skilled readers but also in developing readers. This might also contribute to a deeper comprehension of the developmental trajectory of this effect and to offer new insights into the factors that might underlie it, not only in EP but also in other languages.

Studying syllable effects, and, in particular, the syllable structure effect, is relevant in a language such as EP due to the fact that this is a language with distinct psycholinguistic characteristics, which can make syllable effects at the same time more but also less likely to emerge. In fact, since EP is an intermediate-depth language, having more transparent grapheme-to-phoneme conversion rules than English and French, but less transparent ones than Spanish, might well facilitate the emergence of syllable effects since the relationship between graphemes and phonemes is fairly straightforward. However, EP is classified as a stress-timed language concerning its rhythmic pattern, with fuzzier syllable boundaries than those found in syllable-timed languages such as Spanish and French, and additionally with a greater number of permissible syllable structures. Thus, while its fairly straightforward relationship between orthography and phonology might facilitate the emergence of phonological units such as the syllable during visual word recognition, the complexity of its syllable boundaries might difficult the use of the syllable as a sublexical unit for reading access.

Furthermore, studying the syllable structure effect in EP might also help not only to refine the current models of visual word recognition by implementing this syllable level of processing between the letter and word levels, but also to clarify what underlying factors might be originating the syllable structure effect. Indeed, it is relevant to mention that one of the main hypotheses put forward as the cause for the syllable structure effect is the difference in the frequency of each syllabic structure, CV and CVC, in Spanish and French. In EP these differences are much less pronounced making it a pivotal language in which to investigate the syllable structure effect and to test this hypothesis. Additionally, it also makes it a very relevant language in which to investigate other potential causes for the syllable structure effect, such as syllable complexity and the number of syllabic neighbors, as we have sought to do in the present thesis.

Therefore, this dissertation would contribute to fill important gaps in the current psycholinguistic literature by providing new data aimed to directly account for a poorly understood effect and to promote further developments in current models of visual word recognition. It is also important to note that the results of this dissertation can have other relevant impacts beyond the theoretical level. Indeed, a deeper understanding of the importance of syllables during reading could also have critical implications in the development of more adequate teaching methods for promoting reading skills. It is important to note here that reading is a complex cognitive activity with which a significant number of children struggle, having serious consequences in academic failure (e.g., Cunningham & Stanovich, 1998; Shankweiler et al., 1996; Spreen, 1989) and in later life achievements (e.g., Annie E. Casey Foundation, 2010; Hernandez, 2011).

The present dissertation is made up of five chapters composed of five different papers, all published or submitted for publication (Campos et al., 2018, 2020, 2021a, 2021b, 2021). These chapters will be preceded by the general introduction, meant to give a background into each of the studies conducted, and followed by a general discussion, which will be presenting the major findings and how they relate to the current psycholinguistic findings and models.

Thus, we will begin in this general introduction by defining the syllable as a unit of linguist processing. Afterwards, we will give a brief overview of how this unit has been investigated in the psycholinguistic literature and the main results obtained. We will also be reviewing how the models of visual word recognition have sought to incorporate the syllable as a processing unit, reflecting on its major limitations in accommodating syllable effects, with particular emphasis on the syllable structure effect, which is the main focus of the present dissertation.

Following this general introduction, which seeks to establish our research questions theoretically, empirically, and methodologically, we present the five papers that made up this dissertation. The first one, entitled "The role of syllables in intermediate-depth stress-timed languages: masked priming evidence in European Portuguese" and published in the *Reading and Writing* journal, aimed to analyze the role of the syllable at the early stages of visual recognition of dissyllabic EP words, and, importantly, to examine whether a syllable structure effect was also observed in this language, as no previous studies had been conducted so far on these issues. The second paper, entitled "Syllable effects in beginning and intermediate European-Portuguese readers: Evidence from a sandwich masked go/no-go lexical decision task", published in the *Journal of Child Language*, aimed at investigating how the syllable effects, observed in the first paper with adult EP expert readers, emerge in developing (i.e., beginning and intermediate) readers, and if and when the syllable structure effect might be noticed during reading development. The third and the fourth papers, entitled "Temporal Dynamics of Syllable Priming Effects on Visual Word Recognition: Evidence From Different Prime Durations" and "On the Role of Syllabic Neighbourhood Density in the Syllable Structure Effect in European Portuguese" published in the *Canadian Journal of Experimental Psychology* and submitted in the *Lingua* journal, respectively, were designed to directly analyze the role that syllable complexity and syllabic neighborhood density, respectively, might play in the syllable structure effect observed in the first and second papers. Lastly, the fifth paper, entitled "On the Syllable Structure Effect in European Portuguese: Evidence from ERPs" and submitted for publication in the *Brain and Language* journal used event-related potentials (ERPs) to gain further insights into the syllable structure effect in EP by seeking to investigate if using a technique which is more sensible to the early time course of lexical processing, syllable effects can be equally observed in CV and CVC word. This would highly suggest that previous findings in behavioral studies were an artefact of the paradigm/method used and not a genuine effect.

Defining the Syllable

The syllable has been defined, by many authors, as a phonological constituent used to group segments in a phonologically significant way (e.g., Fudge, 1969; Haugen, 1956; Hockett, 1955; Khan, 1976; Selkirk, 1982). In EP, Mateus (1990) further elaborates on this and defines the syllable, from a phonological standpoint, as a "rhythmic unit, constituted by a sequence of segments that group themselves around a segment that has a greater degree of prominence" (p. 211).

The syllable is organized into two main hierarchical components: the *onset* and the *rime*, with the latter also being divided into two smaller components, the *nucleus* and the *coda*. The more prominent segment, in which other segments would group themselves around, is the nucleus which is the mandatory constituent of all syllables (also referred to as the *syllabic constituent*). The two other possible segments, which can occur either before (i.e., onset) of after (i.e., coda) the nucleus, have less prominence, hence being referred to as *asyllabic constituents*. The nucleus can therefore constitute a syllable, and, in most languages of the world, it almost always comprises vowels. This is the case of EP, where only a single vowel (e.g., <a> - [ɐ]), two vowels (i.e., diphthong – e.g., <ou> - [o]) and three vowels (i.e., triphthong – e.g., <eia> - [ˈej. ɐ]) can constitute a nucleus. There are however some exceptions to this rule. For instance, in English, the consonants <l> - [ɫ] - and <n> - [n] -, and in Servian the <r> - [ɾ] - can be the nucleus, as they can constitute a syllable by themselves. As for the optional constituents of a syllable, the onset and the coda, these can be either consonants or semi-vowels. In EP, a consonant (e.g., <f> - [f]) and a semi-vowel (e.g., <u> - [u]) will always be asyllabic constituents since, as stated, only vowels can assume the role of the nucleus within a syllable.

The way asyllabic and syllabic segments group themselves to form a syllable creates multiple syllable structures within a language. For instance, syllables that only have a nucleus are designated as *simple syllables* (i.e., in EP these are syllables with a V – e.g., <o>- [u] - or VV – e.g., <eu> - [ˈew] - structure), while syllables that can have other asyllabic constituents, the onset, the coda, or both, are designated as *complex syllables* (for example, CV syllables have an onset and a nucleus – e.g., <ru> - [ʀˈu]; VC syllables have a nucleus and a coda – e.g., <em> - [ẽ]; and CVC syllables have a nucleus preceded by an onset and followed by a coda – e.g., <for> - [fˈɔɾ]). The number of permissible syllable structures also varies considerably from language to language, and, in this regard, EP is considered to be a very rich language. Indeed, while in Spanish there are about 16 (data obtained from LEXESP lexical database; Sebastián-Gallés et al., 2002), and in French 15 (Adda-Decker et al., 2005) permissible syllable structures, in EP there are 25 permissible syllable structures considering the first syllable position alone (data obtained from the P-PAL lexical database; Soares et al., 2018). The frequency of occurrence for these syllable structures also varies considerably across languages, and, in many cases, the CV is the most common syllable structure.

Indeed, being the syllable a phonological unit, the first proposals of syllable-sized units having a key role during word recognition were put forward for speech, with subsequent studies later extending this proposal for reading. Many authors considered that compared to other sublexical units, such as phonemes, the more intuitive nature of the syllable and its easier-to-define boundaries would make it a good candidate for an access unit (e.g., Bruck et al., 1997; Courcy et al., 2000; Frauenfelder et al., 1980; Liberman et al., 1974; Mehler et al., 1981). Many studies have empirically supported this claim suggesting that, during speech recognition words would be segmented into syllables (e.g., Mehler et al., 1981; Morais et al., 1989; Sebastián-Gallés et al., 1992). For instance, in one of the first studied to explore if a more global strategy for processing words during speech employed the syllable rather than phonemes, Morais et al. (1989), presented literate and illiterate EP participants with a series of short sentences and asked them to detect a given segment (e.g., <ga> - [gɐ] -, <gar> - [gɐɾ]), embedded in that sentence, as quickly and accurately as possible. These segments could either constitute the first syllable of a target word in the sentence (e.g., as <ga> in "O homem fechou a *ga*ragem" [The man closed the garage]), or not (e.g., as <gar> in "O homem fechou a *gar*agem", since in EP the word *garagem* is syllabified as *ga.ra.gem*). Hence, if the phoneme, and not the syllable, was the unit for speech recognition, then no differences would be expected between the two conditions. Results showed that both literate and illiterate participants had faster detection times when the segment corresponded to the first syllable than when the segment did not correspond to the first syllable of the target word, thus suggesting a syllabic activation during speech perception.

Additionally, speech production studies also provided evidence towards the role of syllable-sized units (e.g., Cholin et al., 2006; Levelt & Wheeldon, 1994; Schiller et al., 1997; Treiman, 1983; Treiman & Danis, 1988; but see Bagemihl, 1995 for a review). For instance, Cholin et al. (2006) asked participants to name high- and low-frequent syllables as quickly as possible. Their results showed that syllables with a high frequency of occurrence were produced more quickly than syllables with a low frequency of occurrence, which was explained in accordance with the initial proposal made by Crompton (1981), and subsequently adopted in the WEAVER ++ model (Levelt et al., 1999; Roelofs, 1997a 1997b, 1998, 1999), claiming that syllables with high frequencies of occurrence would be more easily retrieved from the mental syllabary. According to this syllabarium hypothesis, speakers would store a mental syllabary containing pre-compiled motor-programs of syllable-sized units instead of accessing full words, upon word production.

Further evidence for the functional role of syllables as unit of language production also comes from studies showing that most speech errors occurred at a syllable level (e.g., Nooteboom, 1969; Vousden et al., 2000; but see Meyer, 1992, for a review). Taken together, these results provide empirical evidence to the important role of the syllable during speech production, just as previous studies had done for speech recognition.

Subsequently, the role of the syllable as an access unit was studied during visual word recognition, with many authors claiming that, for words beyond one syllable long, syllable-sized units would be activated in the system to retrieve whole-word information (e.g., Lima & Pollatsek, 1983; Millis, 1986; Rapp, 1992; Spoehr & Smith, 1973; Taft & Forster, 1976; Tousman & Inhoff, 1992). The rationale behind this proposal rested on the fact that reading has a spoken language foundation with evidence showing that there is an activation of phonological codes during printed words' processing (e.g., Frost, 1998; Newman et al., 2012). In fact, several models of visual word recognition include a phonological level during the reading process, claiming there is an activation of the orthographic and phonological word form, even during silent reading (see for instance the DRC model of McClelland et al., 2001).

It is important to mention, however, that this intricate connection between phonology and orthography is more complex in some languages than others, according to the degree of transparency between phonemes and graphemes. While in transparent languages such as Spanish, there is an almost a direct correspondence between graphemes and phonemes (thus, in the majority of the cases, words are written as they are spelled, and syllables are the same in their phonological and orthographical forms), in opaque languages such as English this issue is more complex. Indeed, the correspondence between graphemes and phonemes is not direct, making it that often the orthographic and phonological syllable is not the same. Although EP, like French, is considered to have an intermediate-depth orthography (see Lima & Castro, 2010 for more details), in EP there is often a mismatch between the phonologically and the orthographically defined syllables, sometimes causing a mismatch between orthographic and phonological syllables, as it happens for English. Take, for instance, the nasal vowels existing in Portuguese ([ã], [ẽ], [ĩ], [õ], and [ũ]); these can either be orthographically represented by placing a swung dash on the vowel (e.g., *mãe* [mˈɐ̃j̃]; [mother]), or by adding either an <m>or an <n> to the vowel (e.g., cantor [kɐ̃tˈoɾ]; [singer]). In either case, they represent the same phoneme [N], and the difference lies only on how it is orthographically represented (see Barroso, 1999; Teixeira et al., 1999). On this second case, the conjunction of a vowel with either an <m> or an <n> forms a syllable that, while orthographically has three graphemes and a CVC structure, phonologically it has only two phonemes and a CV syllable structure (e.g., in *cantor* the orthographic first syllable is <can> and the phonological first syllable is [kɐ̃]).

Besides varying on the number on the degree of grapheme to phoneme correspondence, languages also vary in the degree of prominence the syllable takes in speech, more specifically in speech segmentation. In syllable-timed languages, such as Spanish and French, syllables have great perceptual salience since typically each syllable within a word has roughly the same duration. These languages are usually also characterized by having clear-cut syllables (see Nespor et al., 2011). In contrast, however, we have stress-timed languages, such as English and EP. In these, syllables do not have the same duration; instead, since stressed syllables are prolonged, the duration of unstressed syllables varies considerably to keep the interval between the stressed syllable of each word in a sentence fairly equal (see Nespor et al., 2011 for details). Indeed, in stress-timed languages, it is fairly common to observe the vowel reduction phenomenon (i.e., vowels are often not pronounced causing a mismatch between the written and spoken form of a word – e.g., in *álcool* [alcohol], one of the o's is reduced; so, while orthographically the word has three syllables *ál-co-ol*, phonologically it is a disyllabic word [ˈaɫ-kuɔɫ]) and ambisylabicity (i.e., when a given consonant can be the coda of a syllable as well as the onset of a subsequent syllable; e.g., the word *rádio* [radio], can both be pronounced *rá-dio* [ʁˈa-dju], the consonant <d> acting as the onset of the second syllable, but also *rád-io* [ʁˈad-ju], with the consonant <d> acting as the coda of the first syllable), which adds to the complexity of syllable boundaries in this type of language, making them harder to define (see Seidenberg, 1987; but also Selkirk, 1980). Moreover, stress-timed languages also tend to have a larger number of permissible syllable structures when compared to syllable-timed languages.

All of these different characteristics of a language, as explored above, can make that syllables and the syllabification process might be more or less complex, and it is easy to understand how in this regard EP is a particularly interesting language concerning its syllable complexity. While its less opaque than English and French, EP's intermediate depth means that in many instances there is a mismatch between the phonological and orthographical syllable form. Furthermore, as mentioned, EP has a great number of permissible syllable structures, and it is a stress-timed language, making the syllabification process less straightforward.

Indeed, in the following section we will explore how syllable effects have been studied for visual word recognition, and the different results yielded in different languages as well as what psycholinguistic characteristics they have.

The Role of the Syllable in Visual Word Recognition

One of the first studies to investigate the role of the syllable during visual word recognition was the seminal study of Taft and Forster (1976). Over a series of five experiments, their main goal was to investigate how polysyllabic words were stored and retrieved from memory by readers during visual word recognition, and if syllables could potentially be used to activate lexical candidates. To this extent, Experiment I sought to investigate if word constituents, particularly the beginning portion, rather than the whole-word forms were used during the recognition of letter strings. Thus, two types of compound legal nonwords were presented to participants in a standard LDT; those with constituents that formed legal monosyllabic words (e.g., for instance, *dust* and *worth* in the legal nonword DUSTWORTH), and those with constituents that were made up of monosyllabic nonwords (e.g., for instance, *mowd* and *flisk* form the legal nonword MOWDFLISK). The authors proposed that, if words were segmented into smaller constituents during reading, then a nonword like DUSTWORTH would take longer to be responded to than a nonword like MOWDFLISK, since *dust* and *worth* are real monosyllabic English words. Their results did show that nonwords made up of real monosyllabic words took longer to be responded to, leading the authors to conclude that word processing was not done by using whole-word forms, but diving words into smaller constituents. The objective of Experiment II was to further elaborate on these findings and investigate if the syllable could be the constituent used to segment letter strings during visual word recognition. To this extent, another LDT was conducted presenting legal nonwords that had first syllables that constituted legal first syllables in English (e.g., *plat* which is the first syllable of the word *platform*), or not (e.g., *brot* which does not constitute a first syllable in any legal English word). Their reasoning was similar to that in Experiment I, hence, if words were processed as a whole, it should take readers the same amount of time to classify a given stimulus as a nonword, either it had a legal first syllable or not. On the contrary, if words were broken into smaller constituents, such as syllables, seeing a nonword with a first syllable such as *plat*, which constitutes a real first syllable in English, would result in the subsequent activation of several words that contain that same first syllable. Consequently, a nonword with *plat* as a first syllable would take longer to be classified as a nonword than a nonword with a first syllable such as *brot*, since the second one does not constitute a legal syllable and, so, will not result in any word activation. This was precisely what the authors observed, leading them to propose that syllables are activated and used to recognize words in the mental lexicon. Furthermore, Experiment III provided convincing evidence that first syllables were the only ones used at the first stages of visual word recognition. Experiment IV seemed to show that, regardless of a clear syllable boundary or not, the first syllable was used as an access unit, and, finally, Experiment V showed that compound words with high-frequent first syllables were more easily recognized than compound words with low-frequent first syllables, whereas for nonwords, the opposite pattern was observed. Taft and Forster (1976) explained this result suggesting that, after the syllable is activated, a serial search is conducted and, since in nonwords with a high-frequent first syllable a higher number of candidates have to be verified, low-frequent first syllables, with a lower number of words containing this syllable, are easier to classify as nonwords. The authors conclude by stating that the results observed supported the notion that syllables are activated in the visual recognition system, upon the presentation of a target word, and used to access and retrieve lexical information, hence acting as mediators between the letter and the word-form level of processing.

Following this seminal study, several other studies were conducted in the English language, though leading to divergent results (e.g., Katz & Baldasare, 1983; Printzmetal et al., 1986; Seidenberg, 1987, 1989; Taft, 1979). Using a modified version of the LDT of Taft and Forster (1976), where words and nonwords appeared separated by spaces either according to their syllable boundary (e.g., LAN TERN) or not (e.g., LANT ERN), Taft (1979) did not find signs of syllable effects. Instead, their results suggested that during visual word recognition readers segmented the English words according to their Basic Orthographic Syllable Structure (BOSS) and not according to the syllable (as it has been phonologically defined). Indeed, the standard method used to segment words into syllable relies on phonological principles and is the Maximum Onset Principle (MOP) which postulates that consonant graphemes occurring between two vowels would be assigned to the onset positions of the second syllable whenever possible. Contrarily, according to the BOSS, words would be segmented by their "first syllable and as many consonants following the vowel as orthotactic factors allow without disrupting the morphologic structure of that word" (Taft, 1979, p. 24). Thus, while according to the standard syllabication form, the MOP, the word LANTERN would be syllabified as LAN-TERN, according to the BOSS it would be syllabified as LANT-ERN.

Other studies conducted with proficient and developing English readers, using the illusory conjunction paradigm in which words appeared divided by different colors either according to their syllable boundary (e.g., MAYBE), or not (e.g., MAYBE), also yielded to conflicting results (e.g., Katz & Baldasare, 1983; Seidenberg, 1987). For instance, in the study of Katz and Baldasare (1983), skilled adult readers and second-grade readers performed a LDT combined with an illusory conjunction paradigm. The authors observed a syllable advantage (i.e., faster RTs in the syllable congruent condition), but only for the second-grade students with poor reading skills, observing no syllable effect for expert readers. Conversely, Printzmetal et al. (1986), using the same illusory conjunction paradigm with expert readers, asked them to name which was the color of the letter situated at the syllable boundary (e.g., in the case of MAYBE it would be the letter Y), and found that participants tended to name it as having the same color as the other letters in the first syllable, even when it did not, which suggested a reliable syllable effect.

Several different reasons were put forward to account for the divergent results regarding the role of the syllable in visual word recognition, including different definitions of the syllable being used (i.e., some favoring the traditional phonological syllabification, based on the MOP and others on the more orthographic approach, based on the BOSS), as well as the use of different tasks and paradigms (e.g., Seidenberg, 1987, 1989). Indeed, since most studies conducted on syllable effects asked participants to decide whether sequences of letters segmented either by spaces (e.g., Taft, 1979; Taft & Forster, 1976) or by colors (e.g., Katz & Baldasare, 1983; Printzmetal et al., 1986; Seidenberg, 1987) corresponded to a real word, one could argue that this option constitutes a limitation in itself due to the fact that, under normal reading conditions, words do not appear segmented. Moreover, it is important to stress that these pioneering studies were conducted in English, an opaque stress-timed language where syllable boundaries are often difficult to establish, as mentioned before, which might contribute to make syllables to have less perceptual relevance, as syllabic boundaries within words are harder to establish (see Mattys & Melhorn, 2005). A naming study by Ferrand et al. (1997) further highlights the fact that these hard-to-establish syllables boundaries in the English language might explain the inconsistent results observed in the literature as reliable syllable effects were only observed in the naming of English words with straightforward syllable boundaries. Nonetheless, as seen above, other studies suggested that, in English, words are parsed according to their BOSS, instead of the traditional MOP principle that goes in accordance with the phonologically defined syllables (e.g., Álvarez et al., 2016; Taft, 1979, 1992), thus making the role of the syllable as a functional unit in visual recognition of English words less clear.

In other languages with more straightforward syllabic boundaries and a more transparent phoneme to grapheme set of conversion rules, such as Spanish, French, and even German and Korean, the results have been less debatable. Indeed, the vast majority of the studies conducted in these languages point towards the relevance of the syllable during the visual word recognition for polysyllabic words. The vast majority of these studies conducted in Spanish (e.g., Álvarez et al., 1998, 2000, 2001, 2004, 2016; Carreiras et al., 2005; Carreiras & Perea, 2002; Conrad et al., 2008; Perea & Carreiras, 1998), French (e.g., Chetail & Mathey, 2009a; Conrad et al., 2007; Goslin et al., 2006; Mathey & Zagar, 2002), German (e.g., Conrad et al., 2006; Conrad & Jacobs, 2004; Stenneken et al., 2007), and Korean (e.g., Kwon et al., 2011), have followed the seminal study of Carreiras et al. (1993). In this study, using a standard LDT, the frequency of the first syllable was manipulated such there were words presenting a high-frequent first syllable and those with a low-frequent first syllable. This manipulation was based on the idea that, if syllables were indeed activated during visual word recognition and spread its activation to all the words in the lexicon that shared that same syllable, then syllables that occurred in a greater number of words, would activate a larger set of words that will compete with the target for recognition, thus slowing down processing. In support to this claim, Carreiras et al. (1983) found that words with a high-frequent first syllable elicited longer reaction times (RTs) during the LDT when compared to words with a low-frequent first syllable, thus giving rise to an inhibitory syllable frequency effect, also observed in other studies conducted in the Spanish language (e.g., Álvarez et al., 2000, 2001; Carreiras & Perea, 2002; Perea & Carreiras, 1998), as well as in other languages (e.g., French: Conrad et al., 2007; Marín & Carreiras, 2002; Mathey & Zagar, 2002; German: Conrad et al., 2006; Conrad & Jacobs, 2004; Stenneken et al., 2007; Korean: Kwon et al., 2011).

However, other studies aiming at studying syllable frequency effects in developing readers have yielded to less straightforward results (e.g., Chetail & Mathey, 2009b; Jimenéz & Hernández, 2000; Luque et al., 2013). For instance, Luque et al. (2013), but not Jimenéz and Hernández (2000), showed evidence of a syllable frequency effect in beginning readers. Results with intermediate readers did show a more reliable syllable frequency effect, however, with both Chetail and Mathey (2009b) and Luque et al. (2013) observing that intermediate readers took longer to recognize words with high-frequent first syllables, as previous studies with expert readers did. The question of when the syllable emerges as a sublexical unit in visual word recognition for developing readers remains, though, a matter of debate.

With expert readers, the results tend to consistently show evidence of syllabic activation. Nonetheless, as pointed out by Carreiras and Perea (2002), although the studies manipulating syllable frequency do seem to suggest that the syllable has some influence in the word recognition process, the fact that they use a standard LDT does not inform about when during word processing the syllable effect emerges; i.e., if before lexical access, or if only after the lexical access and lexical information has been retrieved. Note that the standard LDT is an offline measure of language processing, meaning that it only allows us to analyze the *result* of word recognition and not the *processes* that underlie word recognition (see Ferreira & Yang, 2019). Consequently, we cannot determine whether the syllable effects observed occurred before or after lexical access has been achieved. This is problematic for studies claiming that the syllable acts as sublexical unit during the process of visual word recognition. In order to support this claim, studies must be able to demonstrate that the effect is pre-lexical in nature, i.e., that it occurs before the word form has been accessed, acting as a mediator between the letter and word level of processing. A reliable way to overcome this limitation is to combine the masked priming paradigm, first introduced by Foster and Davis (1984), with the LDT. The masked priming paradigm allows us to better capture what is happening during the visual word recognition process, and not only the result of that process, hence being considered an online measure (at least it is a more online measure than the standard LDT, although, nowadays, there are more time-sensitive techniques used to study the course of visual word recognition, such it is the case of the ERPs). The masked priming paradigm consists in the brief presentation of an unconscious prime, which is thought to influence subsequent target processing, followed by a mask (#####) for 500 ms and, finally, the target that participants are meant to respond to. Because participants are not informed about the presence of the prime, and the presentation is too brief for them to become conscious of its presence, the masked priming paradigm minimizes the use of potential strategic processes in visual word recognition, making it well suited to study early automatic effects (see Forster and Davis, 1984; and Kinoshita & Norris, 2010 for more details, but also Kinoshita & Lupker, 2003 for a review).

Álvarez et al. (2004), were some of the first authors using an LDT combined with a masked priming paradigm to study syllable effects in the recognition of disyllabic Spanish words with either a consonant-vowel (CV – e.g., JU.NIO [June]) or a consonant-vowel-consonant (CVC – e.g., MON.JA [nun]) first-syllable structure as targets. Specifically, the authors asked Spanish skilled readers to respond as quickly and accurately as possible to these CV and CVC targets that could either be preceded by a syllable congruent (i.e., prime and target shared the first three letters and the first syllable– e.g., jun.as-JU.NIO and mon.di-MON.JA) or syllable incongruent nonword prime (i.e., prime and target shared the first three letters but had different syllable boundaries – e.g., jun.tu-JU.NIO and mo.nis-MON.JA) presented before the target for 64 ms. The use of this CV and CVC primes with CV and CVC targets in the experimental manipulation was chosen to ascertain about the exact nature of the priming effect. Since in both syllable congruent and syllable incongruent conditions there is the same level of orthographic overlap (i.e., in both conditions prime and target share the first three letters), only if an advantage is observed in the syllable congruent condition when compared to the syllable incongruent condition, can we claim that this is due to syllable activation and that it is a genuine syllable effect. Indeed, Álvarez et al. (2004) observed that participants were significantly faster in the syllable-congruent condition when compared to the syllable-incongruent condition, suggesting that there was indeed a syllable activation at the first stages of visual word recognition and that the effect observed was not due to an orthographic overlap between the prime and the target. Nevertheless, an unexpected result that observed was that the syllable advantage only occurred for words with a CV first-syllable structure. For CVC first-syllable structure words, no difference was observed between the syllable-congruent and the syllable-incongruent conditions. The authors interpreted this result claiming that, because the CV is the most common syllable structure, and CV words are much more common than CVC words (i.e., note that in Spanish it is estimated that there are about three times more CV words than CVC words), it would act as the canonical syllable. What this translates to is that a bias towards the CV structure would emerge in the system causing it to process all syllables as CV by default, even when encountering another syllable structure, such as the CVC. Subsequently, and using the same paradigm of Álvarez et al. (2004) but adding a third unrelated condition to serve as a baseline, Chetail and Mathey (2009a) also observed reliable syllable congruency effects in French native speakers, though, once again, only for CV first-syllable structure French words. As Álvarez et al. (2004), Chetail and Mathey (2009a) account for this syllable structure effect due to the difference in the number of CV and CVC first-syllable structure words in the French language.

The explanation proposed for this syllable structure effect, however, might not be as straightforward as it seems. While in languages such as Spanish and French there is, in fact, a considerable difference between the number of words with a CV and CVC structure, this difference is not as pronounced in other languages such as EP. Furthermore, it is unclear in what measure, type or token, did Álvarez et al. (2004) and Chetail and Mathey (2009a) base themselves when they refer to this difference, and if the syllable position within the word is taken into consideration or not. A good way to put this hypothesis to the test would by replicating replicate the masked priming lexical decision study with a new language in which the difference between the number of CV and CVC syllable-structure words could be less pronounced, such as in EP, where 38% of words have a CV first-syllable structure and 30.2% of words a CVC first-syllable structure.

Regarding the different paradigms used however, some considerations should be made about the different results obtained. For starters, it is important to point out that some studies have found evidence of a syllable activation for words with other syllable structures besides the CV structure. Speech recognition and production studies have found virtually the same results for CV and CVC word targets (e.g., Cholin et al., 2006; Mehler et al., 1981; Morais et al., 1989; Sebastián-Galles et al., 1992). In the abovementioned study of Morais et al. (1989) with EP literate and illiterate readers, for instance, the authors found virtually the same effect for CV and CVC syllables, meaning that participants were faster at detecting both CV and CVC segments in target words where these segments constituted the first syllable of the words (i.e., faster at detecting <ga> in *garagem* than <gar> and also faster at detecting <gar> in *garganta* [throat] than <ga>). Furthermore, a few studies using an LDT while manipulating syllable frequency have also found syllable frequency effects for words with different first-syllable structures. For instance, in the study of Conrad and Jacobs (2004), the authors used several different first-syllable structure words (e.g., CV, CVC, VC, and CVV) and still found the syllable frequency effect. Moreover, the study in Korean of Kwon et al. (2011), using only CVC words, they also observed the syllable frequency effect. It is important to note, however, that some factors might be explaining the different results observed regarding the syllable structure effect, however. For starters, the studies on speech perception and production use a different modality from the studies on visual word recognition, which might be causing the different results regarding syllable effects with other syllable structure words rather than the CV. As for the studies of Conrad and Jacobs (2004) and Kwon, Lee, Lee and Nam (2011), as mentioned, the authors only used a standard LDT, unlike Álvarez et al.

(2004) and Chetail and Mathey (2009a) who used an LDT combined with the masked priming paradigm. The latter is a more online measure when compared to the LDT used on its own, that is an offline technique, meaning the results obtained reflect the product of reading and comprehension, instead of giving us access to what is happening during visual word recognition (see Ferreira & Yang, 2019). Hence, there is no certainty if in LDT studies, where syllable effects for other syllable-type words were found, if these are pre or post lexical, and, in fact, the results observed in the masked priming studies might be suggesting that syllable effects for words with other syllable structures could potentially not come into play in the early stages of visual word recognition. Nevertheless, taking into account the hypothesis put forward for the syllable structure effect in Spanish and French, it is also possible that in Germany and Korean, the languages in which the studies of Conrad and Jacobs (2004) and Kwon et al. (2011) were conducted, there might not be such a pronounced difference between the number of CV first-syllable structure words and words with other first-syllable structures. Hence, subsequent studies in such languages must be conducted using a more online measure, like the masked priming paradigm, to verify these distinct results and to better understand what might be originating this syllable structure effect in masked priming lexical decision studies.

Another line of evidence regarding the syllable structure effect comes from studies conducted with developing readers. Chetail and Mathey (2012) used the syllable congruency paradigm, used by Álvarez et al. (2004) with expert readers, with intermediate (sixth grade) French developing readers. The authors observed evidence for the advantage of syllable congruent primes over syllable incongruent primes both for CV and CVC first-syllable structure words. Thus, it remains unclear why syllable congruency facilitation effects were observed both for CV and CVC words in developing readers (at least at intermediate levels of reading proficiency), but not in adult skilled readers, where reliable syllable congruency facilitation effects were restricted to CV words. Further investigation should be conducted to shed light on the syllable congruency structure effect, which has been largely overlooked over the years and, indeed, this is one of the main objectives in the present dissertation.

To gain new insights on the role that syllables paly at early stages of visual word recognition, recent studies have used electrophysiological techniques, namely the event-related potentials (ERPs; e.g., Barber et al., 2004; Carreiras et al., 2005; Chetail et al., 2012; Goslin et al., 2006; Hutzler et al., 2004; Kwon et al., 2011). The ERP is a direct and non-invasive online technique used to study how the brain responds to a cognitive, sensorial, or motor stimulus. The fact that the ERP technique provides a continuous measure of processing in the brain with high temporal resolution (see Luck, 2005 for more details) makes it particularly suited to study the nature (pre vs post lexical) of syllable effects and to establish when during the visual word recognition process does the influence of the syllable occur.

However, the syllable ERPs studies conducted so far have focused on exploring syllable frequency effects in visual word recognition by using a standard LDT (e.g., Carreiras, et al., 2005; Chetail et al., 2012; Hutzler et al., 2004; Kwon et al., 2011, but see Goslin et al., 2006 for some conflicting results regarding the syllable frequency effect in French) by manipulating both the frequency of the first syllable (high vs. low), as in Carreiras et al. (1993) seminal work, or the lexical frequency of the word as a whole (high vs. low), leaving open its potential to further explore the syllable congruency structure effect. In these studies, the brain results tend to show that syllable frequency modulates the P200, a positive deflection occurring at around 200 ms after word presentation, typically associated with high-order attentional and perceptual processes (e.g., Paulmann et al., 2013), including those for visually presented words (e.g., Evans & Federmeier, 2007; Kanske and Kotz, 2007). Typically, results have shown that words with a more frequent first syllable elicited a less positive P200 component, which has been interpreted as indexing facilitation due to syllable frequency (see Chetail & Mathey, 2012 for a deep discussion). Furthermore, syllable effects have also been shown to modulate the N400 component, a negative deflection occurring at around 400 ms after word presentation, which has been associated with lexical-semantic processing (e.g., Kutas, 1997; Kutas & Hillyard, 1980; Luck, 2005). For instance, Barber et al. (2004) showed that words with a high-frequent first syllable elicit an enhanced N400, reflecting the competition that occurs among words sharing the same first syllable for recognition. Critically, in these ERP syllable frequency studies, modulations in the N400 component are interpreted as indexing post-lexical syllable influences, while modulations in the P200 are interpreted as indexing pre-lexical syllable influences (Chetail et al., 2012).

Using the illusory conjunction paradigm combined with an LDT, Carreiras et al. (2005), also explored the electrophysiological correlates of the syllable frequency effect with Spanish skilled readers. Although behavioral data showed only significant effects for pseudowords (i.e., pseudowords in the congruent condition produced longer response times than pseudowords in the congruent condition, as expected), in the ERPs data significant syllable effects were observed for both words and pseudowords. Specifically, in the P200 component, those in the congruent condition produced weaker amplitudes than the targets in the incongruent condition. Moreover, in the N400 component, words and pseudowords in the incongruent condition elicited more negative amplitudes than those in the congruent condition. These results were in accordance with the previous ones (e.g., Barber et al., 2004; Hutzler et al., 2004) and seem to corroborate the notion that the syllable does play an important role at early stages of visual word recognition as indexed by the effect in the P200 component, like behavioral masked priming studies have been demonstrating over the years.

Although previous ERP studies have given additional evidence to an early pre-lexical influence of syllable sized units during visual word recognition, the fact that they have not manipulated words with other syllable types besides the CV makes it that they have not contributed towards a better understanding of the syllable structure effect. The only exceptions to this were the studies conducted by Goslin et al. (2006) and Kwon et al. (2011). Goslin et al. (2006) studied syllable effects in French by manipulating the syllable frequency of CV (e.g., fa.min [hunger]) and CVC (e.g., jas.min [jasmine]) first-syllable words in a standard LDT. In addition, words from each of these categories could have either a CV of high or low frequency (Experiment 1), or a CVC syllable of high or low frequency (Experiment 2), creating two experimental conditions: (i) a matched condition, in which the syllable being manipulated corresponded to the first syllable of the target word (i.e., CV syllables of high or low frequency in CV words and CVC syllables of high or low frequency in CVC words - e.g., <fa> in famin and <jas> in jasmin); and (ii) an unmatched condition, in which the syllable being manipulated did not correspond to the first syllable of the target word (i.e., CVC syllables of high or low frequency in CV words, and CV syllables of high or low frequency in CVC words – e.g., <fam> in famin and <ja> in jasmin). Although virtually the same results were found for CV and CVC first-syllable structure words, syllable frequency effects were only observed at a later time-window, around 350 ms, contrarily to what other studies had shown before (e.g., Barber et al., 2004; Hutzler et al., 2004). Consequently, the results suggested that the syllable frequency effect was post lexical. Furthermore, because the effects were found for the matched and unmatched conditions, the authors also suggested that the effect most likely reflects the activation of the first phonemes more than the activation of the first syllable. The only early effect that goes in line with previous results was found in the 150-300 ms time window, though only for CVC words and for those in the unmatched condition. Although this is a puzzling result, the authors did not put forward a possible explanation concerning what this could be owed to. Concerning the study of Kwon, Lee, and Nam (2011), in Korean, where the authors only used CVC pseudowords, they did find a syllable frequency effect in the 150-300 ms time window, showing that pseudowords with high-frequent first syllables produced lower amplitudes than those with low-frequent first syllables, though, only using pseudowords. Taken together, the results from the ERP studies presented above seem to indicate that syllable effects for CVC words are not only less compelling than for CV words, but in addition that the ERP results for CVC words seem to suggest that the syllable effects found for these words could be post lexical in nature. This could potentially explain why some studies with an LDT have observed them while masked priming studies have not.

In sum, although, the study regarding the role of the syllable during visual word recognition is not new, some important questions still subside in the current literature. The most relevant concerning the locus of the syllable structure effect observed during silent reading, which will be the main theme of the present dissertation. In fact, since so far in the current literature the syllable structure effect remains unexplained, the existing models of visual word recognition also cannot account for this effect. Furthermore, as we will see in the following section, syllable effects have only been included in a limited number of models, mainly because the main focus of psycholinguistic research for a significant period was mostly on monosyllabic words (see Jared & Seidenberg, 1990).

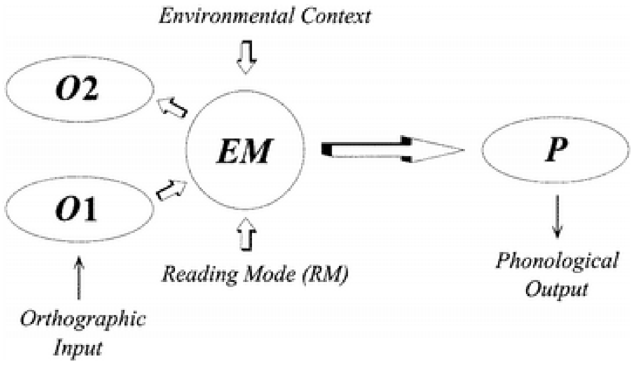
Syllable Implementation in Models of Visual Word Recognition

As mentioned above, most of the current models of visual word recognition (e.g., IA model of McClelland & Rumelhart, 1981; DRC model of McClelland et al., 2001; CDP model of Zorzi et al., 1998 and its successor, the CDP + model of Perry et al., 2007) cannot account for syllable effects simply because they focused exclusively, for simplicity, on the factors affecting monosyllabic words. This is a huge limitation since most words in a language are multisyllabic words, as mentioned before (e.g., Baayen et al., 1993; Balota et al., 2007; Vitevitch & Rodriguez, 2005), and the factors and processes affecting the visual word recognition of monosyllabic words cannot be directly applied to multisyllabic words because many additional processes occur only for multisyllabic words, including syllable segmentation, stress assignment, and vowel reduction, to mention just a few (e.g., Brand et al., 2003; Davis, 2010; Norris & Kinoshita, 2012; Perry et al., 2010; Yap, & Balota 2009).

Nonetheless, despite the limitations of these first models, it is important to note that they greatly influenced subsequent models developed to account for word recognition in words with more than one syllable, as the model of polysyllabic word reading by Ans et al. (1998). This connectionist reading model, based on the assumptions of the DRC model (McClelland et al., 2001), assumes the existence of four layers in the processing of polysyllabic word, as depicted in Figure 1: an orthographic input layer (*O*1); a second orthographic layer (*O*2), with the same structure as *O*1; a phonological output layer(*P*); and an intermediate layer of episodic memory (*EM*) that mediates between *O*1, *O*2, and *P*. The model assumes that each *O*1 unit is connected with an *EM* unit, which, in turn, is connected with *O*2 and *P* units. The *EM* unit also receives input patterns from the current reading mode being used (global or analytic) and from the environmental context surrounding the current orthographic input.

Figure 1

Reading Network of the Model of Polysyllabic Word Reading of Ans et al. (1998).

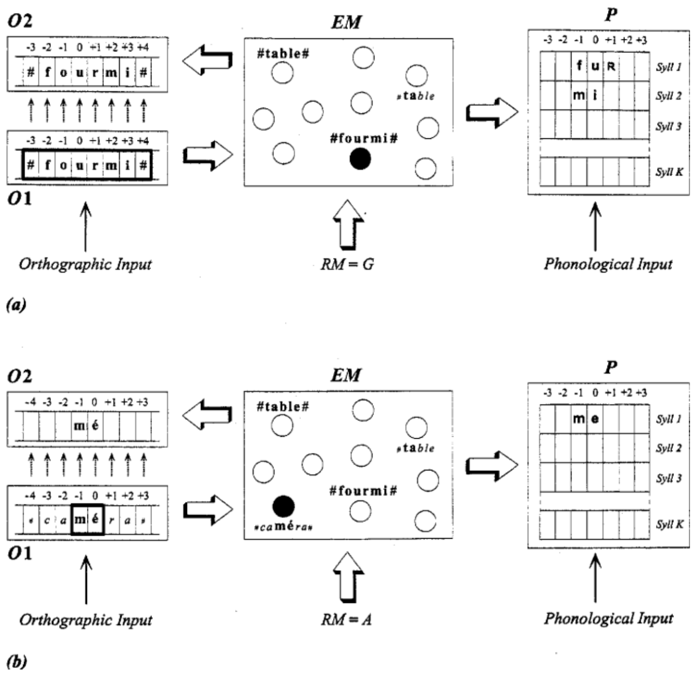


Note. Figure taken from "A Connectionist Multiple-Trace Memory Model for Polysyllabic Word Reading" by B. Ans, S. Carbonnel, and S. Valdois, *Psychological Review, 4*, 678–723, p. 682. Copyright 1998 by the American Psychological Association, Inc.

The model proposes two different processing modes through which words can be computed: the global reading mode, in which words are processed as a whole, and the analytic reading mode, in which words (i.e., typically those with very low frequencies of occurrence, novel words, and nonwords) are parsed into shorter segments (i.e., syllables) and then processed. It is important to point out that these two processes, the global and analytic reading mode, are not parallel, and that the analytic processing mode will only begin if and when the global processing mode fails. When the reading process begins, the orthographic input is held as a whole in the *O*1 through the global reading mode. In response to the input stimulus, orthographic and phonologic echoes are generated in the *O*2 and *P* layers based on the previous word traces in the *EM*, which takes into account each character and its specific position in the letter sequence currently in *O*1. Afterwards, a matching check is performed, in which the orthographic echo generated in *O*2 is compared with the orthographic input in *O*1. If they are the same (i.e., the exact same characters occurred in the same exact position), then the phonological echo is the pronunciation of the orthographic stimulus, and reading is concluded. When the echo in *O*2 is different from the orthographic input in *O*1 (i.e., there is not an exact match between the characters produced in the echo generated by *O*2 when compared to the orthographic input in *O*1), the analytic reading mode is activated. In this mode, instead of the orthographic input being considered as a whole, it is divided into smaller syllable segments and enter in the *EM* layer, which then generates the echoes in *O*2 and *P* for each segment. To summarize this process, when a letter string is encountered, it can be processed through the so-called global reading mode, where knowledge about the entire word is used for recognition, or, if that strategy fails - when the input stimulus generated in *O*1 does not correspond to the echo that the *EM* generates in *O2* - an analytic reading strategy is employed instead, and words are segmented into their syllable components and then processed by the system according to its syllable-size units. It is important to point out, however, the Ans et al. (1998) model does not consider that phonology and orthography are subjected to different computational principles; instead, word pronunciation is supported by the memory trace of previously encountered examples in the *EM* layer.

Figure 2

Coding Principles for Each of the Reading Modes



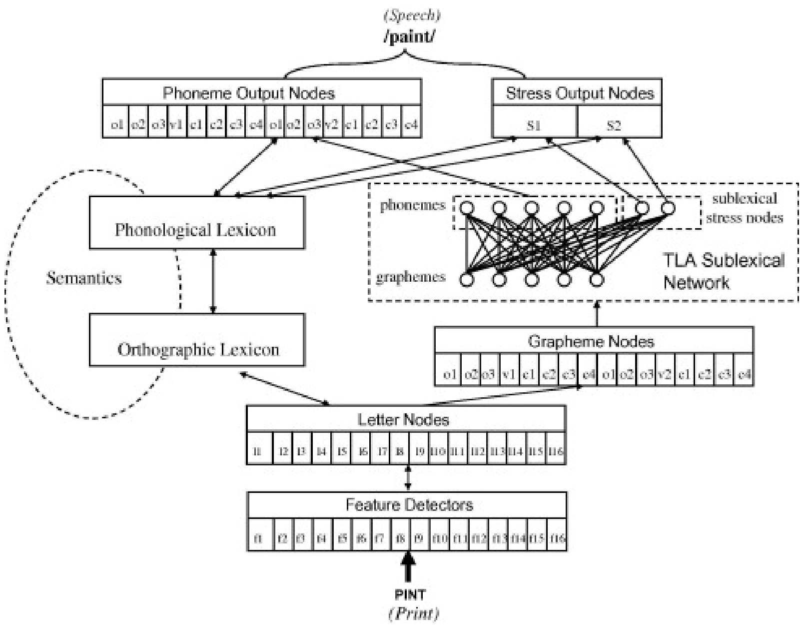
Note. (a) represents the Global Reading Mode and (b) represents the Analytic Reading Mode. Figure taken from "A Connectionist Multiple-Trace Memory Model for Polysyllabic Word Reading" by B. Ans, S. Carbonnel, and S. Valdois, *Psychological Review, 4*, 678–723, p. 684. Copyright 1998 by the American Psychological Association, Inc.

This model faces some important limitations. For once, it was not constructed to take into account syllable effects, which at the time were not very explored, such as the syllable frequency effect. Since the model does not include a syllable layer, and instead syllables are retrieved for memory, one would expect that more frequent syllables would be more easily retrieved from memory, thus, syllable frequency would be facilitative, which is not in accordance with what the literature on syllable frequency effects has shown. Other mechanisms of the model are also not made very clear, such as, for instance, if there is an exhaustive search in the *EM* for the exact orthographic input in *O*1, or if there is a time limit in which the best match generates an echo in *O*2 that, if it is not the same as in *O*1, activates the analytic processing. This would have important implications for the syllable congruency and syllable structure effects since, if an exhaustive search is conducted in the *EM* for the exact orthographic input in *O*1, there is a possibility that with a brief prime, as used in masked priming paradigms, there is not enough time for the global reading mode to switch for the analytic reading mode and, consequently, for a syllable activation to occur in the system. Hence, brief syllable congruent and incongruent primes might not have an effect on the presentation of a subsequent target, and this could happen regardless of their syllable structure.

Another relevant model in the recognition of disyllabic words is the Connectionist Dual Process (CDP) model, in its updated version, the CDP ++, by Perry et al. (2010; see Perry et al., 2007 for more details on the model's predecessor the CDP+, but also Zorzi et al., 1998 for the original CDP model). The CDP++ model is a dual-route model that assumes most of the assumptions of the DRC model (McClelland et al., 2001). It assumes the existence of two routes for visual word recognition: (i) a lexical route, which contains the orthographic and phonological lexicons connected at the letter and semantic level, and the phonological output buffer, and (ii) a sublexical route, which contains the graphemic buffer and the two-layer network of phonological assembly (TLA network), as depicted in Figure 3. In the lexical route, phonological pronunciations are retrieved based on whole-word representations through access to the orthographic and phonological lexicons. The sublexical route, however, generates pronunciations for letter strings regardless of their lexical status, hence making it crucial for learning novel words and reading words with low frequencies and nonwords. The sublexical route is organized through the existence of a graphemic buffer that is connected to the TLA network. The graphemic buffer is constituted by a kind of slot-based system in which syllables and graphemes are aligned in a disyllabic template with an onset constituent containing three slots, a vowel constituent containing one slot, and a coda constituent containing four slots, totaling eight possible slots with an CCCVCCCC structure for each of the two possible syllables. Upon a presentation of a novel word, a low-frequent word, or a pseudoword, the model assumes that, firstly, each of the syllables in the letter string is assigned to eight slots associated either with the first or second syllable and, then, each of the graphemes is assigned to their position in the graphemic buffer, congruent to the position they occupy in the letter string until all the necessary slots are filled. The slots are filled based on a left to right order and the syllabification follows the MOP principle. This means that consonant graphemes occurring after the vowel will be assigned to the onset position of the second syllable whenever possible (e.g., for instance in the word *ra.pid* the model would maximize the <p> and assign it as the onset of the second syllable and not as the coda of the first syllable). Afterwards, the graphemes now placed in the graphemic buffer will send information to the TLA network that is then able to generate the appropriate phonological output.

Figure 3

Architecture of the CDP++ Model



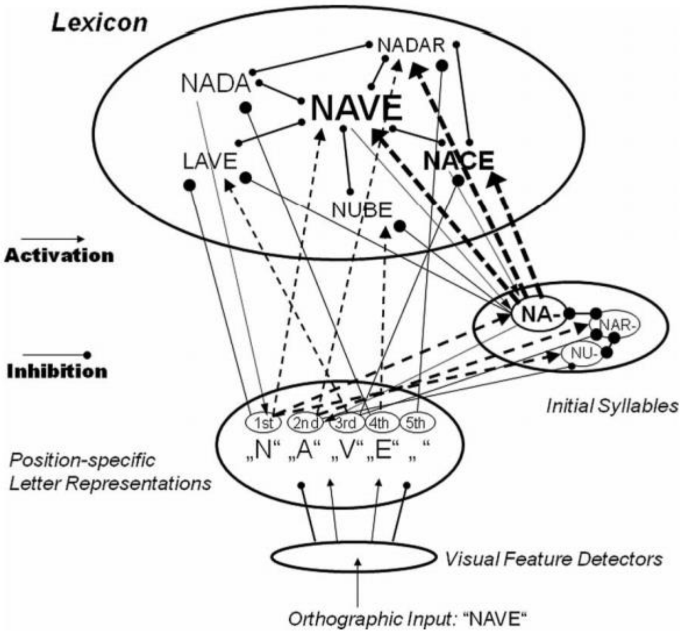
Note. Numbers indicate the slot positions and letters indicate the type of representation (f = feature; l = letter; o = onset; v = vowel; c = coda; S1 = first syllable; S2 = second syllable). Figure taken from "Beyond single syllables: Large-scale modelling of reading aloud with the Connectionist Dual Process (CDP++) model" by C. Perry, J. C. Ziegler, and M. Zorzi, 2010, *Cognitive Psychology, 61*(2), p. 116, Copyright belongs to 2010 Elsevier Inc. All rights reserved.

Although the CDP++ considers syllable segmentation before letter strings are processed, it was not built to directly account for syllable effects and neither does it suppose the existence of a mental syllabary. Instead, the syllable breaks are defined by prior knowledge during learning or determined by where they are more likely to occur, which is determined by the knowledge stored in the lexicon. The model assumes syllabification follows the MOP, according to which consonant graphemes occurring between two vowels would be assigned to the onset positions of the second syllable whenever possible. Nonetheless, it is important to point out that in some languages, such as English, syllabification seems to follow a coda maximization principle instead, as we have previously explored. Hence, following the nucleus, the first syllable would have as many consonants as possible as long as it does not disrupt the word's morphological structure. Since the model was made to simulate English words' reading, this might be an important limitation of the model. Furthermore, the CDP++ offers no explanation either of the syllable frequency effect or the syllable congruency effect (though, as we will see, the MOP syllabification principle might aid with explaining the syllable structure effect). Indeed, so far, only one model was specifically built to account for the syllable frequency effect, and it was a recent implementation of a syllable layer in the original Multiple Read-Out Model (MROM), of Grainger and Jacobs (1996), conducted by Conrad et al. (2010).

The MROM-S model (Conrad et al., 2010) proposes the existence of three levels during word recognition: a letter level, a syllable level, and a lexical level, closely resembling the proposal of the IA model (McClelland & Rumelhart, 1981). Thus, once a word is presented, letter units would be activated and then spread activation to the syllables containing the same letters in the same positions. The activated syllable units would then spread its activation to all the word units that contain the same syllables in the same positions as they appear in the target word. At the lexical level, word representations will compete with each other for word recognition via lateral-inhibition procedures and at the same time send feedback to the letter and syllable units (see Figure 4 for a graphic representation of the MROM-S model).

Figure 4

Application of the Multiple-Read Out Model with a Syllable Layer During LDT (Conrad et al., 2010)

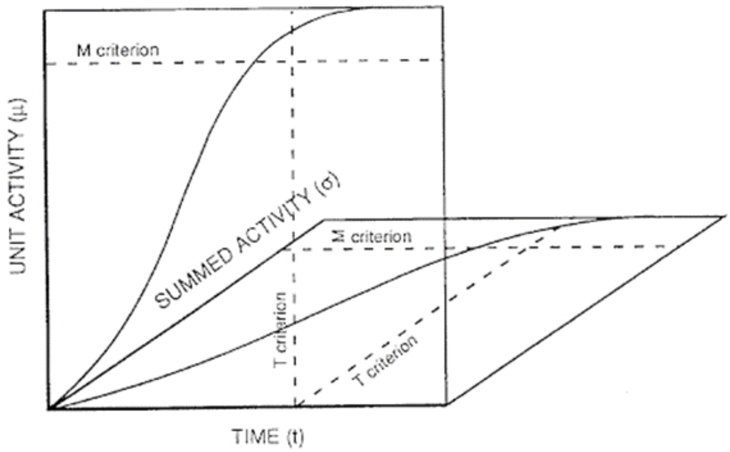


Note. Figure taken from "Simulating syllable frequency effects within an interactive activation framework" by M. Conrad, S. Tamm, M. Carreiras, and A. M. Jacobs, 2010, *European Journal of Cognitive Psychology, 22*(5), p. 872, Copyright belongs to Taylor & Francis Group.

The way the target word will be activated is either through a global activation in the system that reaches a given threshold (∑) corresponding to a "fast-guess" (σ) mechanism or, if it fails to reach this threshold, it will occur when a sufficient level of activation (M) in the system reaches a threshold for the identification of the target (μ). If neither of these response criteria (∑) and (M) are met before the *T* criteria (T stands for time), in other words, if a given duration of time is exceeded, then a "no" response is produced, and the letter string is classified as a nonword. This exact mechanism is illustrated in Figure 5.

Figure 5

Application of the Multiple-Read Out Model in the LDT.



Note. Figure taken from "Orthographic Processing in Visual Word Recognition: A Multiple Read-Out Model" by J. Grainger and A. S. Jacobs, 1998, *Psychological Review, 103*(3), p. 522. Copyright belongs to the American Psychology Association, Inc.

The MROM-S was developed to account for the syllable frequency effect in a similar way that the original MROM did for the orthographic neighborhood effect. While, at earlier stages, syllable frequency allows for a faster syllable activation in the syllabic layer, since more frequent syllables would have a lower threshold level of activation, afterwards, the activation is spread throughout all the words sharing the same syllable in the same position (syllabic neighbors), thus making that words containing high-frequent syllables will generate high levels of competition for word recognition, which delays processing particularly when syllabic neighbors have a greater frequency of occurrence than the target word. Thus, in these circumstances the target word will take longer to reach a sufficient level of activation to allow recognition, resulting in the inhibitory syllable frequency effect.

Although these models emphasize the importance of the syllable during visual word recognition, by proposing either a syllable-based segmentation mechanism, as in the case of the CDP++ and the Ans et al. (1998) models, or by proposing the existence of a syllable layer, as in the MROM-S model, none of them can directly account for the syllable congruency effects observed in the previous studies using an LDT combined with the masked priming paradigm. The MROM-S model is, however, the only one that could be potentially used to explain these syllable effects. Indeed, within the interactive activation framework, it is possible to anticipate that, upon the brief presentation of a nonword prime, the activation from the letter level of processing would spread activation to the syllable level of processing, resulting in the activation of the first syllable. In turn, the syllable would spread activation into the word level of processing to all the words that contained the same syllable in the same position. Subsequently, when a target word with this same first syllable is presented, less activation would be necessary for that word to be recognized due to the pre-activation that it could have received upon the presentation of the prime. Considering the syllable structure effect, it is possible that, because the CV is the most frequent syllable structure in languages such as Spanish and French, they could present a lower threshold level of activation, thus explaining why they might be more easily activated in the system when compared to CVC syllables, in accordance with the "fast-guess" mechanism. An important limitation of the MROM-S, however, is that the model does not explain how syllabification occurs, unlike the CDP++ model, which postulates the words are syllabified according to the MOP. The model suggests the existence of a graphosyllabic template constituted by two CCCVCCCC slots. First, each syllable of a disyllabic word would be placed into either the slot reserved for the first or second syllable, and, secondly, each of the syllable constituents would fill the available slots in the template, beginning with the nucleus and then moving on to the onset. At this stage, either the syllable activation might be concluded, or continue if there is a coda unit. It is easy to understand that, in accordance with the mechanism proposed in the CDP++ model, CV syllables would be activated more quickly than CVC syllables, as they are shorter. It could be possible that a brief presentation of CVC primes would not allow the system enough time to conclude the syllabification process, and, consequently, CVC syllables would not be activated. Hence, a CVC prime would not influence the presentation of a subsequently presented CVC word. Furthermore, it is important to mention that the CDP++ model assumes a syllabification based on the MOP, according to which, there is a maximization of the syllable's onset. Consequently, there is a preference for assigning the consonants following a vowel to the onset of the second syllable, and so, by default, upon seeing a CVC word such as *for.no* instead of assigning the letter <r> as the coda of the first syllable, it could begin by assigning it as the onset of the second syllable instead. Since in EP <rno> is not a permissible syllable, it is possible the system would then rectify this and assign <r> to the first syllable as a coda. In the case of a presentation of a brief prime, however, the first syllable activated in the graphemic buffer following a quick syllabification could be <fo> which has a CV structure, rather than <for>, which has a CVC structure. This could potentially explain why, in masked priming lexical decision studies, there is no advantage of presenting readers with a CVC prime prior to a CVC target.

The Present Dissertation

The studies presented in this dissertation were directly designed to address some important questions that remained open in the current Psycholinguistic literature regarding the role of the syllable during the early stages of visual word recognition, as the information presented in the previous sections aimed to highlight. Specifically, the studies presented here sought to contribute to a better understanding of the syllable congruency structure effect that although being observed in previous lexical decision masked priming studies remains largely overlooked in current literature. Yet, there are other additional questions that this thesis aimed to address. Clear syllable effects have been reported so far in a limited number of languages, and the less straightforward results observed in English raises the question as to whether syllable effects could be observed in other languages, especially in those who might present characteristics that could make the syllable a less prominent unit, as it could be the case of EP, an intermediate-depth stress-timed language in which, so far, no studies have been conducted. Furthermore, when, during the process of reading development, the syllable emerges as an access unit during visual word recognition, which has remained largely unexplored with the few studies conducted with developing readers leading to inconsistent results.

Thus, the main goal of the present dissertation is to investigate syllable effects at the early stages of visual word recognition in a novel language, EP, with beginning and expert readers in order to answer some of the most important issues that remained open in the current literature, and that we can formulate as follows:

1. Are syllable effects, and, in particular, the syllable congruency structure effect, observed at early stages of visual word recognition in a stress-timed intermediate-depth language such as EP?
2. When, during reading development, can these effects be noticed?
3. Is syllable complexity the driving force of the syllable structure effect?
4. How syllabic neighborhood density can modulate the syllable congruency structure effect?
5. How the nature of the task and the type of measures can affect the results?

To answer these questions, five experiments were conducted and organized into five papers corresponding to different chapters.

Chapter 1 presents the first paper, entitled "The role of syllables in intermediate-depth stress-timed languages: masked priming evidence in European Portuguese" and published in the *Reading and Writing* journal, examining whether syllable effects and, in particular, the syllable congruency structure effect were observed at early stages of visual word recognition. We used an LDT task combined with the masked priming paradigm, where the syllable congruency between prime-target pairs was manipulated giving rise to three experimental conditions: (i) syllable-congruent condition (i.e., prime and target share the first three letters and the first syllable - e.g., ru.mis-RU.MOR [rumour], for.pa-FOR.NO [oven]); (ii) syllable-incongruent condition (i.e., prime and target only share the first three letters but not the same syllable boundary - e.g., rum.pa-RU.MOR, fo.rou-FOR.NO); and (iii) an extra unrelated condition to serve as a baseline condition (e.g., ca.fas-RU.MOR, pou.me-FOR.NO), as in the study of Chetail and Mathey (2009a). To that purpose, a set of 48 CV and 48 CVC highly controlled words were selected from the Procura-PALavras database (P-PAL; Soares et al., 2014, 2018) to rule out any potential known variable that can confound the results.

Chapter 2, presents the Paper 2 - "Syllable effects in beginning and intermediate European-Portuguese readers: Evidence from a sandwich masked go/no-go lexical decision task" and published in the *Journal of Child Language*, where we investigated the developmental trajectory of syllable effects in EP using beginning (i.e., third-grade) and intermediate (i.e., fifth-grade) developing readers to ascertain when, during reading development, this sublexical unit emerges as a functional unit for lexical access, and if the syllable structure effect emerges at the same time. To this end, we have used the same paradigm used in Paper 1 with some noteworthy changes. Instead of the standard LDT, we used the go/no-go variant of the task because it has been shown to be more appropriate for younger readers, as it decreases RTs and increases accuracy rates (see Moret-Tatay & Perea, 2011). Additionally, we also used the sandwich variant of the masked priming paradigm because it has been demonstrated to be better suited for younger readers, as the previous presentation of the target, before the prime, boosts priming effects. Besides, the brief presentation of the target before the prime also minimizes potential neighborhood effects at early stages of visual word recognition (see Perea et al., 2014; Stinchcombe et al., 2012).

Chapter 3 presents Paper 3 - "Temporal Dynamics of Syllable Priming Effects on Visual Word Recognition: Evidence from Different Prime Durations" - published in the *Canadian Journal of Experimental Psychology*, which was sought to investigate if syllable complexity was the driving force of the syllable congruency structure effect observed in EP adult skilled readers. To this purpose, the same paradigm as in Paper 1 was used, but increasing the prime durations from 50 ms to 67 ms and to 82 ms instead. The rationale behind this was to test if the 50 ms prime duration on Paper 1 was insufficient to allow CVC primes to produce enough activation to significantly impact the subsequent recognition of a CVC word target. Since CVC syllables are more complex however, due to them having an extra coda unit, unlike CV syllables, it is possible that they require extra time to be processed and fully activated in the system that a 50 ms prime duration would not allow.

Chapter 4 presents Paper 4, “On the Role of Syllabic Neighbourhood Density in the Syllable Structure Effect in European Portuguese” submitted to the *Lingua* journal, which examined whether differences in the number and frequency of CV and CVC syllabic neighbors could explain the syllable congruency structure effect, at least in the EP language. Analogous to what is observed for orthographic neighborhood effect, it is possible that having a higher number of syllabic neighbors (i.e., words that share the same first syllable in the same position), can facilitate visual word recognition, in accordance with the fast-guess mechanism. Indeed, because CV syllables tend to have a higher number of syllabic neighbors when compared to CVC syllables, this discrepancy could potentially explain why CV words benefit from the previous presentation of a congruent prime, while CVC words do not, at least in the same extent as CV words when using the lexical decision masked priming paradigm. Hence, by matching CV and CVC words in this crucial variable, we wanted to investigate if syllable structure effects were still observed, which could potentially explain the syllable congruency structure effect.

Finally, in Chapter 5, Paper 5, “On the Syllable Structure Effect in European Portuguese: Evidence from ERPs” and submitted to the *Brain and Language* journal, is presented. In this last paper, we study the electrophysiological correlates of the syllable structure effect to further analyze if the use of a more sensitive temporal measure of language processing can provide new insights into the syllable congruency structure effect. Specifically, the ERP components elicited by words containing either a CV or a CVC first-syllable structure were analyzed to understand if, contrary to what had been observed in behavioral masked priming studies, words with different syllable structures could produce the same early ERP components. The illusory conjunction paradigm was used instead of the LDT task combined with the masked priming paradigm because EEG experiments require a much larger set of stimuli than a standard LDT, and we were unable to select enough CV and CVC EP words controlled in several critical psycholinguistic variables known to affect processing (e.g., length, type and token syllable frequency, type and token syllabic neighborhood density). It is also worth noting that a particular type of CVC EP first-syllable structure words was also added to the pool of stimuli; i.e., CVC first-syllable structure words that orthographically have a CVC structure but phonologically have a CV structure, as in the case of the EP word pen.te [brush] that has a CVC orthographic first-syllable <pen> and a CV phonological first-syllable /pẽ/), along with CVC first-syllable structure words that do not present a mismatch between the phonological and orthographic syllables, as in the case of for.no [oven], and CV words such as ru.mor [rumour]. Studying these words could also provide further insights into the phonological vs. orthographic nature of the syllable effects in EP, an issue that has also been strongly debated in current Psycholinguistic research.

The present thesis will end with a general discussion of the main findings and conclusions of the five papers, and how can they be accommodated by the current Psycholinguistic literature and by the current models of visual word recognition, as well as suggestions for future studies and implementations of the present results.

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Chapter 1

The role of syllables in intermediate-depth stress-timed languages: masked priming evidence in European Portuguese

Campos, A. C., Oliveira, H. O., & Soares, A. P. (2018). The role of syllables in intermediate-depth stress-timed languages: masked priming evidence in European Portuguese. *Reading and Writing, 31*, 1209–1229. https://doi.org/10.1007/s11145-018-9835-8

Abstract

The role of syllables as a sublexical unit in visual word recognition and reading is well established in deep and shallow syllable-timed languages such as French and Spanish, respectively. However, its role in intermediate stress-timed languages remains unclear. This paper aims to overcome this gap by studying for the first time the role of syllables at early stages of visual word recognition in Portuguese (European), a language where the spelling-sound correspondences are less transparent than Spanish but less opaque than French, and also with fuzzier syllabic boundaries than both languages. To that purpose, 36 native speakers of Portuguese performed a lexical decision task combined with a masked priming paradigm. Ninety-six dissyllabic Portuguese target words, and 96 nonwords, half of which with a CV (*ru.mor* [rumor]) and the other half with a CVC first-syllable structure (*for.no* [oven]), were preceded by a briefly presented nonword prime (50 ms) that could be syllable congruent (e.g., ru.mis-RU.MOR, for.pa-FOR.NO), syllable incongruent (e.g., rum.pa-RU.MOR, fo.rou-FOR.NO), or unrelated (e.g., ca.fas-RU.MOR, pou.me-FOR.NO) with the targets. Results were clear-cut and showed a facilitative syllabic priming effect in Portuguese, as target words preceded by syllable congruent primes were recognized faster and more accurately than when preceded either by incongruent or unrelated primes, although the effect was restricted to CV words. For nonwords there were no signs of syllabic effects. The findings are discussed attending to the characteristics of the Portuguese language and to current models of visual word recognition.

Keywords: Syllable, Visual word recognition, Priming, Sublexical unit

Introduction

Although reading is a fast and virtually an effortless activity for skilled readers, recognizing words is a tremendously complex process (e.g., Coltheart, Rastle, Perry, Langdon, & Ziegler, 2001; Perry, Ziegler, & Zorzi, 2010; Plaut, McClelland, Seidenberg, & Patterson, 1996; Seidenberg & McClelland, 1989; Ziegler, Perry, & Coltheart, 2000; Zorzi, Houghton, & Butterworth, 1998). Identifying the factors that affect its recognition has been a main focus of research in cognitive sciences since its early beginnings (e.g., Huey, 1908; Taft & Forster, 1976). However, most of the models developed so far can only account for the visual word recognition effects of monosyllabic words (e.g., Coltheart et al., 2001; Plaut et al., 1996; Seidenberg & McClelland, 1989; Ziegler et al., 2000). This is an important limitation since polysyllabic words are much more common than monosyllabic words in the majority of languages. For instance, in European Portuguese (EP), Soares et al. (2014) highlighted that only 641 words (0.3%) of the Procura-PALavras (P-PAL) wordform corpus (a printed corpus of approximately 227 million words) corresponded to monosyllables (see also Soares et al., 2015 for additional evidence in a subtitle corpus). The same is also observed in other languages such as English (e.g., Baayen, Piepenbrock, & van Rijn, 1993), or Spanish (e.g., Vitevitch & Rodriguez, 2005). Therefore, understanding the processes and mechanisms that underlie the visual word recognition for words beyond one syllable long is imperative in the current visual word recognition literature (e.g., Brand et al., 2003; Davis, 2010; Norris & Kinoshita, 2012; Perry et al., 2010; Yap, Tse, & Balota 2009). What is known about the lexical and sublexical factors impacting the visual word recognition of monosyllables might not be directly generalized to polysyllables whose processing introduces additional questions such as stress assignment, vowel reduction and syllabic parsing. These phenomena can significantly change the way the majority of words in a language (polysyllables) are processed and recognized.

Syllable as a unit of visual word recognition of polysyllabic words

Although several units such as letters, phonemes (e.g., Pelli, Farell, & Moore, 2003; Rastle & Brysbaert, 2006; Seidenberg, 1988), bigrams (e.g., Conrad, Carreiras, Tamm, & Jacobs, 2009; Doignon & Zagar, 2005; Seidenberg, 1987; Seidenberg & McClelland, 1989) and morphemes (e.g., Rastle, Davis, & New, 2004; Schilling, Rayner, & Chumbley 1989), have been proposed as sublexical components that mediate processing between letter input and lexical representations, most authors agree that above letter features processing, the syllable plays a functional role in reading, due primarily to its importance in speech production and perception (e.g., Mehler, Dommergues, Frauenfelder, & Segui, 1981; Morais, Content, Cary, Mehler, & Seguí, 1989; Sebastián-Gallés, Dupoux, Segui, &

Mehler, 1992). Indeed, although syllables are considered phonological units in word processing, many studies support the idea that phonological representations are activated during reading (e.g., Frost, 1998; Newman, Jared, & Haigh, 2012).

Therefore, it is not surprising that many studies conducted in different languages such as Spanish (e.g., Álvarez et al., 2001, 2004; Álvarez, de Vega, & Carreiras, 1998; Álvarez, Taft, & Hernández-Cabrera, 2016; Carreiras et al., 1993; Carreiras & Perea, 2002; Carreiras, Vergara, & Barber, 2005; Perea & Carreiras, 1998), French (e.g., Chetail & Mathey, 2009; Conrad et al., 2007; Marı´n & Carreiras, 2002; Mathey & Zagar, 2002), German (e.g., Conrad et al., 2008; Conrad & Jacobs, 2004; Conrad, Stenneken, & Jacobs, 2006; Hutzler, Conrad, & Jacobs, 2004; Stenneken, Conrad, & Jacobs, 2007), and English (e.g., Ferrand, Segui, & Humphreys, 1997; Macizo & Van Petten, 2007; Prinzmetal, Treiman, & Rho, 1986; Rapp, 1992; Schiller, 1999, 2000; Taft, 2001, 2002), have analysed the role of syllables in the recognition of printed words. This has been done mainly through the manipulation of the frequency of occurrence of the (first) syllables within words (e.g., Álvarez, Carreiras, & de Vega, 2000; Álvarez et al., 2001; Carreiras et al., 1993; Conrad et al., 2006, 2007, 2008; Macizo & Van Petten, 2007; Perea & Carreiras, 1998; Stenneken et al., 2007), and/or by exploring the (in)congruency of the syllables (first) shared between primes and targets in priming paradigms (e.g., Álvarez et al., 2004; Carreiras & Perea, 2002, 2011; Chetail & Mathey, 2009; Ferrand et al., 1997).

Syllable frequency studies

The rationale of the studies manipulating first-syllable frequency relies on the idea that, if readers parse printed words into syllables then the number of times a syllable occurs in a language (i.e., its frequency of occurrence) should impact word recognition. Carreiras et al. (1993), in one of the first studies conducted to explore the role of the syllable in the visual word recognition of Spanish, manipulated the frequency of the first syllable. Thus, two groups of words were created, words with a high versus low first-syllable frequency. The results demonstrated that high-frequent syllable words elicited longer response times and higher error rates than low-frequent syllables words. This inhibitory effect, observed in subsequent studies conducted in Spanish (see Álvarez et al., 2000, 2001; Carreiras & Perea, 2002; Perea & Carreiras, 1998) and also in other languages (e.g., French: Mathey & Zagar, 2002; German: Conrad & Jacobs, 2004), and using other techniques (e.g., eye tracking: Hutzler et al., 2004; Event Related Potentials [ERPs]: Barber, Vergara, & Carreiras, 2004; Goslin, Grainger, & Holcomb, 2006), was explained by the fact that words beginning with high-frequent syllables activate more lexical candidates than words beginning with low-frequent syllables, thus delaying word recognition for words from larger syllabic neighbourhoods that compete strongly for word selection (see Conrad, Tamm, Carreiras, & Jacobs, 2010 for a recent computational implementation of this mechanism, to account for the syllable frequency inhibitory effect in Spanish).

For English, however, there is much less evidence supporting the role of syllables in visual word recognition (e.g., Macizo & Van Petten, 2007; Prinzmetal et al., 1986; Rapp, 1992; Taft, 2001, 2002; see however the naming study by Ferrand, Segui, & Humphreys, 1997, that showed evidence towards the syllable as a sublexical unit, for words with clear syllable boundaries). The fact that English is a language in which the mapping between orthography and phonology is much more opaque than in other languages (such as Spanish that exhibits a shallow orthography) and also the fact that it presents less clear syllabic boundaries than Spanish, French, or German, have been advanced as the potential explanations for the absence of reliable syllabic effects in English. Moreover, syllables seem to have less perceptual relevance in stress-timed languages, as English, than in syllable-timed languages, like Spanish or French (e.g., Bradley, Sanchez-Casas, & Garcia-Albea, 1993; Cutler, Mehler, Norris, & Segui, 1983, 1986). In syllable-timed languages the duration of each syllable is fairly equal, whereas in stress-timed languages syllables may last different amounts of time. Note that in these languages the duration of unstressed syllables varies considerably in order to make stress syllables occur at roughly equal intervals of time (see Nespor, Shukla, & Mehler, 2011 for details), which could also contribute to attenuate the role of syllables as a perceptual unit for word recognition. Furthermore, as pointed out by Mattys and Melhorn (2005), stress-timed languages are also characterized by exhibiting more syllabic complexity (in number and variety of syllable types), and other phonological characteristics. Specifically, phenomena such as vowel reduction (i.e., in the spoken language, many vowels are not pronounced, causing a mismatch between the syllable division observed in speech and in print) and ambisyllabicity (i.e., the fact that a given consonant could both the coda of one syllable and the onset of the following syllable). These features contribute to make syllabic boundaries fuzzier and the syllable a less likely candidate for lexical access. In these languages, other units can assume a major role in word recognition. For instance, Taft (1979, 1992) proposed that English words are parsed according to the Basic Orthographic Syllabic Structure (BOSS), in which the coda of the first printed syllable is maximized without violating English orthographic rules (for instance the word radio would be syllabified as rad-io and not as ra-dio).

Syllable congruency studies

The role of the syllable in reading has also been investigated with masked priming paradigms that explored the congruency of the syllable structure shared between prime and target (e.g., Álvarez et al., 2004; Brand et al., 2003; Carreiras & Perea, 2002, 2011; Chetail & Mathey, 2009; Ferrand et al., 1997; Schiller, 1999, 2000). The masked priming paradigm, developed by Forster and Davis (1984), is a widely used paradigm to explore sublexical effects (such as syllabic effects) during the first stages of visual word recognition. Indeed, as it involves the brief presentation of a prime (virtually invisible), the information about the prime is (almost) inaccessible to consciousness (Forster, 1988). Yet, strong effects of the prime on the processing of the target were systematically observed in the cognitive literature (for reviews, see Kinoshita & Lupker, 2003; or Van Den Bussche, Van Den Noortgate, & Reynvoet, 2009). Therefore, it is considered the standard paradigm to study early and automatic effects of visual word recognition, as it minimizes the potential influence of other (strategic) effects during lexical access (see Forster 1988 for more details).

Following this paradigm, Álvarez et al. (2004) conducted a LDT with Spanish skilled readers in which disyllabic target words beginning either with a CV (e.g., *ju.nio* [june]) or a CVC first-syllable structure (e.g., *mon.ja* [nun]) (note that C stands for consonant and V for vowel), were preceded by a brief (64 ms) nonword prime that could share the first three letters and the first syllable with the target (prime congruent condition, e.g., ju.nas-JU.NIO; mon.di-MON.JA), or the first three letters but not the first syllable with the target (prime incongruent condition, e.g., jun.tu-JU. NIO; mo.nis-MON.JA). Results showed that participants were significantly faster recognizing words preceded by a syllable congruent than a syllable incongruent prime, though surprisingly the effect was restricted to CV words. The authors attempted to explain this syllable structure effect (i.e., advantage of CV over CVC words) based on the idea that the CV is the most common syllabic structure in Spanish (e.g., in the Spanish lexicon there are three times more words starting with a CV syllable than with a CVC syllable), which might cause the parser to syllabify Spanish words by using a CV first-syllable structure by default. Because CVC words are much less frequent, it is possible that CVC syllables might not produce enough activation, and/or the activation produced is not fast enough as to elicit syllabic congruency effects for CVC words in a masked priming paradigm. Indeed, recent studies using event related potentials (ERPs), have studied the syllable frequency effect with CV and CVC words (see Goslin et al., 2006 for more details) using ERPs. The results showed that words with high frequent first syllables, produced more positive potentials in the time window between 300 and 600 ms, than word with low frequent first syllables. This was obtained for CV and CVC words alike. Therefore, it is possible that masked priming paradigms are not the most adequate to capture syllabic effects in CVC words, perhaps because the prime duration is too brief (note however that Carreiras & Perea, 2011, used longer prime durations and still the syllable congruency effect remained restricted to CV words).

Evidence for syllable effects from masked priming paradigms has also been observed in other languages. For instance, Chetail and Mathey (2009), conducted a LDT using the same procedure as Álvarez et al. (2004), with a 67 ms (Experiment 1) and a 43 ms (Experiment 3) prime durations with French participants, and additionally a naming study (Experiment 2) to analyse if syllable congruency effects could be observed both in visual and spoken modalities using the same materials. An "extra" unrelated condition was also included to test whether the syllable congruency effects could arise from any orthographic overlap between primes and targets. Results showed that when primes were displayed for 67 ms, similar results were found both in the LDT and in the naming tasks. Specifically, the results showed that words preceded by syllable congruent primes produced faster recognition/naming responses than when preceded by syllable incongruent and unrelated primes, but again only for CV words (e.g., *ba.lance* [balance]). For CVC words (e.g., *bal.con* [balcony]), congruent primes produced response times as faster as incongruent primes, both differing significantly only from the unrelated condition, that presented longer latencies. In Experiment 3, no significant priming effect was observed, neither for CV nor for CVC words. These findings not only replicate the results previously observed for Spanish, but also extend them as they show that the syllable congruency effect for CV words was of facilitation as syllable congruent condition differentiated both from the syllable incongruent and the unrelated conditions. However, for CVC words there was no sign of a genuine syllabic effect as, in this case, syllable congruent and syllable incongruent primes eased recognition (note that both conditions differentiated from the unrelated condition but not between each other). In line with the explanation advanced by Álvarez et al. (2004) and Chetail and Mathey (2009) suggested that the advantage of the CV over the CVC words could also arise from the fact that in French, as in Spanish, the CV is also considered the canonical syllable structure, which might make the parser to use a CV syllabification by default.

Although syllable effects in visual word recognition have been widely investigated in French and Spanish, for EP, as far as we know, the only study exploring syllable effects in word recognition was conducted by Morais et al. (1989) in speech perception. In this study, EP participants (illiterates and literates) were asked to detect a given segment (e.g., /ga/ or /gar/) within a CV (e.g., *ga.ragem* [garage]) or a CVC (e.g., *gar.ganta* [throat]) first-syllable structure word. Results showed that both groups made fewer mistakes when the segment to identify corresponded to the first syllable (e.g., /ga/

in *ga.ragem* [garage] and /gar/ in *garganta* [throat]) than when it did not (e.g., /gar/ in *ga.ragem* [garage] and /ga/ in *gar.ganta* [throat]), thus showing that the syllable plays a role in the recognition of EP spoken words. However, to the best of our knowledge, no previous studies were conducted in the written modality, thus remaining unanswered whether the syllable also assumes a functional role during the visual word recognition of EP words.

The present study

In this paper we aimed to study for the first time the role of the syllable at the early stages of visual word recognition, in EP. Studying syllabic effects during the word recognition of EP printed words is relevant not only because it would extend syllable effects in reading to another language, but importantly because EP presents several phonological and orthographic characteristics that place it in-between languages in which syllable effects has been systematically observed (Spanish, French) and not observed (at least so consistently, English). Like Spanish and French, EP is a Romance language, but contrarily to them exhibits a set of rules that govern the grapheme-phoneme correspondences that are more opaque than Spanish but more transparent than French, thus, being considered an intermediate-depth language (see Lima & Castro, 2010 for details). Moreover, it presents a pattern of syllabification that brings it closer to English than to Spanish or French. As with English, EP presents syllabic boundaries blurred by phenomena of ambisyllabicity and vowel reduction. Unstressed syllables, notably at the end of words, are reduced in speech (e.g., see Delgado-Martins, 2002; Mateus & Andrade, 2000), thus causing mismatches between syllable divisions in speech and print (for instance the final letter e in the EP word *leite* [milk] is supressed in speech, hence giving rise to a monosyllable in speech, lˈɐjt, and a dissyllable in print, lei-te). All these features contribute for EP being considered a stress-timed language, just like English (Frota & Vigário, 2001). Moreover, EP is also considered one of the Romance languages with one of the greatest syllabic complexity. For example, when considering disyllabic words, EP presents 25 permissible syllables at first position (data obtained from the P-PAL lexical database; Soares et al., 2014), whilst Spanish presents only 16 (data obtained from EsPal lexical database; Duhon, Perea, Sebastián-Gallés, Martí, & Carreiras, 2013), and French 15 (Adda-Decker, Mareuil, Adda, & Lori, 2005). Thus, the study of the syllable in a language such as EP can shed light into the linguistic characteristics that could contribute to the emergence of the syllabic effect across-languages.

Critically, if syllabic effects in visual word recognition are driven by the suprasegmental characteristics of speech, we expect that syllabic effects observed in EP might not be as strong as those observed for Spanish and French. However, if the syllabic effects are driven by the transparency of the orthography, and/or by and by the clarity of the syllabic boundaries, we expect to observe syllabic effects in EP similar to those observed in Spanish or French. Nonetheless, it is also important to note that if syllable effects would be observed in the recognition of EP printed words, we also expect that they will be observed both for CV and CVC words conversely to what has been observed in Spanish or French languages. Indeed, if we consider that EP presents greater syllabic type diversity, as mentioned, and also that the differences between the number of CV and CVC words are not as pronounced as in Spanish or French (accordingly to the information provided by P-PAL database, in EP, 38% of the words present a CV syllabic structure while 30.2% present a CVC syllabic structure), syllabic structure effects are not expected. This prediction is also in line with the previous results observed by Morais et al. (1989) for spoken word recognition. Finally, we also expect that the locus of the syllabic effects in print will be lexical in nature, since past studies failed to find syllable length effects in nonwords (see Ferrand & New, 2003; Muncer & Knight, 2012).

Research design

To test these hypotheses, we conducted an experimental study involving the use of a lexical decision task (LDT) combined with a masked priming paradigm. This paradigm was chosen because, as mentioned, it is well suited to study early and automatic effects in visual word recognition, and also because it allowed us to directly compare the results obtained here with the ones previously obtained in other studies (e.g., Álvarez et al., 2004; Carreiras & Perea, 2011; Chetail & Mathey, 2009). Nevertheless, we aimed to analyse syllabic effects in this new language with a better control over the pool of CV and CVC stimuli used in previous studies. It is worth mentioning that Álvarez et al. (2004) and Carreiras and Perea (2011) only matched the CV and CVC words used in their studies in length, word frequency and number of orthographic neighbours, and only Chetail and Mathey (2009) matched them on the number of more frequent neighbours. This lack of stimuli control cannot rule out other potential explanations for the syllabic effects observed, nor does it allow researchers to safely state that the syllable structure effect observed in these languages (e.g., syllable advantage restricted to CV words) was due to the differences in the number of occurrences between CV and CVC syllables in the language (e.g., Álvarez et al., 2004; Carreiras & Perea, 2011; Chetail & Mathey, 2009).

Participants (undergraduate students) were recruited from the University of Minho, via an invitation sent to the e-mail addresses of the students who were attending different courses of that university. Students who were willing to participate in the study were asked to complete an online questionnaire aimed to collect socio-demographic and language background information (e.g., sex, age, place of birth, native language, language and reading history). Inclusion criteria involved being an undergraduate student with EP as a native language, and not revealing history of reading problems or learning disabilities. Data were collected individually at the facilities of the Human Cognition Lab from the Centre of Psychology (CIPsi), University of Minho. Written informed consent was obtained from each of the participants that took part in the experiment.

In the experiment the type of target (i.e., word such as *rumor* [rumour] or nonword such as berzo), the structure of the first-syllable of the target (i.e., CV as – ru-mor [rumour], or CVC as for-no[oven]), and the type of prime (i.e., nonwords that could be either syllable congruent (e.g., ru.mis-RU.MOR), syllable incongruent (e.g., rum.pa-RU.MOR), or orthographically unrelated with the target (e.g., ca.fas-RU.MOR, to the target) were manipulated. Three versions of the same task were developed to counterbalance stimuli across prime conditions in a Latin-square design. Participants were assigned randomly to each of the versions of the task, though assuring the same number of participants per version (n = 12). Reaction times (RTs, in milliseconds, ms) and accuracy (Acc) rates (i.e., the number of errors committed in the task) were collected from all participants.

Method

Participants

Thirty-six undergraduate students (M_{age} = 19.4; SD_{age} = 3.57; 32 female) took part in the experiment in exchange of course credits. All of them were native speakers of EP and had normal or corrected-to-normal vision. None of the participants reported history of reading related disorder, therefore all were considered normal skilled readers of EP.

Materials

A total of 96 disyllabic Portuguese words were selected from the P-PAL lexical database (Soares et al., 2014) as target words. Of these, 48 presented a CV (e.g., *ru.mor* [rumor]) and the other 48 a CVC (e.g., for.no [oven]) first-syllable structure accordingly both to the written and to the phonological syllabification information provided by the P-PAL database.[1] Two-hundred and eighty-eight legal nonword primes were also created and assigned to three different prime conditions: (1) 96 nonwords that shared the first three letters and the first syllable with the target (e.g., ru.mis-RU.MOR [rumour], for.pa-FOR.NO [oven]); (2) 96 nonwords that shared the first three letters but not the first syllable with the target (e.g., rum.pa-RU.MOR [rumour], fo.rou-FOR.NO [oven]); and (3) 96 nonwords that did not share any letters or syllables with the target, though they had the same syllabic structure (e.g., ca.fas-RU.MOR [rumour], pou.me-FOR.NO [oven]).

CV and CVC words were matched (all *p*s > .270) in number of letters (M_{cv} = 5.00, M_{cvc} = 5.02), per million word frequency (M_{cv} = 2.39, M_{cvc} = 2.99), neighbourhood size (*N*; M_{cv} = 6.44, M_{cvc} = 6.71), Levenshtein Distance (OLD_{20}; M_{cv} = 1.59, M_{cvc} = 1.53), number of high-frequent neighbours (M_{cv} = 2.19, M_{cvc} = 2.21), and the mean frequency of the most frequent neighbours (M_{cv} = 65.52, M_{cvc} = 76.75) as taken from P-PAL database (Soares et al., 2014). Furthermore, CV and CVC target words were also matched (all *p*s > .149) on several sublexical variables as the number of words with the same number of letters sharing the same bigrams in the same positions (M_{cv} = 367.90, M_{cvc} = 326.67), the summed logarithms (Log_{10}) of the bigram frequencies (SLBF; M_{cv} = 11.03, M_{cvc} = 11.50); and, importantly, in other syllabic measures as the number of disyllabic words containing the same syllables in the same positions (M_{cv} = 106.85, M_{cvc} = 120.71), the summed frequency (Log_{10}) of the disyllabic words that share the first syllable with the targets irrespective of the position (M_{cv} = 2.90, M_{cvc} = 2.78), the mean number of orthographic (M_{cv} = 3.04; M_{cvc} = 2.60) and phonological neighbours (M_{cv} = 2.94; M_{cvc} = 2.46) that share the first syllable with the target in the same position, and the number of words that are simultaneously orthographic and phonological neighbours and share the first syllable with the target in the same position (M_{cv} = 2.06; M_{cvc} = 2.06). Additionally, a set of 96 legal nonword targets and 288 nonword primes were also created for the purpose of the LDT. Nonword targets were created by replacing one or two letters in the medial and final positions in other Portuguese words with similar characteristics to the experimental words (e.g., *berço* [crib] became berzo by replacing the ç with a z). Nonword primes were created by using the same manipulation as the target words (96 per prime condition).

Procedure

The experiment was run individually in a soundproof booth. Presentation of the stimuli and recording of responses (RTs and Acc) were controlled by DMDX software (Forster & Forster, 2003). Participants performed a LDT combined with a masked priming technique. The LDT was composed of 192 trials (96 words and 96 nonwords) that were randomly presented to the participants. Each trial consisted of a sequence of three visual events presented at the centre of the computer screen: (1) a forward mask (#####), presented for 500 ms, (2) the prime, presented in lowercase for 50 ms, and (3) the target, presented immediately after the prime, in uppercase. Targets remained on the screen until participants' response or until 2500 ms had elapsed. Participants were asked to decide as quickly and accurately as possible if the string of letters presented in uppercase (targets) was or was not a real EP word. If participants considered that the string of letters was a real EP word they should press the M key on the keyboard ("*sim*" [yes] response). Conversely, if they considered that it was not a real EP word they should press the Z key on the keyboard ("*não*" [no] response). Both speed and accuracy were stressed in the instructions. Participants were not informed about the presence of lowercase stimuli (primes). Prior to the experimental trials, participants received 24 practice trials (12 words—six with a CV structure and six with a CVC structure—and 12 nonwords) with the same manipulation as in the experimental trials to familiarize them with the task. The whole session lasted approximately 15 min per participant.

Results

Incorrect responses for target words (4.8%) and nonwords (5.7%) were excluded from the data analyses. Words with an error rate above 33% were also excluded (it occurred for 10 words in total, and comprised words such as *cerne* [core], *nesga* [crumb], *babel* [babel] and *foral* [foral], which present a very low raw frequency in Portuguese, ranging from 0.0098 to 10.8601 per million words as obtained from the P-PAL database; and for six nonwords, such as satio and sonce). In addition, RTs that were below 300 ms and above 1500 ms were also excluded. In a second step we also eliminated RTs below and above 3.0 standard deviations from the mean performance of each participant. The mean of the RTs for the correct responses and the percentage of errors committed for the CV and CVC target words and nonwords in each prime condition are presented in Table 1.

Table 1

Mean of Lexical Decision Times (in ms) and of the Errors (%) on Target Words and Nonwords by Experimental Condition

	Prime first-syllable structure		
Target first-syllable structure	CV	CVC	Unrelated
Words			
CV words	762 (5.7)	812 (7.0)	813 (6.4)
CVC words	826 (7.1)	818 (7.4)	828 (7.2)
Nonwords			
CV nonwords	926 (16.4)	929 (14.4)	941 (13.8)
CVC nonwords	934 (14.8)	954 (16.9)	983 (16.9)

Repeated-measures of variance (ANOVAs) considering participants (F_1) and items (F_2) were conducted based on a 3 (type of prime: syllabic congruent, syllabic incongruent and unrelated) x 2 (syllabic structure of the target: CV vs. CVC) x 3 (list: 1, 2, and 3) mixed design, both on RTs and Acc data for word and nonword targets. In the F_1 analyses, type of prime and syllabic structure of the target were considered as within-subject factors and list as a between-group factor, while in the F_2 analyses type of prime was considered a within-subject factor, and syllabic structure of the target and list as between-group factors. List was included in the analyses to remove the error of variance due to the three counterbalancing lists (Pollatsek & Well, 1995).

Word targets

The ANOVA on the RTs data showed a significant main effect of the type of prime, $F_1(2, 66) = 7.499$, $MSE = 5741.150$, $p < .001$, $\eta^2_p = .185$; $F_2(2, 160) = 7.585$, $MSE = 3987.950$, $p < .001$, $\eta^2_p = .087$. This effect showed that participants were faster (31 ms) recognizing words preceded by a syllable congruent prime than by an unrelated prime ($p < .001$), though the differences between the syllable incongruent and the unrelated conditions did not reach statistical significance (a 2 ms difference). Moreover, the effect revealed that participants were also significantly faster (29 ms), recognizing words preceded by a syllable congruent prime than by a syllable incongruent prime ($p = .004$), thus establishing a genuine syllable effect during early stages of visual word recognition of EP disyllabic words. The ANOVA also showed a significant main effect of syllabic structure of the target, $F_1(1, 33) = 15.193$, $MSE = 2798.441$, $p < .001$, $\eta^2_p = .315$; $F_2(1, 80) = 1.138$, $MSE = 22{,}613.125$, $p = .148$, $\eta^2_p = .026$, though restricted to the participant data. This effect showed that participants were faster (28 ms) when the target presented a CV than a CVC first-syllable structure. Importantly, the interaction between the syllabic structure of the target and the type of prime reached statistical significance, $F_1(2, 66) = 3.210$, $MSE = 6561.351$, $p = .047$, $\eta^2_p = .089$; $F_2(2, 160) = 3.771$, $MSE = 3987.950$, $p = .025$, $\eta^2_p = .045$. The pairwise comparisons with Bonferroni correction revealed that the facilitative syllabic effect reported above (i.e., faster RTs for the target words preceded by a syllable congruent prime than both an unrelated and a syllable incongruent primes), was restricted to the EP words with a CV first-syllable structure ($p < .001$). For the EP words with a CVC first-syllable structure, there were no signs of priming as both syllable congruent and syllable incongruent primes did not differentiate significantly from the unrelated primes, and additionally from each other (*p*s = 1.000). On the Acc data, the results of the ANOVA showed a significant main effect of syllabic structure of the target, $F_1(1, 33) = 4.462$, $MSE = .020$, $p = .042$, $\eta^2_p = .119$; $F_2(1, 80) = 1.408$, $MSE = 0.017$, $p = .239$, $\eta^2_p = .017$, though restricted to the participant data. This effect indicated, in line with the RTs results, that participants committed fewer errors when words presented a CV (6.3%) than a CVC first syllable structure (8.8%). Neither the effect of type of prime nor the interaction between the two factors reached statistical significance on the accuracy data.

Nonword targets

The ANOVA on the RTs data showed a significant main effect of the type of prime, $F_1(2, 66) = 5.322$, $MSE = 17,470. 196$, $p = .007$, $\eta^2_p = .139$; $F_2(2, 172) = 3.684,123$ $MSE = 15,500.373$, $p = .027$, $\eta^2_p = .041$. This effect showed that participants were significantly faster (30 ms) recognizing nonwords preceded by syllable incongruent primes than by unrelated primes ($p = .014$). They were also faster (22 ms) recognizing nonwords preceded by syllable congruent primes, than by an unrelated prime ($p = .119$), although the differences were only approach significance. Furthermore, the differences between the syllable congruent and the syllable incongruent conditions (8 ms) did not reach statistical significance. Thus, for nonwords there was no signs of syllabic priming effects. Moreover, the RT results revealed a main effect of the syllabic structure of the target $F_1(1, 33) = 9.560$, $MSE = 33,771.841$, $p = .004$, $\eta^2_p = .225$; $F_2(1, 86) = .334$, $MSE = 5180.632$, $p = .565$, $\eta^2_p = .004$, restricted to the participant data. This effect showed that participants were significantly faster (25 ms) responding to CV words than CVC nonwords ($p = .004$). On the Acc data, the ANOVAs did not show statistically significant effects.

Discussion

Although previous studies conducted in deep and shallow syllable-timed languages, such as French and Spanish respectively, have provided evidence for the relevance of the syllable as a sublexical unit at early stages of visual word recognition (e.g., Álvarez et al., 2004; Carreiras & Perea, 2002, 2011; Chetail & Mathey, 2009), in EP its role has been unexplored. Our study was developed to directly address this issue by using a LDT combined with a masked priming paradigm, as used in previous studies (e.g., Álvarez et al., 2004; Carreiras & Perea, 2011; Chetail & Mathey, 2009). As stated in the introduction, EP is a pivotal language to study syllabic effects in visual word recognition, since it presents phonological and orthographic characteristics that put it between languages in which syllabic effects were systematically observed (e.g., Spanish, French) or not observed (e.g., English). Thus, studying syllabic effects in EP will shed light on the language features that could contribute to the emergence of syllable effects during visual word recognition, in a given language.

The results obtained here clearly demonstrate that, at initial stages of visual word recognition, the syllable functions as a sublexical unit in the recognition of EP printed words. Indeed, the brief presentation (50 ms) of a nonword prime that not only shared the first three letters, but importantly the same syllable boundary with the target, eased the visual word recognition of EP dissyllabic words (note that the use of unrelated primes allows us to conclude that this effect was of facilitation), tough only for CV words. CV words were also recognized faster and more accurately than CVC words. Finally, the results obtained also demonstrated that the locus of the syllabic effect was lexical in nature, since for nonwords targets the presentation of a nonword prime that shared the first-syllable seems to have no impact on the speed and accuracy with which EP nonwords were recognized.

These results partially support our hypotheses. Indeed, as expected, a reliable syllabic congruency effect was observed in EP, which extends previous findings observed by Álvarez et al. (2004), Carreiras and Perea (2011), and Chetail and Mathey (2009), to another Romance language. These findings are interesting and showed with an improved methodological design that even though EP is a stresstimed language, which led us to hypothesize that the role of the syllable as a functional unit in the visual word recognition of EP words might be attenuated, as in English, these suprasegmental characteristics were not relevant enough as to prevent the syllable congruency effect from emerging in EP. The fact that EP is also a Romance language exhibiting clearer syllable boundaries than English (though less than Spanish and French), might explain why presenting a nonword prime that not only shared the first three letters but, importantly, the first-syllable boundary eased the visual word recognition of EP words. Evidence supporting this potential interpretation comes from the naming study of Ferrand et al. (1997) with English native-speakers. Using the masked priming paradigm, the authors found an advantage of the syllable congruent condition over the syllable incongruent and unrelated conditions but only for English words with clear syllabic boundaries (e.g., *bal-cony*; the *l* can only belong to the first syllable because lc cannot constitute a permissible syllable), and not for ambisyllabic words (e.g., *ba-lance*; the *l* can form both the syllable *bal* and the syllable *lan*). Although these results were found in a naming study, they clearly suggest that the unambiguousness of the syllabic boundaries within words in a given language seems to drive the emergence of syllabic effects at early stages of visual word recognition.

Moreover, it is also important to stress here that, although to date no computational model of visual word recognition has attempted to account for the syllable congruency effect observed in different languages (note that the MROM-S model was developed to account for the syllable frequency effects observed in the Spanish language), we can anticipate, however, within an interactive model of activation, that when a nonword syllable prime is presented (e.g., *ru.mis*), it is syllabified on a syllabic layer, as proposed by the MROM-S model (Conrad et al., 2010), thus spreading activation to all of the words in the lexicon that present that syllable in the same position (e.g., *ru.mor* [rumour], *ru.blo* [ruble], *ru.bro* [red], *ru.bra* [red]). Consequently, when a target word that shares that syllable is presented (e.g., *ru.mor* [rumour]), less activation is necessary for that word to be recognized, hence explaining the syllable congruency effect observed. Note that when nonwords were used as primes (as in our case) facilitative and not inhibitory syllabic effects were obtained. This was firstly observed by Carreiras and Perea (2002) in a masked priming study where target words were preceded either by word and nonword primes sharing the first syllable. The findings showed a different pattern of results for each of the two types of primes. When word primes were used, an inhibition syllable effect was observed. Conversely, when nonword primes were used a facilitation syllable effect was observed instead. The authors argued that, because nonwords do not compete directly with the target words for activation, its effect was of facilitation, since the threshold of activation necessary to a "YES" response would be reached quickly when a prime containing the same syllable as the target, in the same position, is presented. This is also consistent with the fast-guess mechanism proposed by the original MROM model (Grainger & Jacobs, 1996) and by the DRC model (Coltheart, Rastle, Perry, Langdon, & Ziegler, 2001), to explain why words that showed a higher level of similitude with other words in the lexicon were recognized faster and more accurately than words that showed less similitude (see Coltheart et al., 2001; Grainger & Jacobs, 1996 for details).

However, if this mechanism could account for the syllabic congruency effect observed in our data, it does not explain how syllabification is achieved during early stages of visual word recognition. The only model that has, to date, attempted to include a syllabic level of word processing has been the MROM-S model (Conrad et al., 2010). Yet, it still does not describe how the syllabification process takes place. Nevertheless, it is possible to anticipate that as in the CDP++ model (Perry et al., 2010) there might be a graphemic buffer that syllabifies words according to the maximal onset principal (MOP), in a syllabic layer that mediates between the letter lever of processing that the lexical level of representation. Specifically, after the letter level, word processing might proceed by extracting information regarding the nucleus of the syllable (vowel), followed by the onset of the first syllable. At this stage, the processing might end, with the syllable being activated, or it might have to continue, if this syllable contains a coda unit. Still, although this mechanism might explain the syllabification process, it does not account for the syllable structure effect observed in our data.

Indeed, contrary to our predictions, and to the results previously observed by Morais et al. (1989) in spoken word recognition, in EP the syllable congruency effect was restricted to CV words, as previously observed for Spanish (e.g., Álvarez et al., 2004; Carreiras & Perea, 2011) and French (e.g., Chetail & Mathey, 2009). So, even though EP is a language with one of the richest collections of syllable structures across all Romance languages and, in addition, a language where the differences between the number of occurrences of CV and CVC first-syllable words are less pronounced than in other languages, reliable syllable congruent effects were still restricted to CV words. Note, however, that for CVC words, syllable congruent primes also produced faster reaction times than both syllable incongruent and unrelated primes, as for CV EP words, though the differences across-prime condition were not large enough to reach statistical significance. One could argue that perhaps because CVC syllables are longer, participants would not have to process the prime until the fourth letter, in order to activate the CVC syllable. Thus, a 50 ms prime might not be sufficient time for the participants to process the CVC syllables, and this could be the cause of the syllable structure effect. However, other behavioral studies have provided evidence favoring an early activation of the phonological information presented in a nonword primes beyond the first letters of the string, as the vast amount of studies with transposition letter effect have demonstrated (e.g., Comesaña, Soares, Marcet, & Perea, 2016; Lupker, Perea, & Davis, 2008; Perea & Acha, 2009; Perea & Lupker, 2004). Taken together, these results suggest that a 50 ms nonword prime duration might indeed be sufficient to allow the syllabification process to occur for both syllabic structures. Moreover, these studies and our results suggest that at early stages of visual word recognition both syllable structures seem to be processed, although the level of activation generated by CVC nonword primes seems not to be strong enough as to allow the syllable congruency effect to emerge for this syllable structure. Furthermore, it is also worth noting here that evidence supporting that both syllable structures are activated at first stages of visual word recognition has also been obtained from recent ERPs studies. These studies have shown not only that syllable frequency effects were modulated in early (P200) ERP components (e.g., Barber et al., 2004), but, importantly, that CV and CVC syllables activate the same neural correlates (e. g., Goslin et al., 2006). Nevertheless, it is also important to consider that, since the CVC syllable structure is more complex than the CV syllable structure, particularly because it presents an extra element (coda) that has been shown to be the hardest syllabic element to process (see Treiman & Danis, 1988 for more details), it is also possible to anticipate that CVC nonword primes might be more difficult to syllabify than CV nonword primes. This might explain the absence of reliable syllable congruency effects for CVC words in our study and in many other studies conducted in other languages (e.g., Álvarez et al., 2004; Carreiras & Perea, 2011; Chetail & Mathey, 2009).

In these studies, the syllable structure effect was explained relying on the idea that the CV is the most common (canonical) syllabic structure in these languages, which might cause the parser to syllabify words by using a CV strategy by default. Nevertheless, since these studies lack a strict control of the stimuli used, as mentioned, it is possible that other variables might explain the results. To overcome these limitations, the CV and CVC stimuli used in our study were matched on a wide range of lexical and sublexical variables, including several type and token positional and non-positional syllable statistics (see the Materials section). However, and despite this highly strict control, syllable priming effects were still only observed for the CV words. In a tentative to further explain the factors that might underlie the advantage of the CV over the CVC syllabic structure, we reanalysed our CV and CVC word stimuli attending only to the composition of first syllable. This reanalysis showed that, when we disregard the composition of the second syllable, the CV words used in our study revealed a higher type (M_{cv} = 74.5, M_{cvc} = 29.9, p = .002) and token (M_{cv} = 2.70, M_{cvc} = 2.22; p = .001) first syllable frequency than the CVC words used, which might explain the syllabic advantage observed. Indeed, since the CV words present both a higher number of words that share the same syllable at the same position, and also words that are more frequent in the EP language, this could have allowed the system to generate a higher level of activation for a 'yes' response when CV words were preceded by a CV congruent nonword prime than when CVC words were preceded by a CVC congruent nonword prime, as proposed by the original MROM (Grainger & Jacobs, 1996) and the DRC (Coltheart et al., 2001) models. Therefore, the levels of activation generated by CVC nonword primes might not have been strong enough as to significantly impact the 'yes' response when CVC target words were presented, at least in the behavioural masked priming paradigm used in our study. Subsequent studies should further investigate the syllable congruency effect with more sensitive on-line techniques, such as ERPs. Moreover, future studies should also attempt to investigate if giving the prime more time to be processed, the syllable congruency effect might emerge for CVC words.

To conclude, it is worth noting that the results presented in this paper clearly demonstrate, with a set of stimuli much more controlled than the ones used in previous studies, that the syllable plays indeed a functional role at early stages of visual recognition of EP words, at least for those beginning with a CV syllable, as captured by a masked priming paradigm. These results not only add to the current literature, because they extend the syllabic effects previously observed in Spanish, French, and German to another language with distinct orthographic and phonological characteristics, but importantly because they shed light into the mechanisms/ language characteristics that can better account for the syllabic effects observed in different languages. It is imperative that the current models of visual word recognition are amended to include, not only a syllabic layer, as in the MROM-S model (Conrad et al., 2010), that could account for the syllable structure effects observed in different languages, but additionally that could specify the principles/ mechanisms by which the syllabification process takes place as in the CDP++ model (Perry et al., 2010). Moreover, it is also important to highlight that, from an applied point of view, these results also draw attention to the importance of using syllabic based methods when teaching EP children how to read and write, an issue that has been attracting a growing interest in the literature (e.g., Chetail, Colin, & Content, 2012; Doignon-Camus et al., 2013; Ecalle, Kleinsz, & Magnan, 2013; Zhang & Wang, 2014).

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Chapter 2

Syllable effects in beginning and intermediate European-Portuguese readers: Evidence from a sandwich masked go/no-go lexical decision task.

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Abstract

Reading is one of the most important milestones a child achieves throughout development. Above the letter level, the syllable has been shown to play a relevant role at early stages of visual word recognition in adult skilled readers. However, studies aiming to examine when, during reading acquisition, the syllable emerges as a functional sublexical unit are scarce, and the studies conducted so far have led to inconsistent results. In this work, beginning and intermediate European-Portuguese (EP) developing readers performed a sandwich masked lexical decision task in which CV (e.g., RU.MOR[rumour]) and CVC (e.g., CIS.NE[swan]) first-syllable EP words were preceded either by syllable congruent (e.g., rum.ba-RU.MOR, cis.ra-CIS.NE), syllable incongruent (e.g., rum.ba-RU.MOR, ci.ser-CIS.NE), unrelated (e.g., va.craRU.MOR, zar.vo-CIS.NE) pseudowords primes, or identity (e.g., ru.mour-RU.MOUR, cis.ne-CIS.NE) primes. Results showed reliable syllable effects only for intermediate readers and for CV and CVC words alike. Findings are discussed attending to current models of visual word recognition.

Keywords: Syllable effects; developing readers; visual word recognition; masked priming

Introduction

Reading is one of the most important milestones a child achieves throughout development. It is also a complex cognitive task to fulfil, involving the mapping of new orthographic representations into a set of pre-existent phonological representations in our lexicon (e.g., Grainger, Lété, Bertrand, Dufau & Ziegler, 2012). Many children struggle in mastering this important skill, which often has a negative impact not only on learning and academic success, but also in other lifelong accomplishments as citizenship, employment, and income (e.g., Hernandez, 2011; Maughan, Pickles, Hagell, Rutter & Yule, 1996; Spreen, 1989). Estimates indicate that almost 20% of all school-aged children are at risk of reading difficulties (e.g., Grigorenko, 2000), and that about 3% to 10% of them reveal reading impairments despite normal IQ and adequate educational and socioeconomic opportunities (e.g., Shaywitz, 1998; Snowling, 2001). Hence, ascertaining the processes and mechanisms by which children learn to read is of utmost importance not only to deepen our understanding of how this complex skill is achieved, but also to contribute to the development of programs aimed to enhance reading abilities and/or to help children who struggle with reading problems to overcome their difficulties.

An important line of research in this domain focuses on examining the factors that affect reading between the letter level of representation and the word (lexical) level of processing, which includes sublexical units such as phonemes (e.g., Pelli, Farell & Moore, 2003; Rastle & Brysbaert, 2006; Seidenberg, 1988), bigrams (e.g., Conrad, Carreiras, Tamm & Jacobs, 2009; Doignon & Zagar, 2005; Seidenberg, 1987; Seidenberg & McClelland, 1989), syllables (e.g., Álvarez, Carreiras & Perea, 2004; Campos, Oliveira & Soares, 2018, 2019; Carreiras, Álvarez & de Vega, 1993; Prinzmetal, Treiman & Rho, 1986; Rapp, 1992), and morphemes (e.g., Rastle, Davis & New, 2004; Schilling, Rayner & Chumbley 1989). Of these, the syllable has received a great amount of attention due mostly to its importance both in speech perception (e.g., Mehler, Dommergues, Frauenfelder & Segui, 1981; Morais, Content, Cary, Mehler & Segui, 1989; Sebastián-Gallés, Dupoux, Segui & Mehler, 1992) and production (e.g., Cholin, Levelt & Schiller 2006; Schiller, 1997). In an example of one of these studies, Morais et al. (1989) investigated if there was a syllabification process during speech recognition with Portuguese illiterates and ex-illiterates. To this extent, the authors presented participants with short sentences and asked them to detect the occurrence of a CV or a CVC target syllable in CV and CVC words that appeared within those sentences. So, in the sentence "O homem fechou a garagem [The man closed the garage]" they could be asked to detect the segment /gA/ or /gAr/. Results showed that participants had a higher number of correct detections when the target bearing word had the same syllable boundary of the target syllable they were meant to detect. Thus, in the example sentence given above, they would have a higher number of detections for /gA/ than for /gAr/, since the first target corresponds to the first syllable of the word "garage", while the other does not. This syllable effect was observed for CV and CVC target syllables, and for both groups of participants, suggesting that syllable processing is not dependent on formal instruction and happens naturally. Evidence of syllable effects were also observed in speech production studies, as for instance in the study of Cholin et al. (2006). In their experiment, the authors' goal was to test the existence of a mental syllabary by which we quickly retrieve syllables during speech processes. They presented participants with high- or lowfrequency first-syllables which they were instructed to name as quickly and accurately as possible. In their hypothesis, if the mental syllabary consists of retrievable representations corresponding to syllables, then the retrieval process should be sensitive to frequency differences. Their results showed a significant syllable frequency effect, with high-frequency first syllables being more quickly produced than low-frequency first syllables, which went in accordance to their predictions. Besides the evidence obtained in these studies, it's also important to mention that the fact that in alphabetic languages, learning to read rests heavily on a spoken language foundation (e.g., Goswami & Bryant, 1990; Shankweiler, Crain, Brady & Macaruso, 1992; Snowling, 1991) and that phonological units are activated during reading (e.g., Jared, Levy & Rayner, 1999; Van Orden, Pennington & Stone, 1990), have also been pointed out as reasons why the syllable should be an important sublexical unit during silent reading.

Indeed, evidence for the relevance of the syllable has been obtained in visual word recognition with adult skilled readers from not only syllable-timed languages with clear syllabic boundaries such as Spanish (e.g., Álvarez et al., 2004; Álvarez, Carreiras & Taft, 2001; Álvarez, Carreiras & de Vega, 2000; Carreiras, Álvarez & de Vega, 1993; Carreiras & Perea, 2002; Perea & Carreiras, 1998) and French (e.g., Chetail & Mathey, 2009a; Conrad, Grainger & Jacobs, 2007; Mathey & Zagar, 2002), but also from stress-syllable languages with less-clear syllabic boundaries as EP (e.g., Campos, Oliveira & Soares, 2018, 2019). Yet, studies focusing on tracking when the syllable emerges as a functional unit of lexical access during reading acquisition and how it evolves as literacy unfolds are scarce, and the studies conducted so far have led to some inconsistencies.

One of the first studies aimed at investigating if developing readers use the syllable to guide visual word recognition was conducted by Colé, Magnan, and Grainger (1999). The authors presented fifth-grade French children with a visual segment detection task in which consonant-vowel (CV; e.g., *so.leil* [sun]) and consonant-vowel-consonant (CVC; e.g., *sol.dat* [soldier]) French first-syllable structure words were preceded either by CV (e.g., SO) or CVC (e.g., SOL) syllables displayed on the computer screen for 150 ms. Participants were asked to decide whether the syllable presented before corresponded, or not, to the first syllable of the target word (note that the dots in the examples were only included here to facilitate comprehension but were not presented in the experiment). As expected, results showed facilitative effects for French words preceded by syllables that corresponded to the first syllable of the words (e.g., SO-*so.leil* or SOL-*sol.dat*) when compared to those preceded by syllables that did not correspond to the first syllable of the words (e.g., SOL-*so.leil* or SO-*sol.dat*), though for CVC words the advantage of the syllable congruent condition over the syllable incongruent condition was observed in the accuracy data. Other studies conducted in other languages using the same paradigm with children from either early (e.g., Doignon & Zagar, 2006; Jiménez, García, O'Shanahan & Rojas, 2010; Maïonchi-Pino, Magnan & Écalle, 2010) or later stages of reading acquisition (e.g., Colé & Sprenger-Charolles, 1999; Doignon & Zagar, 2006; Maïonchi-Pino et al., 2010) observed similar results, hence suggesting that children use the syllable as a sublexical unit for the recognition of both CV and CVC first-syllable structure words from early stages of reading acquisition. Recently, Álvarez, García-Saavedra, Luque, and Taft (2017), also found evidence for the use of the syllable in second- and sixth-grade Spanish developing readers using a new (word spotting) paradigm. Specifically, in this paradigm, children were asked to decide whether a monosyllabic Spanish word was or not embedded in the beginning of visually presented Spanish disyllabic pseudowords as *FIN.LO*, or *BER.NO*, for example. In this specific case, children should respond "yes" to the Spanish pseudoword *FIN.LO* because *FIN* corresponds to a real monosyllabic Spanish word, whereas they should answer "no" to the Spanish pseudoword *BER.NO*, because *BER* is not a Spanish word. Note that, in the stimuli used, the authors also manipulated the congruency of the syllabic boundary of the monosyllabic words embedded in the pseudowords, which could be consistent (e.g., *FIN.TO*), or inconsistent (e.g., *FI.NUS*) with the existing (*FIN*) monosyllabic Spanish word. In both grades results showed that children were faster at recognizing the monosyllabic words embedded in the pseudowords when the syllable boundary was consistent rather than inconsistent with the target word (i.e., faster at recognizing *FIN* in *FIN.TO* than in *FI.NUS*), which was taken as indicative of the use of the syllable by beginning and intermediate readers.

Additional evidence for the role of the syllable in developing readers comes from other studies asking children to decide whether a string of letters presented at the centre of the computer screen corresponded or not to a real word (i.e., the standard lexical decision task [LDT]) in which the frequency of the first syllable was manipulated (e.g., Chetail & Mathey, 2009b; Luque, López-Zamora, Álvarez & Bordoy, 2013). As in previous studies conducted with adult skilled readers (e.g., Álvarez et al., 2001; Carreiras et al., 1993; Conrad et al., 2007; Mathey & Zagar, 2002; Perea & Carreiras, 1998), these studies assumed that, if printed words were parsed into syllables, words containing high-frequency first-syllables should be recognized slower than words containing low-frequency first-syllables because the former would activate more lexical candidates and generate more lexical competition than the latter. As expected, Chetail and Mathey (2009b) with fifth-grade French children, and Luque et al. (2013) with second- and fourth-grade Spanish children, found longer RTs for words from larger syllabic neighbourhoods. These results are accounted by a recent implementation made in the Multiple read-out model (MROM; Grainger and Jacobs, 1996), the Multiple read-out model with a syllabic layer by Conrad and colleagues (MROM-S; Conrad, Tamm, Carreiras & Jacobs, 2010), the only computational model of visual word recognition that has implemented syllable-sized units to account for the inhibitory syllable frequency effect observed in languages like Spanish and French (see Conrad et al., 2010 for details). There is another model, however, that also postulates the existence of a syllable layer of word processing, though it takes a different approach to the MROM-S: the model for polysyllabic word reading by Ans, Carbonnel, and Valdois (1998). According to it, words can be recognized by two different processes, a global reading strategy or an analytic reading strategy. In the first strategy, words would be recognized as a whole, whilst in the latter they would be segmented into their syllable components. In this model the authors propose that whilst expert readers read most words through the global reading strategy, the opposite would be true for the developing readers, who would read most words through the analytic reading strategy. Thus, the younger the readers, the more they would rely on a syllable-segmentation strategy during visual word recognition. Nonetheless, there have been some studies that place some questions into this assumption, as they have not yielded such straightforward results when it comes to syllable effects with young readers, particularly those in the beginning stages of reading acquisition. For example, Jiménez and Hernández (2000) in a study with first-grade Spanish children manipulating the frequency of the first syllable, as in the studies of Chetail and Mathey (2009b) and Luque et al. (2013), did not find any differences between high and low-frequent first-syllable words. Also, Katz and Baldasare (1983) and Chetail and Mathey (2009c), in studies with English and French second-grade children, respectively, using the standard LDT where words were presented segmented according either to their syllable boundaries or not, by using slashes or different colours (e.g., pa/per, p/aper), failed to show any signs of syllable effects. In both studies, facilitative syllable effects (i.e., faster RTs for pa/per than p/aper) were only observed for the less-skilled readers in a post-analysis considering children's reading performance as assessed by standardized reading tests.

Hence, from the studies presented above, it is not clear if and when, during reading development, the syllable emerges as a functional unit of visual word recognition. The inconsistency of the results can emerge from different sources, like the use of different tasks and paradigms (e.g., visual segment detection task, LDT, word spotting), the use of different reading proficiency groups (from first- to fifth-grade children), and also the use of different languages. Specifically, the languages used have more or less clear syllable boundaries, and they also differ on the level of orthography-phonology opacity, which might strongly influence the level of activation of phonological representations during reading, and hence the stage at which certain sublexical units, such as the syllable, might come into play. Moreover, it is also important to note that some of the tasks used so far did not provide compelling evidence towards the use of the syllable as a sublexical unit at early stages of visual word recognition. Indeed, to decide if a given syllable is embedded in the beginning of a subsequent word, as in the visual segment detection task, participants only have to read the beginning of the word to successfully complete the task, and there is no way of assuring that the lexical access was actually reached. Furthermore, in the visual segment detection task, as well as in the LDT in which the words appeared explicitly segmented according to their syllable-boundaries, or not, by the use of slashes or different colours, the conscious manipulation of the syllable prevents us from drawing conclusions about the existence of an automatic activation of syllable-size units at early stages of visual word recognition. Although the word spotting task provides a more implicit mode of syllable processing, the use of pseudowords also raises some problems. There have been both studies showing (e.g., Álvarez et al., 2000; Chetail, 2014), and not showing (e.g., Campos et al., 2018; Ferrand & New, 2003; Muncer & Knight, 2012) syllable effects with pseudowords. Hence, they appear to be less straightforward than syllable effects with words. Besides, in the word spotting task, there is also no way of assuring that participants read the full string of letters (pseudowords) as in the lexical decision task, for instance.

The best way to overcome these limitations is to use the masked priming paradigm combined with a LDT, as Álvarez et al. (2004) did with Spanish adult skilled readers (see also Chetail & Mathey, 2009a and Campos et al., 2018, 2019, for a similar procedure with French and EP expert readers, respectively) and also Chetail and Mathey (2012) with French intermediate readers. Specifically, following Álvarez et al. (2004), Chetail and Mathey (2012) presented sixth-grade French children with CV (e.g., VO.LUME [volume]) and CVC (e.g., VUL.CAN [volcano]) French words that were preceded by briefly presented (67 ms) primes that could be either syllable congruent (e.g., vo.liar-VO.LUME, vol.tie-VOL.CAN [vulcan]) or syllable incongruent (e.g., vol.cer-VO.LUME, vo.ode-VOL.CAN) with the targets. Results showed that children were faster at recognizing words preceded by syllable congruent primes than by syllable incongruent primes, thus suggesting that the syllable acts indeed as a sublexical unit that aids lexical access at early stages of visual word recognition, as previously observed with French adult skilled readers (e.g., Chetail & Mathey, 2009a). However, conversely to the results obtained with adult skilled readers, not only in French (Chetail & Mathey, 2009a), but also in Spanish (Álvarez et al., 2004), or in EP (Campos et al., 2018, 2019), the advantage of the syllable observed by Chetail and Mathey (2012) with intermediate French developing readers was found for CV and CVC first-syllable French words alike. In those studies with expert readers, the advantage of the syllable congruent condition over the syllable incongruent condition (indicative of facilitative syllable priming effects) was restricted to CV words (i.e., faster responses to ba.lieux-BA.LANCE [balance] than bal.veux-BA.LANCE, but not to ba.lave-BAL.CON [balcony] than bal.nat-BAL.CON), giving rise to the syllable structure effect that remains largely unexplained in the literature. Although both Álvarez et al. (2004) and Chetail and Mathey (2009a) have suggested that this effect might rely on the fact that the majority of words in Spanish and French have a CV first-syllable structure, thus making CV syllables be activated even when a CVC syllable is presented, in languages such as EP this issue may be more complex. Indeed, the difference between the number of CV and CVC words in the EP lexicon, as obtained from the Procura-PALavras (P-PAL) lexical database (freely available at http://p-pal.di.uminho.pt/tools; see Soares, Medeiros, Simões, Machado, Costa, Iriarte, Almeida, Pinheiro & Comesaña, 2014a, 2018), is much less pronounced in EP than in other languages (see Campos et al., 2018 for more details), thus requiring further explanation. Furthermore, it is worth pointing out that not even the few computational models of visual word recognition that explicitly assume the existence of a syllable layer (see the models of Ans et al., 1998 and Conrad et al., 2010) make any predictions of a mechanism that can explain why syllable structures may modulate the role of the syllable during visual word recognition.

Concerning the results obtained by Chetail and Mathey (2012) with sixth-grade French children, although these were interesting and overcame many of the limitations observed in previous studies with developing readers, there are still some issues left unanswered. For example, because the authors only used intermediate (i.e., sixth-grade) readers, the extent to which syllable effects can be also observed at early stages of reading acquisition (beginning readers) and to which kind of words (CV and/or CVC) remains open. Moreover, the issue of the syllable structure effect was largely overlooked.

The experiments reported in this paper were designed to directly address these issues by using third-grade (Experiment 1) and fifth-grade (Experiment 2) EP developing readers who performed a LDT (go/no-go), combined with a sandwich masked priming paradigm (Lupker & Davis, 2009). We opted for the go/no-go variant of the LDT, as many other studies with developing readers (e.g., Perea, Soares & Comesaña, 2013; Soares, Perea & Comesanã, 2014b; Soares, Lages, Oliveira & Hernández, 2019), since Moret-Tatay and Perea (2011) demonstrated that it is more appropriate for young readers as it decreases RTs and increases accuracy rates. Additionally, we also chose to use the sandwich variant of the masked priming paradigm because the brief presentation of the target (i.e., around 33 ms) before the presentation of the prime seems to boost masked priming effects that are typically of small size, particularly with developing readers, and also because it contributes to mitigate neighbourhood effects at early stages of visual word recognition (see Perea, Mallouh & Carreiras, 2014; Stinchcombe, Lupker & Davis, 2012). Finally, in addition to the syllable congruent and incongruent conditions, we also used an 'extra' unrelated condition, as in the Chetail and Mathey (2009a) and Campos et al. (2018, 2019) studies, plus an 'extra' identity prime condition, in which primes and targets were repeated. Note that only including an unrelated baseline condition, which both congruent and incongruent condition were compared to, allows the establishment of genuine facilitative or inhibitory syllable priming effects, as the direct comparison of syllable congruent and incongruent conditions only allows to conclude for differences in processing. The use of the additional identity prime condition is also highly recommended in masked priming studies with young children to assure that the priming task is working appropriately even when no other effects are observed (see Soares et al., 2014b, 2019; Perea et al., 2013 for examples). Since reliable masking priming syllable effects were already observed with EP adult skilled readers in studies using a similar paradigm (Campos et al., 2018, 2019), the main question at stake here is if syllable effects in EP can be noticeable with non-skilled readers and at which stage of reading development (beginning and intermediate). This would also provide valuable insights into the role that language characteristics might play in the emergence of syllable effects in different languages. Álvarez et al. (2017) and Luque et al. (2013) have suggested that because, in more opaque languages, readers take longer to automatize the reading process, syllable effects might not emerge as early as in a transparent language such as Spanish, as readers might still heavily rely on a letter-by-letter strategy of reading. Besides, it is also possible that other language characteristics can also affect the emergence of syllable effects in reading. For instance, EP is a language with fuzzier syllable boundaries than French or Spanish, and with a greater syllable complexity and diversity than observed in most of the Romance languages (see Campos et al., 2018 for details). Consequently, masked priming syllable effects might only be noticeable at later (intermediate) stages of reading acquisition, and for CV and CVC words alike, as observed in most of the studies conducted with developing readers. Although in EP Campos et al. (2018) only observed reliable syllable priming effects for CV words are mentioned, it is important to note that this was an unexpected result because not only had previous studies investigating the role of the syllable during EP speech recognition found syllable effects for both CV and CVC words (Morais et al., 1989), but also because in EP the difference between CV and CVC words is less pronounced than in other languages, as previously mentioned.

General Method

Materials

A total of 144 EP words were selected from the ESCOLEX database (Soares, Medeiros et al., 2014a) as targets. ESCOLEX is an EP grade-level lexical database that provides several word frequency statistics for 6- to 11-year-old children (first to sixth grade) computed from elementary textbooks (see Soares et al. (2014a) for details). Half of the words had a CV first-syllable structure (e.g., *ru.mor* [rumour], *ca.racol* [snail]) while the other half had a CVC first-syllable structure (e.g., *cis.ne* [swan], *per.fume* [perfume]). For each group of words (CV and CVC), half were disyllabic, and the other half were trisyllabic. CV and CVC words were matched in several psycholinguistic variables shown to affect EP word processing (e.g., Soares et al., 2015, 2019) (see Table 2) as obtained both from the ESCOLEX (Soares et al., 2014a) and the P-PAL lexical databases (e.g., Soares et al., 2018).

Table 2

Psycholinguistic Variables Matched Between CV and CVC Words

	CV words		CVC words		
Psycholinguistic variables	*M*	*SD*	*M*	*SD*	*p*
Length (number of letters)	5.97	1.04	6.01	1.02	.759
Frequency (per million)	4.15	3.86	3.74	4.77	.561
Contextual Diversity (CD)	0.099	0.112	0.096	0.069	.806
Neighbourhood Size (*N*)	4.39	4.70	4.46	4.67	.929
Number of higher frequency orthographic neighbours	1.15	1.87	1.40	2.44	.491
Mean frequency of higher frequency orthographic neighbours	31.71	197.88	38.33	93.83	.798
Levenshtein Distance (OLD_{20})					
Number of words sharing orthographic syllables with	1.76	0.39	1.72	0.37	.532
the target	693.82	805.07	744.25	770.38	.702
Summed syllable frequency					
Number of words sharing syllable 2 in position 2	10.17	12.59	14.65	18.11	.087
Number of words sharing syllable 2 in any position	300.54	356.09	307.79	312.92	.897
Number of words sharing trigrams with the target	642.69	812.79	569.32	606.37	.540
Mean trigram frequency	142.32	169.38	139.25	175.75	.915
Summed frequency of words sharing trigram 1 in	9.38	20.90	13.99	20.38	.187
position 1	83.71	230.04	148.79	256.61	.096
Number of words sharing trigram 2 in position 2					
Summed frequency of words sharing trigram 2 in any	25.67	25.54	20.03	15.74	.113
position	308.99	508.35	530.99	889.72	.068
Number of words sharing bigrams with the target					
Summed bigram frequency	977.65	723.53	981.65	832.18	.975
Mean bigram frequency	5335.17	2440.65	6310.53	3622.65	.060
Number of words sharing the 1st bigram in position 1	11.43	19.85	11.61	10.69	.946
Summed frequency of words sharing the 1st bigram in position 1	170.51	176.24	206.75	210.21	.264
Number of words sharing the 1st bigram in any position	934.83	827.94	1204.62	1122.03	.103
Summed frequency of words sharing the 1st bigram in any position	537.69	564.76	561.56	539.99	.796
Summed frequency of words sharing the 3rd bigram in position 3	2519.52	1881.28	2962.86	2296.97	.207
	979.19	1463.49	807.56	1031.96	.417

Four hundred and thirty-two pseudoword primes were also created and assigned to one of three priming conditions: (i) 144 pseudowords that shared the first three letters and the first syllable with the target (i.e., syllable congruent condition – e.g., ru.mes-RU.MOR [rumour], cis.ra-CIS.NE [swan]); 144 pseudowords that shared the first three letters, but not the first syllable with the target (i.e., syllable-incongruent condition – e.g., rum.ba-RU.MOR, ci.ser-CIS.NE); and (iii) 144 pseudowords that neither shared the first three letters nor the first syllable with the target (i.e., unrelated condition – e.g., va.cra-RU.MOR, zar.vo-CIS.NE). Additionally, the 144 words used as targets were also used as primes in the identity prime condition (e.g., ru.mor-RU.MOR, cis.ne-CIS.NE). A set of 144 pseudowords were also created as targets for the purpose of the LDT. Pseudoword targets were created by replacing one or more letters from other EP words with similar lexical characteristics to the experimental words used in the task. The manipulation for the pseudowords targets was the same as for the word targets (i.e., syllable congruent condition- e.g., la.sor-LA.SES, vor.mo-VOR.CA; syllable incongruent condition- e.g., las.mo-LA.SES, vo.rus-VOR.CA; unrelated condition- e.g., be.zos-LA.SES, cas.za-VOR.CA; and identity condition- e.g., la.ses-LA.SES, vor.ca-VOR.CA). Four lists of materials were created to counterbalance targets across the prime conditions. Participants were randomly assigned to each list, though assuring the same number of participants per list (n = 9). In each list, participants responded to the full set of words and pseudoword targets (N = 288), with one third of each associated to the different prime conditions. The full list of prime-target pairs be found at https://bit.ly/37pTmKf.

Procedure

The experiments were run in a quiet room in the schools attended by the participants in groups that did not exceed four children per experimental session. Presentation of the stimuli and recording of responses were controlled by the DMDX software (Forster & Forster, 2003). Participants performed a go/no-go LDT combined with a sandwich masked priming technique, as mentioned before. The go/no-go task entailed 288 trials (144 words and 144 nonwords) that were randomly presented to the participants. Each trial consisted of a sequence of four visual events presented at the centre of the computer screen: (i) a forward mask (#######) presented for 500 ms; (ii) the target, presented in uppercase for 33 ms (Courier New, size 14); (iii) the prime, presented in lowercase for 50 ms (Courier New, size 14); and (iv) the target again, presented in uppercase (Courier New, size 14) until participants response or until 2,500 ms had elapsed. An interval of 1,000 ms between trails was used. Participants were asked to decide as quickly and accurately as possible if the string of letters presented in uppercase (targets) at the centre of the computer screen constituted or not a real EP word. If participants considered that the target was a real word, they were instructed to press the *M* key on the keyboard (*sim* [yes] response). Conversely, if they considered that it was not a real word, they were instructed to refrain from responding and to wait until a new letter string appeared at the computer screen. Three pauses were introduced during the experiments (each 96 trials) to allow participants to rest. Participants decided when to continue with the task by pressing the spacebar in the computer's keyboard. Participants were not informed about the presence of the primes before target presentation. Prior to the experimental trials, participants received eight practice trials (four words and four pseudowords) with the same manipulation as the experimental trials to familiarize them with the task.

None of the participants reported having perceived the primes when asked after the experiment. The whole session lasted approximately 25 minutes in the fifth-grade group, and 35 minutes in the third-grade group. Written informed consent was obtained from the parents of the children involved in the experiments. The study was approved by the local Ethics Committee (University of Minho, Braga, Portugal).

Experiment 1 (Beginning Readers)

Participants

Thirty-six third-grade children (M_{age} = 8;7; SD_{age} = 0;4; 22 female) from two private schools of Braga took part in the experiment. All were native speakers of EP with normal or corrected-to-normal vision, and did not have any reading or learning disorder, as reported by their teachers.

Materials and procedure

See the General Method section.

Results

Latency (RTs in ms) and accuracy (% of correct responses) were analysed for word targets with linear mixed effects (lme) models using the R software (Bates, Maechler & Bolker, 2011). Incorrect responses (12.96% of the word data) and correct responses below 500 ms and above 2,000 ms, as well as above and below 3 *SD* of the mean RTs of each participant per experimental condition were also excluded from the latency analysis (5.89%). The lme on RTs were conducted with participants and items as crossed random intercept with the two repeated-measure factors: Type of prime (identity|congruent|incongruent|unrelated) and Type of target (CV|CVC) with random slope per subject but not per item (see Barr, Levy, Scheepers & Tily, 2014; but also Matuschek, Kliegl, Vasishth, Baayen & Bates, 2017). All factors were treated as fixed factors in the analyses. For accuracy, we used a generalised lme with logistic link function and binomial variance. The models were fit by using the lme4 R library (Bates et al., 2011) and the lmerTest R library in order to contrast simple effects with differences of least squares means. For the effects that reached statistical significance, the second degree of freedom of the F statistic was approximated with Satterthwaite's method (see Satterthwaite, 1941; and, Khuri, Mathew & Sinha, 1998 for a review). The p-values were adjusted with Hochberg's method for all post-hoc comparisons equal or below .05 (see Benjamini & Hochberg, 1995, and Hochberg, 1988 for details). Table 3 presents the mean RTs (in ms) for the correct responses and the % of errors (in brackets) for the CV and CVC target words used by prime condition.

Table 3

Mean of Lexical Decision Times (in ms) and of the Errors (%) on Target Words by Experimental Condition in the Beginning Readers Group (Third-Grade Students)

	Prime first-syllable structure			
Target first-syllable structure	Identity	Congruent	Incongruent	Unrelated
CV words	1112 (15.6)	1107 (16.5)	1105 (18.8)	1184 (17.7)
CVC words	1070 (8.5)	1119 (9.7)	1136 (8.0)	1160 (8.8)

On the accuracy data there were no statistically significant results.

Results on the latency data revealed a main effect of the type of prime, $F(3, 4056.1) = 16.3146$, $p < .001$ indicating that participants were faster in the identity prime condition than in the unrelated condition (81 ms, difference, $p < .001$), and also in the identity prime condition than in the syllable incongruent condition (32 ms difference, $p = .033$). The difference between the identity and the syllable congruent conditions was not statistically significant (23 ms, $p = .068$). Furthermore, the effect showed that participants were also faster both in the syllable congruent (58 ms difference, $p < .001$) and in the syllable incongruent conditions (50 ms difference, $p = .001$) than in the unrelated condition. The difference between the syllable congruent and syllable incongruent conditions were statistically non-significant (8 ms difference). The interaction between the two factors also failed to reach statistical significance.

Taken together, these findings showed that, although third-grade EP readers were faster at recognizing CV and CVC words preceded by syllable congruent and syllable incongruent primes than unrelated primes, thus revealing significant priming effects in both conditions, the difference between syllable congruent and syllable incongruent primes failed to reach statistical significance, hence failing to show genuine syllable masked priming effects for EP beginning readers. Note that, for a genuine syllable effect to be observed, participants should present significantly faster responses in the syllable congruent condition than in the syllable incongruent condition, which would indicate that the masked priming effect observed was not a product of the orthographic overlap between primes and targets. In the following section the results obtained with intermediate EP readers are presented.

Experiment 2 (Intermediate Readers)

Participants

Thirty-six fifth-grade students (M_{age} = 10;6; SD_{age} = 0;3; 20 female) from the same private schools as Experiment 1 took part in the experiment. All participants were native speakers of EP, with normal or corrected-to-normal vision. As in Experiment 1, none of the children had any reading or learning disorder, as reported by their teachers.

Materials and procedure

See the General Method section.

Results

The analyses and trimming procedures used in Experiment 2 followed those adopted in Experiment 1. Incorrect responses (4.82% of the word data) and outliers (3.68%) were excluded from the analysis. Table 4 presents the mean RTs for the correct responses and the % of errors (in brackets) on each experimental condition.

Table 4

Mean of Lexical Decision Times (in ms) and of the Errors (%) on Target Words by Experimental Condition in the Intermediate Readers Group (Fifth-Grade Students)

	Prime first-syllable structure			
Target first-syllable structure	Identity	Congruent	Incongruent	Unrelated
CV words	942 (6.0)	949 (6.0)	987 (6.9)	1016 (7.1)
CVC words	900 (2.9)	941 (3.2)	975 (2.8)	1005 (3.5)

On the accuracy data no effects reached statistical significance

Results on the RT data, showed a main effect of the type of prime, $F(3, 4590.6) = 31.9817$, $p < .001$, indicating that participants were faster at recognizing words preceded by identity primes than both unrelated (90 ms difference, $p < .001$) and syllable incongruent primes (60 ms difference, $p < .001$), as in Experiment 1, and also faster at recognizing words preceded by identity primes than by syllable congruent primes (25 ms difference, $p = .008$). The type of prime effect also showed that fifth-graders were also faster at recognizing words preceded by syllable congruent primes (65 ms difference, $p < .001$) and syllable incongruent primes than by unrelated primes (30 ms difference, $p = .001$) and, critically, that the difference between syllable congruent and syllable incongruent primes reached statistical significance (35 ms difference, $p = .009$).

The findings allow us to establish the emergence of a genuine masked priming syllable effect at this stage of EP reading acquisition and, importantly, that this effect was virtually the same for CV and CVC words, as predicted. Indeed, although both syllable congruent and syllable incongruent primes produced facilitative masked priming effects, as both differentiated significantly from the unrelated condition, as in Experiment 1, participants were still significantly faster in the syllable congruent condition than in the syllable incongruent condition. This result leads us to interpret the advantage of the syllable congruent condition as an early and automatic activation of the syllable per se and not a product of the orthographic overlap between prime and target as observed in third-grade EP children.

General discussion

The importance of the syllable as a phonological unit, and also the fact that reading rests heavily on a spoken language foundation, at least in alphabetic languages, has led several authors to propose that, above the letter level, the syllable acts as relevant sublexical unit during lexical access and reading. Although several studies conducted with expert readers have provided strong evidence for an automatic activation of syllables at early stages of visual word recognition (e.g., Álvarez et al., 2004; Campos et al., 2018, 2019; Chetail & Mathey, 2009a), studies are scarcer on developing readers investigating the extent to which the syllable also plays a role at early stages of visual word recognition, and at what stage during reading development. Moreover, the few studies conducted so far have used different tasks and paradigms, and also groups of developing readers with different levels of reading proficiency and recruited from languages with different characteristics, which may contribute to explain the inconsistency of the results observed in the developing reading literature. Here we used a LDT (go/no-go), combined with the sandwich variant of the masked priming paradigm with beginning (third-graders) and intermediate (fifth-graders) EP readers to overcome the limitations of previous studies, and to further examine the developmental trajectory of syllable effects at early stages of visual word recognition in EP, an intermediate-depth stress-timed language, where syllabification is less clear and more complex than in French and Spanish.

The results obtained from lme analyses were clear-cut and showed that, in EP beginning (third-grade) readers, there was no evidence of genuine syllable effects, as both syllable congruent and syllable incongruent conditions produced similar facilitative priming effects in the recognition for both

CV and CVC words. Indeed, besides the advantage of the identity prime condition over all the other prime conditions, and the advantage of the syllable congruent and incongruent conditions over the unrelated condition, the difference between the syllable congruent and incongruent conditions, indicative of genuine syllable effects, did not reach statistical significance. This finding suggests that the facilitation observed in these conditions results from the orthographic overlap between primes and targets for CV and CVC words alike, and not from the share of the syllable per se. In the intermediate reader group (fifth-graders), however, the results seem to support the view that the syllable really acts as a sublexical unit at early stages of word recognition in EP. Not only did the syllable congruent and incongruent conditions differentiate from the unrelated condition, but, importantly, they distinguish between each other with fifth-graders being significantly faster at recognizing CV and CVC words preceded by syllable congruent primes than by syllable incongruent primes.

These findings are in line with our predictions and with the results obtained by Chetail and Mathey (2012) with sixth-grade French children, though not with the results obtained from other masked priming studies conducted with expert readers both in EP (Campos et al., 2018, 2019), and in other languages (e.g., Álvarez et al., 2004; Chetail & Mathey, 2009a). Indeed, conversely to what we found with fifth-readers, in these studies, reliable syllable effects were observed for CV, but not for CVC words, which has been accounted for by the fact that CV syllables are much more frequent than CVC syllables at least in languages as Spanish and French (e.g., Álvarez et al., 2004; Chetail & Mathey, 2009a). This might make the visual recognition system to develop a bias towards the processing a CV syllable even when a word has a CVC first-syllable instead. In EP, however, as mentioned before, the difference between the number of words presenting a CV and a CVC syllable structure is much less pronounced than in those languages. This made Campos et al. (2018) anticipate the absence of a syllable structure effect in EP adult skilled readers in accordance with which has been previously observed in speech recognition by Morais et al. (1989) with literate and illiterate EP adult native speakers. Nonetheless, the results showed that reliable masked priming syllable effects were only observed for CV words, as previous studies in the Spanish (e.g., Álvarez et al., 2004) and French (e.g., Chetail & Mathey, 2009a) languages also demonstrated. Other variables, like the number of syllable neighbours of CV and CVC words, were put forward by Campos et al. (2018) as alternative explanations. Indeed, although Campos et al. (2018) matched the CV and the CVC words used in their experiment in several psycholinguistics measures, including the number of words sharing the same first syllable in the EP lexicon, this control was made regardless of syllable position. So, considering not only recent studies showing that the first syllable plays a more relevant role during visual word recognition than syllables in other positions (see for instance Álvarez et al., 2000), but also the definition of syllable neighbour, which states that it refers to words that share the same syllable in the same position (Perea & Carreiras, 1998), and with the same word length (Chetail & Mathey, 2011), it is possible that the difference in the number of neighbours sharing the first syllable might account for the results. Specifically, the authors proposed that the denser syllable neighbourhood of CV words relative to CVC words, when considering the first position, may have made CV words be more easily activated in the visual recognition system, thus justifying the results. This explanation was further supported by a recent study conducted by Campos et al. (2019), where the authors ruled out syllable complexity (CVC syllables are more complex than CV syllables and, hence, might require more time to be fully activated) as an alternative explanation for the syllable structure effect observed in EP by increasing prime durations from 50 ms to 67 ms and 82 ms (see Campos et al., 2019 for details). It is also worth noting that the use of the sandwich masked priming paradigm in the current work with EP developing readers could have also contributed to the absence of the syllable structure effect both in third- and fifth-reader children as this paradigm also allows to better control for neighbourhood effects, as mentioned in the introduction (Lupker & Davis, 2009). Note that, conversely to the conventional masked priming paradigm (Forster & Davis, 1984), the brief presentation of the target before the prime in this variant of the paradigm pre-activates the target representation, hence minimizing the influence of other similar lexical competitors on target recognition.

Nevertheless, even though Chetail and Mathey (2012) did not advance any explanation for the fact that sixth-grade French children showed reliable masked priming paradigm syllable effects both for CV and CVC words, which contrasts with the results observed with French adult readers (e.g., Chetail & Mathey, 2009a), we can anticipate that, in intermediate stages of reading acquisition, children may indeed rely on the use of the syllable for lexical access and word recognition, and, in a wider way, than adult expert readers do. Although current models of visual word recognition cannot account for this developmental trajectory of the syllable structure effect (see for instance the MROM model by Grainger & Jacobs, 1996), we can anticipate that, because children rely more strongly on the sublexical than on the lexical route during visual word recognition, as the whole-word orthographic representations are still being developed, intermediate readers, particularly from languages with deep and intermediate-depth orthographies, rely more on the phonological recodification processes, thus making syllable effects to be observed both for CV and CVC words. Furthermore, this view is also supported by the Ans et al.'s (1998) model – which suggests that at early stages of reading acquisition children read most words by segmenting them into their syllable components – and also by studies conducted with expert readers showing that in tasks recruiting phonological processes more extensively, as in speech recognition (e.g., Mehler et al., 1981; Morais et al., 1989), syllable effects were observed for CV and CVC words alike.

It is also worth mentioning that EP beginning readers failed to show any signs of reliable syllable effects, which is in accordance with our predictions. Since EP is an intermediate-depth stress-timed language with a more complex pattern of syllabification than syllable-timed languages like Spanish and French, and less straightforward grapheme-to-phoneme conversion rules, unlike Spanish (which is a shallow language) it is possible that reading processes in EP would take longer to be automatized: hence making reading, at the earliest stages of reading acquisition, occur through a slower serial letter-by-letter decoding strategy (see Álvarez et al., 2017; Luque et al., 2013 for similar arguments). However, with increased exposure to print and accumulated experience, children are able to develop sublexical orthographic representations that allow them to recognize words in a faster and efficient way by using units above letter-level. From this theoretical framework, it is possible that, because of the characteristics of the EP language, our beginning readers are still at a more immature stage of reading acquisition, hence making syllable effects to be noticeable only at a later (intermediate) stage. Note that, although our beginning readers were third-grade readers, the experiment was conducted at the beginning of the school year, thus making their reading skills to be more similar to second-grade children, which might explain the results – note that previous masked priming studies conducted with EP second-grader children also failed to observed any significant effects besides identity priming effects (see for instance Soares et al., 2014b for a study aimed to track the developmental trajectory of the consonantal bias in EP developing readers).

Taken together, the present results seem to suggest that, as exposition to print increases and literacy unfolds, syllable effects are observed for CV and CVC words alike, at least in a reading stage where sublexical orthographic representations above the letter-level of processing are already at stake, allowing the syllable to play a functional role at early stages of visual word recognition. However, as readers become more proficient, it is also possible that the visual word recognition system also begins to take into consideration other fine-grained variables, like the number of times a given syllable appears in a given position in the lexicon and/or the number of words sharing the same syllable in a given (first) position, to optimize reading. Nonetheless, more studies are needed to better understand the syllable structure effect in skilled readers, particularly using measures highly sensitive to the time course of processing as event related potentials (ERPs). Current models of visual word recognition should also be further developed to account for this syllable structure effect. Bear in mind that, although the MROM-S model of Conrad et al. (2010) and the model of Ans et al. (1998) have proposed the existence of a syllable layer during the process of visual word recognition, neither of them specify the mechanisms by which a word is syllabified into its components, nor how the syllable structure might affect this process and might change as reading proficiency unfolds. Additionally, from a more applied point of view, considering that the syllable acts indeed as a mediator between the letter level of representation and the word level of processing, it might be relevant to develop teaching techniques focused on using a syllable approach to reading, not only with normal children that have no history of language or reading related disorders, but also to those who might reveal some type of reading or language disabilities.

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Chapter 3

Temporal Dynamics of Syllable Priming Effects on Visual Word Recognition: Evidence from Different Prime Durations

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Abstract

Although the syllable has been shown to play a relevant role at early stages of visual word recognition, several studies using consonant-vowel (CV) and consonant-vowel-consonant (CVC) first-syllable words have also shown that reliable effects are observed for CV but not for CVC words. Several proposals have been advanced to account for this syllable structure effect, though studies aiming to directly address this issue are scarce. Here we tested whether syllable complexity might underlie the syllable structure effect observed in several languages, by replicating the masked priming lexical decision study conducted by Campos, Oliveira, and Soares (2018) with Portuguese adult skilled readers using 50-ms pseudoword primes, but using longer (67-ms and 82-ms) prime durations. If the structure syllable effect is driven by syllable complexity, increasing prime durations should make facilitative syllable priming effects to emerge for CVC words. Furthermore, by manipulating prime durations we can also provide new insights into the temporal dynamics of syllable effects at early stages of visual word recognition. Results from linear mixed effects (lme) models analyses showed that even with increased prime durations, reliable syllable effects were still restricted to CV words. Increasing prime durations to 67 ms and 82 ms only strengthened orthographic priming effects for CVC words. Moreover, the magnitude of the priming effects for CV words remained fairly constant across these prime durations, thus suggesting that the CV advantage on visual word recognition is not a short-lived effect. Results are discussed attending to current findings in the literature.

Keywords: syllable structure effect, prime durations, syllable complexity, CV priming effect

Public Significant Statement

Previous studies conducted in different languages have shown that the syllable plays a relevant role at the early stages of visual word recognition for CV, but not for CVC first-syllable words. Here we tested whether syllable complexity can account for this syllable structure by manipulating prime durations using a masked priming lexical task. Linear-mixed models (lme) analyses revealed that reliable syllable effects were still observed for CV words and remain fairly constant, even with longer prime duration. Increasing prime durations only strengthened orthographic effects for CVC words. Syllable complexity is not the driving force of the syllable structure effect observed at the early stages of visual word recognition, at least within the range of the prime durations tested in this paper with the masked priming paradigm.

Introduction

Attempts to unveil the processes by which readers recognize words so quickly and virtually effortlessly have a long tradition in psycholinguistics (see Yap & Balota, 2015 for a review). Although most studies agree that expert readers neither process words as whole, nor on a letter-by-letter basis, identifying the sublexical units that mediate lexical access and reading remains a matter of intense debate (see Carreiras & Grainger, 2004, for a review on the role of sublexical units during visual word recognition). Due mainly to its importance in speech production and perception, the syllable has been put forward as one of the best sublexical candidates in the recognition of polysyllabic words, the most common type words in numerous languages (see, for instance, Baayen, Piepenbrock, & van Rijn, 1995, for evidence in English; Vitevitch & Rodriguez, 2004, for evidence in Spanish; or Soares et al., 2014, 2018, 2019, for evidence in the European variant of Portuguese). In fact, several studies conducted in different languages such as Spanish (e.g., Álvarez, Carreiras, & Perea, 2004; Barber, Vergara, & Carreiras, 2004; Carreiras, de Vega, & Álvarez, 1993; Carreiras & Perea, 2002), French (e.g., Chetail & Mathey, 2009; Mathey & Zagar, 2002), German (e.g., Conrad & Jacobs, 2004; Conrad, Stenneken, & Jacobs, 2006), or Portuguese (e.g., Campos, Oliveira, & Soares, 2018) have provided robust evidence that the syllable indeed plays a functional role at the early stages of visual word recognition. Nonetheless, recent lexical decision studies using a masked priming paradigm have also shown that reliable syllable effects were observed for consonant-vowel (CV, e.g., ru.mor [rumour]), but not for consonant-vowel-consonant (CVC, e.g., for.no [oven]) first-syllable words. Specifically, following a seminal study conducted by Álvarez, Carreiras, and Perea (2004), subsequent masked priming studies presented participants with CV and CVC words, preceded by brief pseudoword primes that could be either syllable congruent (e.g., ru.mis-RU.MOR [rumour], for.pa-FOR.NO [oven]) or syllable incongruent with the targets (e.g., rum.pa-RU.MOR and fo.rou-FOR.NO) to examine the early and automatic effects of the syllable at the first stages of visual word recognition. Indeed, because it involves the presentation of virtually invisible primes that are (almost) inaccessible to consciousness, it minimizes the influence of other (strategic) effects, hence enhancing the "prelexical" nature of the effect (see Forster & Davis, 1984 and Forster, 1998, for details). Some recent studies (e.g., Campos et al., 2018; Chetail & Mathey, 2009) have also added an "extra" unrelated prime condition (e.g., ca.fas-RU.MOR and pou.me-FOR.NO) to additionally test whether the syllable effects were of facilitation or inhibition.

The rationale behind these masked priming studies was that, if the syllable plays a relevant role at the early stages of visual word recognition, words preceded by briefly presented syllable congruent primes should be recognized faster and/or more accurately than words preceded by briefly presented syllable incongruent (and unrelated) primes. Note that, in this paradigm, congruent and incongruent primes share the first three letters with the targets, though only in the first case, and also the same syllable boundary, which rules out the orthographic overlap between primes and targets as a potential explanation for the syllable effect observed (see Carreiras & Perea, 2002). Nonetheless, an unexpected, but systematically, observed result, was that reliable syllable priming effects (i.e., the difference between congruent and incongruent conditions) emerged for CV but not CVC words.

Several hypotheses have been advanced to account for this syllable structure effect. Álvarez et al. (2004) and Chetail and Mathey (2009) proposed that, due to the fact that CV words are the most common words in most languages, this might cause the visual word recognition system to process a CV syllable “by default” even when encountering a CVC word. However, if this is the case for languages as Spanish and French, in which CV words are approximately three times more common than CVC words (see Álvarez et al., 2004; Chetail & Mathey, 2009), there are other languages, as Portuguese, in which this difference is much less pronounced and where reliable syllable priming effects were still observed only for CV words (see Campos et al., 2018)— data taken from the ProcuraPALavras (P-PAL) lexical database (Soares et al., 2018) shows that, in Portuguese, about 38% of the words start with a CV syllable, whereas 30.2% of the words start with a CVC syllable. This led Campos, Oliveira, and Soares (2018) to suggest that the advantage of CV over CVC words might arise from two alternative main reasons. First, although in their study they used CV and CVC words matched in a greater number of lexical and sublexical variables than in previous studies, the CV words used presented a higher number of syllable neighbors than CVC words, when the positional type and token frequency of the first-syllable was considered. However, because previous studies suggested that words with a higher number of syllable neighbors are harder to recognize than words with a low number of syllable neighbors (see the MROM-S model for a recent implementation, Conrad, Tamm, Carreiras, & Jacobs, 2010), a reverse pattern of results would be expected if the syllable neighborhood density explained the syllable structure effect. Alternatively, the authors suggested that syllable complexity might underlie the effect. Indeed, if one assumes that CV syllables are simpler and easier to process than CVC syllables (note that, for a syllable to be fully activated, the prime only has to be processed until the third letter for CV words, whereas it should be processed until the fourth letter for CVC words), one may also consider that CVC syllables might require more time to be fully processed. Therefore, it is possible that 50-ms primes as used by Campos et al. (2018), and even slightly longer primes (64 ms, 67 ms), as used by Álvarez et al. (2004) and Chetail and Mathey (2009), respectively, might not allow CVC syllables to be fully activated. Consequently, reliable CVC syllable effects may possibly not emerge. Additional support to this claim arises from other studies showing that, unlike CV syllables, CVC syllables present another element, the coda, which has been demonstrated to be the hardest unit to be processed within the syllable (see Treiman & Danis, 1988). Altogether, these arguments seem to converge on the idea that CVC syllables might require more processing time. Nonetheless, to the best of our knowledge, no previous studies have directly tested this hypothesis. The current study was designed to examine if syllable complexity can account for the syllable structure effect observed in several languages by replicating the masked priming lexical decision experiment conducted by Campos et al. (2018) but increasing prime durations from 50 ms to 67 ms and 82 ms. The use of these prime durations stems from the fact that we aimed to increase prime durations whilst continuing to guarantee that these remained almost inaccessible to conscious processing as 50 ms primes; and also from the use of the DMDX software (Forster & Forster, 2003), in which each time increase, measured in ticks, corresponds to 16.67 ms for a screen running at a refresh rate of 60 Hz, as in our case. Thus, the increment of one tick and two ticks to Campos et al. (2018) procedure gives rise to the 67-ms and 82-ms primes durations. If syllable complexity is indeed preventing CVC words from showing reliable syllable effects at 50-ms prime duration, CVC syllable priming effects are expected to be observed for CVC and CV words alike with 67- and 82-ms prime durations.

Method

Participants

Seventy-two undergraduate students (M_{age} = 20.4; SD_{age} = 3.1; 55 female) from University of Minho took part in the experiment in exchange for course credits. All were native speakers of Portuguese with normal or corrected-to-normal vision and no history of reading- or language-related disorders. Written informed consent was obtained from all the participants. The study was approved by the local Ethics Committee (University of Minho).

Materials

The same set of materials used by Campos et al. (2018) were used in the current article: 48 dissyllabic Portuguese target words with a CV first-syllable structure, 48 dissyllabic Portuguese target words with a CVC first-syllable structure matched in several lexical and sublexical variables known to affect European Portuguese word processing (see Soares et al., 2019) as word frequency (per million words), word length (in number of letters), neighborhood size (*N*), orthographic Levenshtein distance (OLD_{20}), and nonpositional token frequency of the first-syllable as obtained from the P-PAL lexical database (Soares et al., 2018; http://escola.psi.uminho.pt/arquivos/ana.paula.soares/CV.and.CVC.target.words.pdf). Additionally, the 288 pseudowords primes created by Campos et al. (2018) to assign each of the target words to the three prime conditions (syllable congruent, syllable incongruent, and unrelated) and the 96 pseudoword targets and the 288 pseudoword primes created for the purpose of the lexical decision task were also used. These stimuli were distributed across three lists of materials to counterbalance targets across prime conditions. Participants were randomly assigned to each list, assuring the same number of participants per list (*n* = 12). The complete list of prime-target pairs, are available at https://www.psi.uminho.pt/pt/CIPsi/Unidades_Investigacao/Psicolinguistica/Documents/Appendix_A.pdf.

Procedure

The experiment was run individually in a soundproof booth. Participants were asked to perform a lexical-decision task, that is, to decide as quickly and accurately as possible if the string of letters presented in uppercase (targets) at the center of a 22 in. computer screen running at a refresh rate of 60 Hz was or was not a real Portuguese word, by pressing two different keyboard buttons ("M" for a yes response and "Z" for a no response). Half of the participants performed the lexical-decision task with 67-ms prime duration and the other half with 82-ms prime duration. Presentation of the stimuli and recording of responses were controlled by DMDX software (Forster & Forster, 2003). The task entailed 192 trials (96 words and 96 pseudowords) which were randomly presented to the participants. Each trial consisted of a sequence of three visual events: (a) a forward mask (#####), presented for 500 ms; (b) a lowercased prime presented in 14-point Courier New either for 67 ms or 82 ms; and (c) an uppercase target, presented immediately after the prime, in 14-point Courier New. Targets remained on the screen until participants' response or 2,500 ms had elapsed. Both speed and accuracy were stressed in the instructions. Participants were not informed on the presence of the primes. Prior to the experiment, 24 practice trials with the same manipulation as experimental trials were used to familiarize participants with the task. The whole session lasted approximately 15 min per participant.

Results

Latency (RTs in ms) and accuracy (% of errors) data were analyzed for word targets with linear mixed effects (lme) models using R software (Bates, Machler, & Bolker, 2011). Following current practices in lme analyses (e.g., Fernández-López, Marcet, & Perea, 2019; Marcet, Perea, Baciero, & Gomez, 2019; Soares et al., 2019; Soares et al., 2019), incorrect responses (12.3% of the word data) and correct responses below 200 ms or above 2 SDs of the mean RTs of each participants per condition (5.32% of word data) were excluded from the latency analyses. The lme on RTs were conducted with participants and items as crossed random intercept with the two repeated-measure factors (prime type: congruent|incongruent|unrelated; and target type: CV|CVC) and the between-subjects prime duration factor (67 ms|82 ms) with random slope per subject and not per item (see Barr, Levy, Scheepers, & Tily, 2013; but also Matuschek, Kliegl, Vasishth, Baayen, & Bates, 2017). All the factors were treated as fixed factors in the analyses. For accuracy, we used a generalized lme with logistic link function and binomial variance. The models were fit by using the lme4 R library (Bates et al., 2011) and the lmerTest R library in order to contrast simple effects with differences of least squares means. There was no average of the data prior to the analyses. Table 5 presents the mean and standard deviations (in parentheses) of RTs for the correct responses and the % of errors on target words for the CV and CVC words by prime condition in each of the prime durations used in the experiment.

Table 5

Mean and SDs (in Parentheses) of Response Times (RTs) and Percentage of Errors (%E) Committed on Target Words by Experimental Condition

Prime duration	Target type	Prime type					
		Congruent		Incongruent		Unrelated	
		RT	%E	RT	%E	RT	%E
67 ms	CV	715 (±188)	11 (±32)	735 (±189)	13 (±33)	755 (±176)	16 (±36)
	CVC	746 (±203)	14 (±34)	736 (±186)	11 (±31)	761 (±193)	13 (±34)
82 ms	CV	697 (±158)	11 (±32)	724 (±181)	14 (±35)	742 (±177)	13 (±34)
	CVC	745 (±187)	12 (±32)	729 (±180)	14 (±32)	758 (±189)	10 (±31)

For the effects that reached statistical significance, the second degree of freedom of the F statistic was always approximated Satterthwaite's method (see Satterthwaite, 1941 and Khuri, Mathew, & Sinha, 1998 for a review). The p values were adjusted with Hochberg's method for all post hoc comparisons equal or below .05 (for more details on this, please see Benjamini & Hochberg, 1995, and Hochberg, 1988). On the latency data, the results revealed a main effect of prime type, $F(2, 5580.2) = 23.4918$, $p < .001$ thus indicating that participants were faster at recognizing words preceded by syllable congruent primes than by unrelated primes (28 ms, $p < .001$), and also faster at recognizing words preceded by syllable incongruent primes than by unrelated primes (22 ms, $p < .001$). The difference between syllable congruent and incongruent primes was nonsignificant (6 ms, $p = .284$). Moreover, the twofold Target Type X Prime Type interaction reached statistical significance, $F(2, 5580.1) = 5.5243$, $p = .004$. This interaction revealed that participants were faster at recognizing CV words preceded by syllable congruent primes than by unrelated primes (42 ms, $p < .001$) and also faster at recognizing CV words preceded by syllable incongruent primes than by unrelated primes (18 ms, $p < .001$). Importantly, the difference between syllable congruent and syllable incongruent primes was statistically significant (24 ms, $p = .006$). For CVC words, however, the results showed that, although participants were faster in the syllable congruent condition than in the unrelated condition (13 ms, $p = .025$) and in the syllable incongruent condition than in the unrelated condition (26 ms, $p < .001$), the difference between syllable congruent and incongruent conditions failed to reach statistical significance (13 ms, $p = .202$). Neither the main effect of prime duration nor its interaction with any of the other factors reached statistical significance (all p's < .115). Regarding the accuracy data, the effects also failed to approach significance.

Discussion

In this article we tested whether syllable complexity accounts for the syllable structure effect observed in several languages, including Portuguese (e.g., Álvarez et al., 2004; Campos et al., 2018; Chetail & Mathey, 2009). To that purpose, we replicated Campos et al. (2018) study with Portuguese skilled readers, while using increased prime durations (i.e., from 50 ms to 67 ms and 82 ms). Lme analyses revealed that, even with longer prime durations, reliable syllable effects were still restricted to CV words. Indeed, for CV words, the results showed that participants were significantly faster in the syllable congruent and in the syllable incongruent condition than in the unrelated condition and, importantly, in the syllable congruent condition relative to the syllable incongruent condition. This reflects a genuine syllable facilitative effect for this kind of Portuguese words. Note that the fact that syllable congruent and incongruent primes share the first three letters with the targets, makes the difference between syllable congruent and incongruent primes mandatory as to assure that the advantage of the syllable condition was not simply due to an orthographic overlap between primes and targets. For CVC words, however, the results failed to show any signs of syllable effects. Although participants were faster at recognizing CVC words preceded by syllable congruent and syllable incongruent primes than unrelated primes, the absence of a significant difference between syllable congruent and incongruent primes suggests that the facilitative priming effects observed for these words stem from the orthographic overlap between primes and targets and not from the sharing of the syllable boundary per se.

These results are in line with those observed by Chetail and Mathey (2009) for CVC French words using 67-ms primes, as facilitative priming effects were reported both for syllable congruent and syllable incongruent conditions over the unrelated condition, although the two conditions did not differ significantly as in Álvarez et al. (2004) study with 64-ms primes. Hence, the results obtained in the current experiment with even longer primes (82 ms) clearly demonstrate that syllable complexity is not the driving force of the syllable structure effect observed in Portuguese and in many other languages (e.g., French, Spanish).

Another point that deserves mention, is that the magnitude of CV syllable priming effects for 67-ms and 82-ms primes are fairly constant across these prime durations. Indeed, at 67 ms, there was a 40-ms advantage of the syllable congruent condition over the unrelated condition and a 20-ms advantage of the syllable congruent condition over the syllable incongruent condition, whereas at 82-ms prime duration there was a 45-ms advantage of the syllable congruent condition over the unrelated condition and a 27 ms, which explains the absence of the threefold prime Duration*Target Type*Prime Type interaction effect in the data. These results reveal not only that the CV advantage on visual word recognition is not a short-lived effect as it is still observed beyond 50 ms primes, but also that they remain remarkably constant. In addition, it should be also noted that a comparison of the magnitude of these priming effects with those obtained by Campos et al. (2018) with 50-ms primes showed that the CV advantage of syllable congruent condition over the unrelated condition was 43 ms, and the advantage of the syllable congruent condition over the syllable incongruent condition was 50 ms when the data were reanalyzed following the same statistical procedures as used in this article (lme analyses) to allow for a direct comparison of the results. As such, although syllable facilitative effects stay fairly stable across prime durations (43 ms, 40 ms, and 45 ms for 50 ms, 67 ms, and 82 ms primes, respectively), the difference between syllable congruent and incongruent conditions is greater for 50-ms than for 67-ms and 82-ms primes, thus suggesting that this sublexical unit impacts word recognition more strongly at the earliest stages of visual word recognition. Nevertheless, after this stage, CV syllables still continue to affect processing and in a fairly continuous way until at least 82 ms of prime duration. For CVC words, however, increasing prime durations only strengthened orthographic priming effects. Note that, at 67-ms and 82-ms prime durations, syllable congruent and syllable incongruent conditions differentiated from the unrelated condition, which was not observed with 50-ms primes. At

50-ms prime duration neither congruent nor incongruent primes differentiated from unrelated primes, thus suggesting no signs of any priming effect at this prime duration.

To sum up, these results clearly demonstrate that syllable complexity is not the driving force of the syllable structure effect observed at the early stages of visual word recognition in Portuguese, as in several other languages, at least within the range of the prime durations tested in this article. Nevertheless, future studies should be conducted to directly explore if other possible explanations, such as the syllable neighborhood, can account for the syllable structure effect. Although it is unlikely that the higher number of CV than CVC syllable neighbors might explain the results as mentioned in the Introduction, this is a possibility that deserves further attention. Indeed, it is possible that, due to the fact that pseudowords were used as primes, they did not compete with target words for activation, thus words from larger syllabic neighborhoods (i.e., CV words) reach the threshold of activation for a "yes" response in the LDT more quickly than words from smaller syllabic neighborhoods (i.e., CVC words). This is in accordance with the "fast-guess" mechanism proposed by the original Multiple Read-out model (MROM; Grainger & Jacobs, 1996) and the Duarl-route Cascaded model (DRC; Coltheart, Rastle, Perry, Langdon, & Ziegler, 2001). Future studies should also consider the use of other techniques as eye-tracking or event-related potentials (ERPs) that are much more sensitive to the temporal course of processing. CVC syllable effects might be too subtle as to be captured by behavior (RTs/accuracy) measures obtained from masked priming paradigms, hence making the use of these techniques to provide valuable data on the locus of the syllable structure effect observed in EP and in several other languages.

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Chapter 4

On the Role of Syllabic Neighbourhood Density in the Syllable Structure Effect in European Portuguese

Campos, A. D., Oliveira, H. O., & Soares, A. P. (2021). *On the Role of Syllabic Neighbourhood Density in the Syllable Structure Effect in European Portuguese.* [Manuscript Submitted for Publication]. CiPSI. University of Minho.

Abstract

Previous lexical decision masked priming studies have shown that the advantage of syllable-congruent primes over syllable-incongruent primes is observed for CV (e.g., JU.ROS [interests]), but not for CVC first-syllable words (e.g., TUR.BO [turbo]), given rise to the so-called syllable structure effect (e.g., ju.ral-JU.ROS<jur.ga-JU.ROS; tur.ta-TUR.BO=tu.res-TUR.BO). This effect is puzzling since it is not accounted for either by the distributional frequencies of CV and CVC syllables in European Portuguese (EP) or by syllable complexity. Here we examine whether the number of words of the same syllabic length sharing the same (first) syllable in the same (first) position, a measure taken as an index of syllabic neighbourhood density, may account for the syllable structure effect. To that purpose, 36 EP skilled readers performed a lexical decision masked priming task in which 48 CV and 48 CVC words matched in the number of syllabic neighbours, amongst other variables, were preceded by syllable-congruent (e.g., ju.ral-JU.ROS and tur.ta-TURBO), syllable-incongruent (e.g., jur-ga-JU.ROS and tu.res-TUR.BO), and unrelated primes (e.g., pu.cas- JU.ROS and binva-TURBO). Syllable priming effects were still observed only for CV words, even though CVC words with a CV phonological structure (e.g., PEN.TE[comb] - /pˈẽtɨ/) tended to behave similarly to CV words, suggesting that EP syllable effects may be driven by phonological factors.

Keywords: syllable effects, syllable structure effect, syllabic neighbourhood, masked priming, visual word recognition

Introduction

The role of the syllable as a sublexical unit in visual word recognition has been well established in several languages such as Spanish (e.g., Álvarez et al. 1998, 2000, 2001, 2004; Carreiras et al., 1993; Carreiras & Perea, 2002; Conrad et al., 2008; Perea & Carreiras, 1998), French (e.g., Chetail & Mathey, 2009; Conrad et al., 2007; Mathey et al., 2013; Mathey & Zagar, 2002), German (e.g., Conrad & Jacobs, 2004; Conrad et al., 2006; Hutzler et al., 2004; Stenneken et al., 2007), Korean (e.g., Kwon et al., 2011), and European Portuguese (EP; e.g., Campos et al., 2018, 2020). Nonetheless, most lexical decision masked priming studies where the syllable congruency between primes and targets was manipulated, only observed reliable syllable effects for words with a CV first-syllable structure as JU.ROS [interests] - note that C stands for consonant and V for vowel; and not for words with a CVC first-syllable structure as TUR.BO [turbo]) casting serious doubts on the role of the syllable as a relevant sublexical unit for lexical access at early stages of visual word recognition.

This syllable structure effect was first observed in the pioneering study of Álvarez et al. (2004), where CV and CVC words were presented to participants preceded by brief 64 ms primes that could be syllable congruent, sharing the first three letters and the same syllable boundary with the target (e.g., ju.nas-JU.NIO [june] - dots are only used here to ease comprehension) or syllable incongruent, sharing the same three letters with the target but a different syllable boundary (e.g., jun.tu-JUN.IO). Note that, since primes could share, or not, the syllable boundary with the targets, Álvarez et al. (2004) opted to include words with a CVC first syllable and not only words with a CV first syllable following the same manipulation (i.e., syllable-congruent -e.g., mon.di-MON.JA [nun]; and syllable-incongruent condition – e.g., mo.nis-MON.JA) as a control measure. As expected, participants were faster at recognizing targets preceded by syllable-congruent than syllable-incongruent primes, which could not be explained by the orthographic overlap between primes and targets. However, the advantage of the syllable-congruent condition over the syllable-incongruent condition was only observed for CV words, giving rise to the so-called *syllable structure effect*, later observed in other studies conducted in other languages such as French (Chetail & Mathey, 2009) and EP (Campos et al., 2018, 2020).

This unexpected result was accounted for by Álvarez et al. (2004) in Spanish and Chetail and Mathey (2009) in French based on the fact that that words with a CV syllable are much more common than words with a CVC syllable in these languages (see Álvarez et al., 2004 and Colé et al., 1999 for estimates). This unbalanced distribution was taken as potentially creating a bias in the visual recognition system that would make CV syllables to be more easily activated even when a CVC syllable is presented instead- note that, in most CVC first-syllable words, a CV permissible syllable is also embedded, which can account for the absence of significant differences between the syllable-congruent and syllable-incongruent conditions since both structures would receive activation (see Álvarez et al., 2004; Chetail et al., 2009; Mathey et al., 2006). This proposal was further supported in a lexical decision study conducted by Conrad and Jacobs (2004) in German, a language in which there is a greater diversity of syllable structures, less than 30% of the words have a CV or a CVC first-syllable structure, and where syllable effects were observed for different syllable structures (see Conrad & Jacobs, 2004 for details).

This hypothesis, however, has recently been challenged by the results observed in a masked priming lexical decision study conducted in EP by Campos et al. (2018), following the same paradigm employed by Álvarez et al. (2004), but using a 50 ms prime duration and adding an extra unrelated condition to ascertain whether syllable effects were facilitative. While an advantage of the syllable-congruent condition over the syllable-incongruent and the unrelated conditions were observed, indicating that syllable effects in EP were, indeed, of facilitation, the authors only found signs of reliable syllable priming effects for CV first-syllable words; for CVC first-syllable structure words, no differences were observed between the three conditions, replicating the same syllable structure effect observed in other languages (Álvarez et al., 2004; Chetail & Mathey, 2009). Nonetheless, unlike Spanish and French, in EP while CV words still constitute the majority of words in the lexicon, the difference between CV and CVC words are far less pronounced - according to the Procura-PALavras lexical database (P-PAL; Soares et al., 2014, 2018), 38% of the EP words present a CV first-syllable structure and 30.2% present a CVC first-syllable structure – making it unlikely that this frequency-based account might fully explain why in EP syllable effects during visual word recognition are still restricted to CV words. Furthermore, the syllable structure effect observed at early stages of visual word recognition becomes even more intriguing when we consider that previous studies investigating syllable effects in speech recognition and production in the same languages have found syllable effects both for CV and CVC words (Spanish: Sebastián-Galles et al., 1992; French: Cholin et al., 2006; Mehler et al., 1981; EP: Morais et al., 1989). For instance, Morais et al. (1989), in a pioneering study investigating if the syllable emerged as a unit of lexical access during speech recognition, asked literate and illiterate EP readers to detect as soon and accurately as possible if CV (e.g., /ga/) or CVC syllables (e.g., /gar/) were embedded in words (e.g., *garage* [garage] and *garganta* [throat]) presented into short sentences. The authors observed that participants were faster at detecting the target segments when they corresponded to the first syllable of the word than when they only shared the same first three letters but a different syllable boundary (i.e., faster at detecting /ga/ in *garagem* than in *garganta* and /gar/ in *garganta* than in *garage*), hence showing that, in speech, syllable effects are observed both for CV and CVC structures.

To account for the syllable structure effect observed at the early stages of visual word recognition in EP, Campos et al. (2020) recently proposed syllable complexity as a potential source of the effect. Since CVC syllables present an additional syllable unit when compared to CV syllables, the coda, which was proven to be one of the hardest syllable components to be processed (see Content et al., 2001; Treiman & Danis, 1988), it is reasonable to anticipate that 50 ms of prime duration, as used by Authors et al. (2018), might not suffice to allow CVC syllables to be fully activated. Note that, when a CV prime is presented, readers only have to process the stimulus until the third letter position to the syllable segment to be extracted. However, for CVC syllables, readers must process the CVC prime until, at least, the fourth letter position for syllable parsing to occur. To directly test this hypothesis, Campos et al. (2020) replicated the study previously conducted by Campos et al. (2018) with the same materials but increasing prime durations to 67 ms and 82 ms to allow more time for processing. Although Campos et al. (2020) observed similar facilitation effects for CV and CVC words alike, as participants were faster at recognizing CV and CVC words preceded by syllable-congruent (and also syllable-incongruent primes) when compared to the unrelated primes, differences between syllable-congruent and syllable-incongruent primes (indicative of a genuine syllable effect) were only observed for CV words. The absence of statistical differences between the syllable-congruent and syllable-incongruent conditions for CVC words, suggests that the facilitative effects observed in both conditions were likely due to the orthographic overlap between primes and targets and not to a syllable activation *per se*.

Here, we tested another hypothesis to account for the syllable structure effect: the number of words with the same number of syllables sharing the same (first) syllable with the target, i.e., an analogous of the *N* orthographic neighbourhood density measure proposed by Coltheart et al. (1977) to the syllabic domain. The rationale behind this proposal is the following: because CV words tend to occur more frequently than CVC words (even in EP, although, as mentioned before, the difference is much less pronounced than what is observed in other languages), CV syllables tend to present a higher number of syllabic neighbours (i.e., words with the same number of syllables sharing the same first syllable) than CVC syllables. We can hypothesize that since CV words tend to present a higher number of syllabic neighbours than CVC words, it is possible that the larger syllabic neighbourhood of CV words might speed up their recognition as the higher number of syllabic neighbours might make CV words present lower levels of activation, thereby needing less input for a 'yes' response to be produced during a lexical decision task. This account also agrees with the 'fast-guess' mechanism proposed within the Dual-Route Cascaded model (DRC - Coltheart et al., 2001) or the Multiple Read-Out model (MROM - Grainger & Jacobs, 1996) and its recent MROM-S extension (Conrad et al., 2010), which implements a syllabic layer to explain the syllable inhibitory frequency effect observed in the Spanish language. Within the MROM-S model, it is claimed that although, initially, words with high-frequent syllables would spread activation to a large number of words sharing the same syllable boosting syllable activation, later, this high number of lexical candidates would compete with the target for activation via lateral-inhibition, hence explaining the syllable inhibitory frequency effect. This inhibition would be particularly prominent when lexical candidates had a higher frequency of occurrence than the target word. Nevertheless, due to the fact that in masked priming lexical decision studies the primes are typically pseudowords, which do not have a lexical representation (see Mathey et al., 2013 for more details), they are not expected to compete with word targets for recognition (see, however, Dominguez et al., 1997 and Mathey et al., 2013 for a detailed account of how pseudoword primes might, in certain cases, hinder word recognition). Therefore, syllabic neighbourhood effects in lexical decision masked priming studies using a syllable congruency paradigm are expected to be facilitative.

Although the MROM-S was not designed to account for the syllable structure effect observed in syllable congruency masked priming studies, we can nevertheless hypothesize that when a CV syllable-congruent pseudoword prime is presented (e.g., jural) it might be syllabified in a syllabic layer (e.g., ju.ral), as the MROM-S model claims (Conrad et al., 2010). This activation would then spread out to all the words in the lexicon that present the same CV syllable in the same position (e.g., JU.LHO [july], JU.IZ [judge], JU.NHO [june], etc.), hence making that, when a CV target word is subsequently presented (e.g., JU.ROS), less activation is needed to recognize it as a word. However, because CVC words tend to come from sparser syllabic neighbourhoods, the level of activation generated from the previous presentation of CVC congruent pseudoword primes might lag clearly behind the one generated from CV congruent pseudoword primes, hence explaining the syllable structure effect observed in EP as well as in other languages such as Spanish and French. It is also worth noting that although Authors et al. (2018, 2020) have matched the CV and CVC words used in their experiments in a high number of psycholinguistics variables known to affect word processing (see Authors et al., 2015, 2019 for evidence in the EP language), such as the frequency of the word as a whole, the number of letters, several orthographic neighbourhood measures, as the *N* (Coltheart et al., 1977), the Orthographic Levenshtein Distance (OLD_{20}) measure (see Yarkoni et al., 2008), obtained from the P-PAL EP lexical database (Soares et al., 2014, 2018) and also in the summed frequency of the words with the same number of syllables sharing the same first syllable with the targets (i.e., in the token frequency of the CV and CVC syllabic neighbours), a post-analysis of their stimuli revealed that the CV words used in the studies of Campos et al. (2018, 2020) presented effectively a higher number of words sharing the same syllable in the same position than CVC words (i.e., type frequency of the CV and CVC syllabic neighbours), which might have accounted for their results.

Furthermore, it is also important to emphasize that, despite previous studies have examined the role that syllabic neighbourhood plays on syllabic processing, in particular in the syllable inhibitory frequency effect above mentioned (e.g., Álvarez et al., 2000, 2001; Carreiras et al., 1993; Conrad et al., 2006, 2007, 2008; Mathey & Zhagar, 2002; Perea & Carreiras, 1998; Stenneken et al., 2007), all these studies lack a clear definition of what syllabic neighbours are, which might explain the inconsistency of the results observed (see Chetail & Mathey, 2011 for a review). Indeed, while in some studies syllabic neighbourhood is defined as the number of words sharing the same syllable (not necessarily the first) with the target, regardless of word length (e.g., Álvarez et al., 2000; Carreiras et al., 1993; Conrad & Jacobs, 2004; Perea & Carreiras, 1998), others adopted a more strict definition, describing it as the number of words with the same length (i.e., number of syllables) sharing the same (first) syllable in the same position (e.g., Chetail & Mathey, 2011; Conrad et al., 2007, 2009; Mathey et al., 2006; Mathey & Zagar, 2002). As Chetail and Mathey (2011) noted, the definition of syllabic neighbours is critical towards a clear understanding of how the syllable comes into play. In fact, a broader definition of syllabic neighbours might very well translate into a higher set of competitors with higher summed frequencies, when compared to a measure that only considers those lexical entries with the same number of syllables. Moreover, in some studies, the measures of type (number of words of the same syllabic length sharing the same syllable in the same positions) and token (summed frequency of the words with the same number of syllables sharing the same syllable with the targets) syllabic neighbourhood are often used indistinctively. Despite being highly correlated (e.g., Álvarez et al., 2001; Chetail & Mathey, 2011), it is important to highlight that they are not the same and, some studies have even demonstrated that they produce opposite effects. For instance, Conrad et al. (2008), contrasting effects of type and token syllable frequency during the visual word recognition of Spanish words, showed that while high syllable type frequency produced facilitative effects in the standard lexical decision task even when the number of higher frequency syllabic neighbours was controlled for, high syllable token frequency produced an inhibitory effect. These results seem to be consistent with the vast number of studies conducted on the role of orthographic neighbours in visual word recognition, showing that words from denser neighbourhoods were recognized faster/more accurately than words coming from sparser neighbourhoods, when the number and the frequency of high-frequent orthographic neighbours were controlled for (e.g., Andrews, 1989, 1997; Grainger et al., 1989; see also Perea, 2015, for a review). The absence of lexical databases providing reliable syllabic measures (e.g., type and token syllabic positional and non-positional frequencies, number of more frequent syllabic neighbours, frequency of more frequent syllabic neighbours) certainly contributed to this state of affairs. To the best of our knowledge, the only exceptions are the InfoSyll for French (Chetail & Mathey, 2010) or the Syllabarium for the Basque language (Duñabeitia et al., 2010). Even in EP, the number of syllable measures provided by the P-PAL database is quite restrictive (see Soares et al., 2014, 2018). The present study was specifically designed to investigate if syllabic neighbourhood density, defined as the number of words with the same number of syllables sharing the same (first) syllable with other words in the lexicon, can account for the syllable structure effect observed in EP. Additionally, we also sought to analyse if, with a new set of stimuli, syllable effects could also be observed for EP pseudowords, as observed in other languages (e.g., Álvarez et al., 2000; Carreiras et al., 1993) since in a previous study Campos et al. (2018) have failed to obtain any sign of syllable effects for pseudoword targets. To this purpose, EP skilled readers performed a lexical decision masked priming task, in which CV and CVC EP word targets controlled on several variables known to affect word processing, including several type and token syllabic neighbourhood measures, were preceded by brief 50 ms pseudoword primes in three different prime condition (congruent, incongruent and unrelated) as in Campos et al. (2018, 2020).

Although a more direct way to test the role that syllabic neighbourhood density might play on the syllable structure effect would involve the manipulation, rather than the control of the syllabic neighbourhood density measures, it is worth noting that because in EP, as well as in other languages, CV syllables tend to come from denser syllabic neighbourhoods, we were not able to find enough CV words with a sufficiently low number of syllabic neighbours, or enough CVC words with a sufficiently high number of syllabic neighbours with the high strict control imposed to the stimuli to allow its manipulation. Thus, the only viable option was to control for the CV and CVC syllabic neighbourhood measures. Therefore, we hypothesized that if the syllabic neighbourhood density was the driving force of the syllable structure effect observed in EP, and possibly in other languages, when CV and CVC words were matched on all the relevant psycholinguistics variables known to affect word processing, including type and token syllabic neighbourhood measures, facilitative syllable priming effects should be observed for CV and CVC words alike.

Method

Participants

Thirty-six undergraduate students (M_{age} = 21.2, SD_{age} = 2.7; 27 women) took part in the experiment in exchange for course credits. Sample size was estimated with G*Power software (Faul et al., 2009) showing that 33 participants would provide adequate power (1-β = .80; α = .05) for an effect size of f(U) = 0.4 (η^2_p = .14). All the participants had normal or corrected-to-normal vision and were native speakers of EP with no history of learning or reading-related disabilities. Prior to the experiment, written informed consent was obtained from all the participants. The study was approved by the local Ethics Committee.

Materials

A total of 96 disyllabic EP words, all between five and six letters long, were selected as targets from the P-PAL lexical database (Authors et al., 2014, 2018). From these, 48 words have a CV first syllable (e.g., JU.ROS [interests]) while the other 48 have a CVC first syllable (e.g., TUR.BO [turbo]). The CV and CVC words were matched (all *p*'s > .162) on several orthographic syllable measures, including the number of syllabic neighbours sharing the first syllable (i.e., type frequency), their summed frequency (i.e., token frequency), and the number and frequency of higher frequency syllabic neighbours, as computed from the P-PAL lexical database (Soares et al., 2018). Besides, CV and CVC words were also matched on several variables known to affect word processing, such as the frequency of the word as a whole, number of letters, and several orthographic neighbourhood measures, as *N* and OLD_{20} (see Authors et al., 2015, 2019 for recent evidence in EP). Table 6 displays the mean and standard deviations (in brackets) of the psycholinguistic variables in which the CV and CVC words used in the experiment were controlled for.

Table 6

Psycholinguistic Variables in Which CV and CVC Words Were Matched as Obtained from the P-PAL Database (Soares et al., 2018) and Measures of Familiarity (i.e., Measured by Subjective Frequency), Imaginability and Concreteness as Obtained from the Minho Word Pool Database (Soares et al. 2017)

Psycholinguistic variables	CV words *M* (*SD*)	CVC words *M* (*SD*)	*p-value*
Word length (number of letters)	5.08 (0.27)	5.17 (0.38)	.221
Word length (number of phonemes)	4.88 (0.44)	4.83 (50.59)	.698
Word frequency (per million)	6.09 (7.84)	7.37 (10.83)	.508
Orthographic neighbourhood Size (O*N*)	5.06 (4.04)	5.77 (3.35)	.352
Phonologic neighbourhood Size (P*N*)	5.21 (4.26)	5.96 (3.82)	.366
Mean frequency of the orthographic neighbours	20.75 (67.05)	25.93 (52.92)	.676
Number of higher frequency orthographic neighbours	1.46 (1.65)	1.94 (1.85)	.184
Number of higher frequency phonologic neighbours	1.35 (1.85)	2.02 (1.92)	.090
Mean frequency of higher frequency orthographic neighbours	42.72 (138.09)	63.85 (114.29)	.416
Orthographic Levensthein Distance (OLD_{20})	1.67 (0.27)	1.60 (0.23)	.162
Number of orthographic syllable neighbours sharing the first syllable	44.77 (13.69)	41.50 (13.45)	.241
Summed orthographic frequency of the syllabic neighbours	678.41 (659.32)	620.28 (657.29)	.666
Summed phonological frequency of the syllabic neighbours	793.97 (841.34)	491.78 (701.79)	.059
Number of higher frequency orthographic syllable neighbours	11.48 (9.04)	10.02 (6.66)	.371
Mean frequency of higher frequency orthographic syllable neighbours	74.94 (80.23)	64.67 (81.20)	.535
Frequency of the most frequent orthographic syllable neighbour	352.18 (385.37)	257.66 (321.51)	.195
Number of words sharing bigrams with the target	346.02 (211.96)	390.60 (190.40)	.281
Mean number of words sharing bigrams with the target	83.71 (48.10)	91.59 (35.22)	.362
Summed frequency (log10) of words sharing bigrams with the target	4576.87 (2483.65)	5316.59 (2667.71)	.163
Mean frequency of words sharing bigrams with the target	14.78 (8.94)	14.79 (7.59)	.996
Subjective frequency (1-7)	3.79 (1.26)	4.05 (1.32)	.655
Imageability (1-7)	5.04 (1.75)	5.07 (1.70)	.493
Concreteness (1-7)	5.28 (1.46)	5.27 (1.32)	.194

Concreteness (M_{cv} = 5.28 and M_{cvc} = 5.27; p = .194), imaginability (M_{cv} = 5.04 and M_{cvc} = 5.07; p = .493), and familiarity (operationalized as subjective frequency, M_{cv} = 3.79 and M_{cvc} = 4.05; p = .655), measures were also controlled for, though they were only available for 22 of the CV and 26 of the CVC words used in the experiment as obtained from the Minho Word Pool (MWP) EP database (see Soares et al., 2017) . Furthermore, it is also worth noting that CV and CVC words were also controlled for in number of phonemes (M_{cv} = 4.88 and M_{cvc} = 4.83; p = .689), number of phonological neighbours (M_{cv} = 5.21 and M_{cvc} = 5.96; p = .366) and number of higher frequency phonological neighbours (M_{cv} = 1.35 and M_{cvc} = 2.02; p = .090). The opacity of the EP language makes the simultaneous control of the orthographic and phonological measures particularly hard to achieve; thus, although CV and CVC words were matched on the type and token orthographic syllable neighbourhood measures displayed in Table 6, CV words present, nevertheless, a higher number of phonological syllable neighbours than CVC words (M_{cv} = 55.21 and M_{cvc} = 32.85; p < .001), as well as a tendency for the words that constitute their syllabic neighbours to present a higher frequency of occurrence as well (M_{CV} = 793.97 and M_{CVC} = 491.78; p = .059). Because of these factors, and also due to the fact that the task was presented in the visual domain, we opted to control for the orthographic syllable neighbourhood measures as they were assumed to be more relevant for visual word processing.

Two-hundred and eighty-eight pseudowords were created as primes and assigned to each of three experimental conditions: (i) syllable-congruent condition (i.e., prime and target shared the first three letters and the syllable boundary – e.g., ju.ral-JU.ROS, tur.ta-TUR.BO); (ii) syllable-incongruent condition (i.e., prime and target share the first three letters but not the syllable boundary – e.g., jur.ga-JU.ROS, tu.res-TUR.BO); and (iii) unrelated condition (i.e., prime and target do not share either the first syllable or the same letters - e.g., po.car-JU.ROS and bin.va-TUR.BO). Additionally, a set of 96 pseudowords targets and a set of 288 pseudowords primes, following the same manipulation as the word targets, were created for the purposes of the lexical decision task, by replacing one or two letters in the medial positions of words with similar characteristics to those used in the experiment (e.g., for instance, the pseudowords VERVE was created by replacing the <m> in the EP word *verme* [maggot] with a <v>) following common practices in the literature (e.g., Perea et al., 2013; Soares et al., 2018, 2019, 2020, 2021; Sze et al., 2014; Yap et al., 2010). These stimuli were distributed across three lists to counterbalance targets across the three prime conditions. Participants were randomly assigned to a list while assuring that each list had the same number of participants (n = 12). The complete list of the prime-target pairs can be found in Appendix B.

Procedure

The experiment was run individually in a soundproof booth. Participants were asked to decide as quickly and accurately as possible whether each of the letter strings presented in uppercase at the centre of a 22'' inch computer screen was a real EP word or not by pressing two different keyboard buttons: "M" for words and "Z" for pseudowords. The DMDX software (Forster & Forster, 2003) was used for the presentation of the stimuli and recording of the responses. The task entailed 192 trials (96 words and 96 pseudowords) randomly presented to the participants. Each trial consisted of a sequence of three visual events: (i) a forward mask (######) presented for 500 ms; (ii) the prime, presented in lowercase (14-point Courier New), for 50 ms; and (iii) the target, presented in uppercase (14-point Courier New), that remained on the screen until participants' response or 2,500 ms had elapsed. At the beginning of the experiment, 24 practice trials (12 words with a CV structure, 12 words with a CVC structure, and 12 pseudowords) were used to familiarize participants with the task. The entire session lasted approximately 15 minutes per participant.

Results

The analyses were conducted on the latency (RTs in ms) and accuracy (% of incorrect responses) data for word and pseudoword targets using linear mixed effects (lme) models in the R software (Bates et al., 2011). The lme analyses on RTs were conducted after response times for incorrect responses (5.7% for the word data and 4.8% for pseudoword data) and response times for correct responses bellow 200 ms or below/above 2 *SD*s of the mean RTs of each participant, per experimental condition, were excluded from the dataset (4.9% for the word data and 6.2% for pseudoword data). The factors Prime type (congruent|incongruent|unrelated) and Target type (CV|CVC) were treated as repeated measures in the lme analyses with participants and items as crossed random intercept and with random slope per subject but not per item (see Barr et al., 2013 and Matuschek et al., 2017). The lme analyses on accuracy data were conducted for word and pseudoword targets with logistic function and binomial variance. To contrast simple effects with differences of least squares means the lme4 R library (Bates et al, 2011) and the lmerTest R library were used. For the effects that reached statistical significance (α = .05), the second degree of freedom was reported based on the Satterthwaite's method (see Satterthwaite, 1941, and Khuri et al., 1998) and the *p* values were adjusted with Hochberg's method for multiple comparisons (see Benjamini & Hochberg, 1995, and Hochberg, 1988 for details). Because measures of effect sizes similar to the eta-squared (η^2) and omega-squared (ω^2), available in the *F* tests (ANOVA), are not currently available for lme analyses in R (see Bates et al., 2015; Kuznetsova et al., 2017 for discussions), we computed, as in previous studies (see Authors et al., 2019 for an example), the Cohen's delta (*d*) statistic (Cohen, 1988) by dividing the mean adjusted for each of the factors in the model (estimated mean) by the residual of the estimated model (unexplained variance). Hence, *d* values are reported for main effects involving a two-level factor (Target type: CV|CVC), as well as for each of the post-hoc comparisons that reached statistical significance both in main effects with more than two levels (Prime type: congruent|incongruent|unrelated) and in interaction effects (Target type*Prime type effects) that reached statistical significance. Table 7 presents the means and standard deviations (in brackets) of the RTs (in ms) as well as the percentage of errors (%E) committed by participants for CV and CVC words and pseudowords in each of the three prime conditions (i.e., congruent, incongruent, and unrelated).

Table 7

Mean and Standard Deviations (in brackets) of Response Times (RTs) and Percentage of Errors (%E) per Prime Condition

Target type		Prime type					
		Congruent		Incongruent		Unrelated	
		RT	%E	RT	%E	RT	%E
Words	CV	697 (68)	7.3 (26)	723 (187)	6.5 (25)	737 (192)	6.5 (25)
	CVC	730 (181)	3.0 (17)	738 (205)	4.5 (21)	717 (159)	3.8 (19)
Nonwords	CV	874 (250)	4.3 (20)	873 (246)	5.9 (24)	883 (264)	5.2 (22)
	CVC	851 (227)	4.0 (20)	862 (251)	4.6 (21)	881 (258)	5.1 (22)

Word Data

The results conducted on the latency data showed a main effect of the prime type, $F(2, 2982.54) = 3.2858$, $p = .038$, indicating that participants were significantly faster responding to words preceded by syllable-congruent primes than by unrelated primes ($p = .038$, $d = 0.11$). The difference between syllable-congruent and syllable-incongruent primes ($p = .144$), as well as the difference between syllable incongruent and unrelated primes ($p =.496$), failed to reach statistical significance. The main effect of target was not significant ($p = .508$). However, the twofold prime type*target type interaction was statistically significant, $F(2, 2982.50) = 5.0723$, $p = .006$. This effect revealed that participants were significantly faster at recognizing CV words preceded by syllable-congruent than by unrelated primes (40 ms, $p < .001$, $d = 0.25$) and, also, to CV words preceded by syllable-congruent than syllable incongruent-primes (26 ms, $p = .037$, $d = 0.15$), thus revealing a genuine syllable priming effect for this type of EP words. The difference between syllable-incongruent and unrelated conditions was not statistically significant ($p = .106$), hence indicating that syllable-incongruent and unrelated primes produced virtually the same amount of priming. For CVC words, however, neither the difference between syllable-congruent and unrelated primes ($p = .866$), the difference between the syllable-incongruent and unrelated primes ($p = .866$) nor the difference between syllable-congruent and syllable-incongruent primes ($p = .866$) reached statistical significance, hence failing to show any sign of syllable priming effects.

On the accuracy data, none of the effects (prime type, $p = .372$; target type, $p = .070$) nor the interaction effect ($p =.381$) approached statistical significance.

Pseudoword Data

The lme analyses revealed that in latency data neither the main effect of prime (p = .194), the main effect of target (p = .447), nor the two-fold interaction (p = .555) reached statistical significance. In the accuracy data, the results also failed to show any significant main (prime type, p = .362; target type, p = .763), or interaction effect (p = .741), thus revealing the absence of any syllable effects in pseudoword data.

Discussion

Although syllable effects have been widely studied in different languages, the syllable structure effect - i.e., the fact that reliable syllable priming effects were only observed for CV and not for CVC first-syllable structure words in studies using the syllable congruency masked priming paradigm, remains largely overlooked. Though different explanations have been put forward, with some authors suggesting that the syllable structure effect is rooted on the difference between the number of times CV and CVC words occur in a given language (e.g., Álvarez et al., 2004; Chetail & Mathey, 2009), and others claiming that it could arise from syllable complexity (e.g., Authors et al., 2018), both hypotheses have been recently challenged. Campos et al. (2018) showed that, in languages such as EP, where the difference between the number of times CV and CVC words occur is much less pronounced than what is observed in Spanish or French, reliable syllable priming effects were still observed only for CV words. In addition, Campos et al. (2020), in a recent study aimed to test if syllable complexity could account for the syllable structure effect by increasing prime durations, also failed to show reliable syllable effects for CVC words.

The goal of the present study was to investigate if the syllabic neighbourhood density, operationalized as the number of words with the same number of syllables that share the same first syllable at the first position could account for the syllable structure effect observed in EP as well as in other languages. To this purpose, CV and CVC EP words were matched in the syllabic neighbourhood density measure, as well as in several other orthographic and phonological variables known to affect visual word recognition, including the summed frequency of orthographic syllable neighbours (i.e., token syllable frequency), using the syllable congruency masked priming paradigm as in previous studies. Although, as mentioned before, manipulating the number of syllabic neighbours of CV and CVC words would have been the preferable methodological option, the strict control imposed to the stimuli and the characteristics of the EP language did not allow us to select either a sufficient number of CV words with a sufficiently low number of syllabic neighbours or an adequate number of CVC words with a sufficiently high number of syllabic neighbours, in order to achieve the syllabic neighbourhood density manipulation. Nevertheless, the control of the CV and CVC words on their number of syllabic neighbours (besides all the other variables) led us to hypothesize that if syllabic neighbourhood density accounted for the syllable structure effect observed in the EP, similar facilitative syllable priming effects should be observed for CV and CVC words.

The results obtained from the lme analyses revealed, however, that genuine syllable priming effects were still only observed for CV EP words, as participants were not only significantly faster at recognizing CV words preceded by syllable-congruent primes than by unrelated primes but, importantly, also significantly faster at recognizing CV words preceded by syllable-congruent primes than by syllable-incongruent primes. For CVC words, however, the differences across prime conditions failed to reach statistical significance, including differences between both the syllable-congruent and the syllable-incongruent conditions when compared to the unrelated condition, replicating previous findings in EP (Campos et al., 2018). It is important to mention that the use of unrelated primes that shared the same syllable structure with the target (e.g., pu.cas-JU.ROS and bin.va-TUR.BO), as done in this study and in the study of Campos et al. (2018), could possibly attenuate orthographic priming effects, particularly with a short prime duration. Note that not only in CVC targets were there no significant differences between the syllable-congruent, syllable-incongruent, and unrelated conditions, but, in CV targets, only for the syllable-congruent condition was there a facilitation effect, as no significant differences were found between the syllable-incongruent and unrelated conditions. Critically, however, this result further sustains the claim that the advantage of the syllable-congruent condition stems from a genuine syllable activation. Results in the pseudoword data also replicated those previously observed in EP (Campos et al., 2018), showing no evidence of a syllable effect.

Thus, these results showed, once again, that reliable syllable congruency priming effects in EP were only observed for CV words (e.g., Campos et al., 2018, 2020), as seen in other languages (Spanish: Álvarez et al., 2004; French: Chetail & Mathey, 2009) even when the number of syllabic neighbours was controlled for. Although these results seem to suggest that the syllabic neighbourhood density of CV and CVC words does not account for the syllable structure effect, it is relevant to highlight that, before definitive conclusions can be drawn, it would be important to conduct other studies matching the CV and CVC words not only on the orthographic syllable neighbourhood density, as we have done here, but also on the phonological syllable neighbourhood density. Note that, because EP is an intermediate-depth language, where the correspondences between graphemes and phonemes are not regular and unambiguous, as observed in shallow orthographies such as Spanish, there are considerable differences when the orthographic and the phonological codes are considered. For instance, in many cases, words might have a higher number of syllabic neighbours when we consider phonology rather than orthography. An example of this found in our stimuli would be the CV word *xadrez* [chess], which has 7 orthographic syllable neighbours but 41 phonological syllable neighbours. The contrary also happens, however, and, in many cases, orthographically there are more syllabic neighbours than phonologically, such is the case of the CVC word *pasmo* [stunned] that has 47 orthographic syllable neighbours and only 8 phonological syllable neighbours. Thus, this makes it that the simultaneous control between phonological and orthographic syllable neighbours would be extremely difficult in the EP language, and as mentioned, it was not possible for the purposes of this study to have both the orthographic and the phonological syllable neighbourhood density controlled at the same time. Nevertheless, it would be important for future studies, particularly in transparent languages such as Spanish, to have this simultaneous control of orthographic and phonological syllable variables in order to investigate the influence of syllabic neighbourhood density on the syllable structure effect.

Indeed, in EP, while orthographically the difference between the number of CV and CVC words is not very pronounced (i.e., 38% of words have a CV first-syllable structure and 30.2% have a CVC first-syllable structure), when we consider phonology, however, this difference is much more evident since CV first-syllable words occur for 43.9% of the words in the EP lexicon, whereas CVC first-syllable words only occur in 15.3% of the cases – data taken from the P-PAL lexical database (Soares et al., 2014, 2018). Consequently, CV words tend to have a greater number of syllabic neighbours, particularly when phonology is considered. Note that, in the pool of stimuli selected for our study, while orthographically CV words had an average of 45 syllabic neighbours and CVC words an average of 41 syllabic neighbours, phonologically CV words had on average 55 syllabic neighbours, but CVC words only had 33 syllabic neighbours, on average. One of the reasons for this disparity between the number of CV and CVC words when orthography or phonology are considered stems from the fact that CVC syllables can present a match, as in the word tur.bo [tˈuɾbu], which has a CVC orthographic (<tur>) and phonological structure ([tˈuɾ]); or, in a considerable number of cases, a mismatch between their orthographic and phonological syllable structure, as in the word *pente* [brush], which has a CVC orthographic structure (<pen>) but a CV phonological structure ([pẽ]). In the case of an orthographic-phonological mismatch, CVC words usually contain a nasal vocalic sound ([ã], [ẽ], [ĩ], [õ], and [ũ]), in this case, represented by the conjugation of a vowel (‘a’, ‘e’, ‘i’, ‘o’, ‘u’) with an <m> or an <n> (e.g., *bom* [bˈõ; good]). Hence, while in print, the nasal vowel is represented by two letters, in speech only one sound is produced (see

Barroso, 1999 and Teixeira et al., 1999). For CV syllables, however, there is almost always a complete match between the orthographic and phonological syllable forms (e.g., *ju.ros* [ʒˈuɾuʃ], so in), the only exception being when the first consonant of a CV syllable is an <h>; because in EP that sound is silent (e.g., in the word *holofote* [olufˈɔtɨ]), so the first orthographic syllable has a CV structure, but the first phonological syllable has a V structure.

Thus, to gain further insights into the extent to which phonological variables could account for the results, we conducted an a posteriori analysis based on a new classification of the words used in our dataset into three categories: the CV words (e.g., CV, JU.ROS [ʒˈu.ɾuʃ]), the CVC words presenting both a CVC orthographic (O) and phonological (P) syllable structure (i.e., CVC_{O+P+}, e.g., TUR.BO [tˈuɾ.bu]), and the CVC words that present a CVC orthographic structure, but a CV phonological structure (i.e., CVC_{O+P-}, e.g., PEN.TE [pˈẽ.tɨ]). Because the CVC_{O+P-} words constitute a small pool of stimuli in our dataset (14 words), we selected 14 CV words out of the 48 CV words and other 14 CVC_{O+P+} words out of the remaining 34 CVC words, matched in all the variables in which the total pool of CV and CVC words were controlled for (see Table 7), to avoid confounds. Furthermore, concerning the number of phonological syllable neighbours, CV and CVC_{O+P-} words were also matched in this variable (M_{CV} = 63 and $M_{CVCO+P-}$ = 54; p = .968), though the same control was not possible for CVC_{O+P+} words ($M_{CVCO+P+}$ = 23). It is also relevant to mention here that although reliable phonological priming effects tend to be observed with longer prime durations, it is also worth mentioning that previous studies have shown phonological priming effects both with 50 ms and even with shorter prime durations (e.g., Comesaña et al., 2016; Davis et al., 1998; Frost et al., 2003; Lee et al.,1999; Lukatela et al., 1998; Perea & Lupker, 2004; Shen & Forster, 1999). Thus, if phonological syllable information is the driving force of the syllable structure effect, then we would expect CVC_{O+P-} words to behave similarly to CV words since both present the same CV phonological structure. Results from the lme analyses conducted based on the same experimental design, except that the Target type factor entered now with three levels (CV | CVC_{O+P+} | CVC_{O+P}), are presented in Appendix C. As can be noticed, although the effects failed to reach statistical significance, due probably to lack of statistical power (note that we only used data from 14 items per condition), participants tended to be faster responding to CVC_{O+P-} targets preceded by syllable-congruent primes than by both unrelated and syllable-incongruent primes, as observed for CV targets. Such a pattern was not observed for the CVC_{O+P+} words, where participants tended to respond even faster to CVC_{O+P+} words preceded by unrelated primes than by syllable-congruent and syllable-incongruent primes (see Appendix C).

Even though these results were statistically nonsignificant, they nevertheless provide interesting clues for future studies to examine the role phonological variables could play in the syllable structure effect observed in EP. Other factors that future studies should also consider is the similarity of the CV skeletal structure (i.e., the combination of vowels and consonants in a word) or the similarity of the consonantal structure (i.e., the consonants existing in a word) between primes and targets (e.g., Blythe et al., 2014; Chetail & Drabs, 2014; Chetail et al., 2016; Perea et al., 2018; Authors et al. 2014; see also Authors et al. 2020 for a letter similarity account on the consonant bias), even though they are not able to fully explain the results obtained here. While Chetail and Drabs (2014), using a same-different task, showed that readers were slower at naming "different" trials when the words shared the same CV skeletal structure (e.g., piorver–poivrer [CVVCCVC-CVVCCVC]) compared to when they had a different CV skeletal structure (e.g., povirer–poivrer [CVCVCVC-CVVCCVC]), suggesting that there was an early activation of the CV skeletal structure, this would not be able to account for the syllable structure effect. Note that in our study CV and CVC words present the same CV skeletal structure in the syllable-congruent condition (e.g., ju.ral- JU.ROS [CVCVC-CVCVC] and tur.ta-TURBO [CVCCV-CVCCV]) and a different CV skeletal structure in the syllable-incongruent condition (e.g., jur.ga-JU.ROS [CVCCV-CVCVC] and tu.res-TUR.BO [CVCVC-CVCCV]), so it does not explain the differences found between CV words and CVC words. More recently, however, Perea et al. (2018) demonstrated using a masked priming lexical decision task that, at the earliest stages of visual word recognition, it is not the CV skeletal structure of the words (e.g., PAISAJE [CVVCVCV]), but rather the consonantal structure of the words that is activated (i.e., [psj] in the word PAISAJE). Nevertheless, this account based on an early activation of the consonantal structure also cannot fully explain our results since the degree of overlap between the consonantal structure of CV and CVC conditions are roughly the same in the syllable-congruent and syllable-incongruent conditions, as the number of consonants preserved between primes and targets is the same - all except one as [jrl-jrs] in ju.ral-JU.ROS, [jrg-jrs] in jur.ga-JUROS; [trt-trb] in tur.ta-TUR.BO, and [trs-trb] in tu.res-TUR.BO.

Still, the different roles played by consonants and vowels during visual word recognition, in general, and in syllabic parsing, in particular, should be not disregarded in future studies. In fact, in EP, as in most languages, vowels are the nucleus of the syllable, and, as such, they are, presumably, automatically assigned to that syllable position (see Taft et al., 2017). Consonants, on the contrary, can be positioned either as the onset or as the coda of the syllable, except if they constitute the first or final letter of a word, in which case they can only assume the role of onset or coda, respectively (see Lee & Taft, 2009; Taft et al., 2017; Taft & Krebs, 2013). Thus, while in a CV syllable, the consonant and the vowel are unambiguously assigned to their positions, in CVC syllables, the second consonant could potentially be assigned either to the coda of the first syllable or the onset of the second syllable. This issue is further complexified by the fact the vast majority of CVC syllables in EP have a permissible CV syllable embedded. It is relevant to note here that our results with CVC words seem to support this notion that there might be a competition between the CVC syllable and the CV syllable embedded, at early stages of visual word recognition, since although the advantage was only numerical, for CVC words, participants had shorter RTs in the unrelated condition than in the syllable-congruent and syllable-incongruent condition, which could be due to this particular factor in CVC syllables. This ambiguity and potential competition between the different positions in which the last consonant can be assigned to, may also contribute to hamper CVC syllable activation and word recognition, which should be further explored in future studies by considering, for example, if CVC syllables with and without a CV syllable embedded show the same processing. Future studies should also use techniques more sensitive to the temporal course of processing, such as eye-tracking or Event-Related Potentials (ERPs). The use of those techniques would allow to better investigate the temporal course of syllable effects, especially for CVC syllables, since there is a possibility that this activation occurs at such early stages of visual word recognition, that the use of a masked priming paradigm might not be well suited to capture them.

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Chapter 5

On the Syllable Structure Effect in European Portuguese: Evidence from ERPs

Campos, A. D., Oliveira, H. O., López-Caneda, E., Gutiérrez-Domínguez F., & Soares, A. P (2021). *On the Syllable Structure Effect in European Portuguese: Evidence from ERPs* [Manuscript Submitted for Publication]. CiPSI. University of Minho.

Abstract

The advantage of CV over CVC syllables at early stages of visual word recognition is puzzling since it is not explained either by the distributional frequencies of CV and CVC syllables, syllable complexity, or syllabic neighbourhood density. Here, we collected electroencephalographic (EEG) data from twenty-four European Portuguese (EP) skilled readers while they performed a colour-congruency lexical decision task to investigate if syllable effects for CV and CVC words and pseudowords could emerge with this high-temporal resolution technique. Furthermore, the CVC words used presented either a match (CVC_{O+P+}) or a mismatch (CVC_{O+P-}) between their orthographic (O) and phonological (P) syllable structure to further ascertain if syllable effect in EP were driven by the activation of orthographic and/or phonological information. Results showed syllable congruency effects in the N100, P200, and N400 event-related potentials, suggesting the influence of different factors underlying the syllable structure effect observed in EP and, possibly, in other languages.

Keywords: Syllable Structure Effect; European Portuguese; Electroencephalography, Event-Related Potentials; Orthographic Information; Syllable Complexity; Syllabic Neighbourhood; CV Skeletal Structure.

Introduction

Although much evidence has been gathered in the last decades concerning the role of the syllable as a sublexical unit during visual word recognition in studies conducted in different languages and using different tasks and paradigms (e.g., lexical decision: Álvarez et al., 1998, 2000, 2001; Carreiras et al., 1993; Conrad et al., 2006, 2007, 2008; Conrad & Jacobs, 2004; Kwon et al., 2011; Perea & Carreiras, 1998; Stenneken et al., 2007; naming: Carreiras et al., 1993; Chetail & Mathey, 2009; Stenneken et al., 2007; masked priming: Álvarez et al., 2004; Campos et al., 2018, 2020, 2021; Carreiras & Perea, 2002; Chetail & Mathey, 2009; Mathey et al., 2013; illusory conjunction: Katz & Baldasare, 1983; Seidenberg, 1987), several questions remain unclear. One of the most overlooked issues in this literature is why syllable effects observed in masked priming lexical decision studies emerge for words with a CV (C stands for consonant and V for vowel) first-syllable structure (e.g., ru.mour), but not for words with a CVC first-syllable structure (e.g., car.bon) – note that the dots are only used in the examples to ease comprehension and not in the stimuli presented to participants in the above-mentioned studies. Another relevant question concerns the extent to which syllable effects are restricted to words or may also be observed in pseudowords, since several studies conducted in different languages have yielded mixed results, with some of them suggesting syllable effects with pseudowords (e.g., Álvarez et al., 2000; Carreiras et al., 1993), whereas others have failed to show such effects (e.g., Campos et al., 2018, 2021; Ferrand & New, 2003; Muncer & Knight, 2012). Moreover, the issue of whether syllable effects are driven by orthographic and/or phonological information, and if its nature can change as a function of the stage of visual word recognition (earlier vs. later stage), task requirements, and the characteristics of the language in use, are other issues that remain open in the psycholinguistic literature.

The advantage of CV over CVC syllables in masked priming lexical decision studies, the so-called *syllable structure effect*, was first observed by Álvarez et al. (2004) in a seminal study conducted with Spanish skilled readers to test whether syllable effects occurred at early stages of visual word recognition while controlling for the orthographic overlap between primes and targets. Specifically, in that study, the authors presented participants with disyllabic Spanish words beginning either with a CV (e.g., *JU.NIO* [june]) or a CVC first-syllable structure (e.g., *MON.JA* [nun]), which were preceded by briefly-presented (64 ms) pseudoword primes that could share the first three letters and the first syllable with the target (e.g., ju.nas-JU.NIO; mon.di-MON.JA), or the first three letters but not the first syllable with the target (e.g., jun.tu-JU.NIO; mo.nis-MON.JA), giving rise to the syllable-congruent and the syllable-incongruent conditions, respectively. Results showed that participants were faster at recognizing words preceded by syllable-congruent than syllable-incongruent primes, though, unexpectedly, only for CV words.

This result, that casts serious doubts about the role that syllables play as a sublexical unit for lexical access (see Taft & Álvarez, 2014, for a discussion), was explained by the authors based on the idea that CV is the most common syllable structure in the Spanish language (it is estimated to occur three times more than the CVC syllable structure – see Álvarez et al. (2004)), which might cause the parser to syllabify words by using a CV syllable structure by default. This explanation was also advanced by Chetail and Mathey (2009) in a similar study conducted with French skilled readers where the syllable structure effect was also observed. However, despite the plausibility of this frequency-based account, this proposal was recently challenged by Campos et al. (2018) in a masked priming lexical decision study conducted with European Portuguese (EP) skilled readers, a language where the difference between the number of CV and CVC syllables is much less pronounced than in the Spanish or French languages (according to the ProcuraPALavras lexical database - P-PAL; Soares et al., 2014, 2018, 38% of the EP words present a CV first-syllable structure while 30.2% present a CVC first-syllable structure), but where syllable priming effects were still only observed for CV words.

In an attempt to ascertain the factors that might underlie the syllable structure effect observed in EP and, possibly, in other languages, Campos et al. (2020) tested whether syllable complexity could account for that result by increasing prime durations from 50 ms (as used in Campos et al.'s 2018 work) to 67 ms and 82 ms. The rationale behind that manipulation was that since CVC syllables are more complex than CV syllables (note that CVC syllables not only entail an additional syllable component, the coda, but also a component that has been proven to be the hardest to process - see Content et al., 2001 and Treiman & Danis, 1988), it would be possible that CVC syllables might require more time to be activated. Yet, the results failed to show any signs of syllable effects for CVC words at both prime durations as, once again, syllable effects were only observed for CV words.

Recently, Campos et al. (2021) examined if syllabic neighbourhood density could account for the syllable structure effect using a lexical decision task combined with the masked priming paradigm as in previous studies (Campos et al., 2018, 2020) but with a new set of highly-controlled stimuli. Note that although Campos et al. (2018, 2020) had matched the CV and CVC words used in their experiments in a broad range of psycholinguistics variables known to affect word processing (see Soares et al., 2015, 2019 for evidence in the EP language), including the number of times CV and CVC words occurred in EP language, a post-analysis revealed that the CV words used present a higher number of words with the same number of syllables sharing the first syllable in the same (first) position than the CVC words -

a measure taken as an index of syllabic neighbourhood density (see Campos et al., 2021); which might explain the results. Specifically, the authors hypothesized that because CV words present a higher number of syllabic neighbours than CVC words, this might speed up the recognition for CV words since these syllables would present lower threshold levels of activation for recognition. Thus, upon the presentation of a syllable-congruent pseudoword prime such as *rumis*, the letter string would be syllabified as *ru.mis*, and subsequently the first syllable would send activation to all the words in the lexical layer with the same number of syllables, that had the syllable <ru> at first position (e.g., *rua* [street], *rubi* [ruby], *rubor* [blush], *rubro* [red], *rudez* [rudeness], *rumor* [rumour]...). Because typically CV words have a larger number of syllabic neighbours than CVC words, the activation generated by the presentation of the prime would be sent to a larger number of words when the prime had a CV first syllable (e.g., ru.mis-RU.MOR) than a CVC first syllable (e.g., for.pa-FOR.NO [oven]), thus, generating more activation for CV syllables in the system and decreasing the time needed to produce a "yes" response upon the subsequent presentation of a CV word. This explanation also agrees with the "fast-guess" mechanism proposed within the Multiple Read-Out Model (MROM; Grainger & Jacobs,1998) and in its recent extension (MROM-S; Conrad et al., 2010), which implemented a syllabic layer between the letter level and the word level of processing to account for the syllable inhibitory frequency effect observed in Spanish. It is relevant to mention here that although in studies manipulating the frequency of occurrence of the first syllable (e.g., Álvarez et al., 1998, 2000, 2001; Carreiras et al., 1993; Carreiras & Perea, 2002; Conrad & Jacobs, 2004; Conrad et al., 2006, 2007, 2008; Kwon et al., 2011; Perea & Carreiras, 1998), syllable frequency is usually linked to an inhibitory effect since a higher number of syllabic neighbours would mean a higher number of lexical entries competing with the target word for recognition (see Conrad et al., 2010), in studies manipulating syllable congruency, syllable effects are expected to be facilitative since the brief presentation of pseudoword primes would spread out activation to all the words sharing the same syllable. These primes, however, would not compete with the target word for selection, since they do not have a lexical representation (see however Mathey et al., 2013 for a detailed account of how pseudowords might, under certain cases, produce inhibition).

Nonetheless, an important result from Campos et al.'s (2021) work, that deserves mention for the purposes of the current paper, is that in a posteriori analysis splitting the CVC words used into those in which the orthographic (O) and phonological (P) syllable structure match (i.e., CVC_{O+P+} words, e.g., *TUR.BO* [turbo - tˈuɾ.bu] - note that in both cases the first syllable presents a CVC structure) and those in which there was a mismatch between the O and P syllable structure (CVC_{O+P-} words, e.g., *CAN.TOR* [singer – kɐ̃.tˈoɾ] - in this case the first syllable present a CVC O structure, but a CV P structure), the authors found a tendency for CVC_{O+P-} words to behave similarly to CV words. Although the result of that a posteriori analysis was nonsignificant, likely due to the lack of statistical power as only a small pool of items were used, the finding left open the possibility that syllable effects in EP might be driven by the activation of P rather than O information, which might also contribute to the syllable structure effect observed in EP. Indeed, while orthographically the differences between CV and CVC words in EP are subtle when phonology is considered, the difference increases considerably (i.e., while 43.9% of the phonologically defined EP words have a CV first-syllable structure only 15.3% have a CVC first-syllable structure – as obtained from the P-PAL lexical database, Soares et al., 2014., 2018). This occurs because in EP while CV syllables almost always present a match between the O and the P first-syllable structure (with few exceptions such as in the word *há* [exists] – [ˈa] that presents a CV orthographic syllable structure and a V phonological syllable structure since in EP the letter <h> is silent), CVC syllables can either present a match or a mismatch between the O and the P syllable structure. One of the most frequent cause for these mismatches occurs when the nucleus of a CVC orthographically defined syllable is followed by a <m> or a <n> consonant in the coda position forming a nasal vowel, such in the case of the EP word *cantor*, which orthographically has a CVC first syllable (<can.tor>), but phonologically displays a CV first syllable ([kɐ̃.tˈoɾ]) instead.

The idea that syllable effects might be driven by the activation of phonological rather than orthographic information is not new as the syllable is, by definition, a phonological unit of processing. Moreover, several studies conducted in different languages such as Spanish (e.g., Álvarez et al., 2004), French (e.g., Chetail & Mathey, 2009; Conrad et al., 2007), and even Korean (e.g., Kwon et al., 2011) have already shown that it seems to be the case. Nonetheless, because phonological effects are harder to capture with masked priming paradigms (see Forster & Davis, 1984; Kinoshita & Lupker, 2003; Lupker & Davis, 2009), it would be helpful to further examine this issue through use a more time-sensitive brain activity mapping technique as the event-related potentials (ERPs) as we did in the current paper.

Although to the best of our knowledge this is the first study aimed to directly address these issues using ERPs, it is worth noting that previous studies have used this technique to examine syllable effects at early stages of visual word recognition (e.g., Ashby, 2010; Barber et al., 2004; Carreiras et al., 2005; Chetail et al., 2012; Goslin et al., 2006; Hutzler et al., 2004; Kwon et al., 2011). For example, Barber et al. (2004), manipulating both the frequency of the first syllable (high vs. low) and the frequency of CV dissyllabic words containing those syllables (high vs. low), observed that while words with high-frequent first syllables elicited a reduced amplitude in the P200 component compared to words with low-frequent syllables, high-frequent words elicited a reduced N400 amplitude when compared to low-frequent words, and, in addition, words with high-frequent syllables elicited a larger N400 amplitude when compared to words with low-frequent syllables. The syllable effect observed in the P200 component was interpreted as indexing early facilitation due to syllable activation, whereas syllable effects observed in the N400 component were taken as reflecting competition between words sharing the same first syllable with the target (syllabic neighbours).

Other studies using the same (e.g., Chetail & Mathey, 2012; Hutzler et al., 2004; Kwon et al., 2011; but see Goslin et al., 2006 for conflicting results) or different paradigms (e.g., Carreiras et al., 2005) have found virtually the same ERP results. For instance, Carreiras et al. (2005), using a colour-congruency paradigm, asked Spanish skilled readers to decide whether CV dissyllabic Spanish words and pseudowords that appeared segmented by two different colours (red and green), corresponded or not to a real Spanish word (i.e., to perform the standard lexical decision task). The words appeared segmented in a way that the colours could match their syllable boundary (i.e., syllable-congruent condition; e.g., casino) or not (i.e., syllable-incongruent condition; e.g., casino). Results showed that targets presented in the syllable-congruent condition elicited modulations in the P200 and the N400 components, as in previous works (e.g., Barber et al., 2004; see also Hutzler et al., 2004). Differences in the processing of words and pseudowords only emerged in the N400 component showing that pseudowords elicited a larger N400 amplitude when compared to words in line with other works (e.g., Vergara-Martínez & Swaab, 2012). The fact that modulations in the P200 component were observed for words and pseudowords alike supported the view that syllable effects (at least in the Spanish language) are pre-lexical, though the use of only CV words and pseudowords limits this interpretation. Since the CV stimuli in the syllable-congruent condition always present a letter less than in the syllable-incongruent condition, these results may be indexing a difference in the number of letters in the two conditions, rather than a genuine syllable effect. One way to rule out this confound implies the use of CVC in addition to CV words. Note that only the observation that CV and CVC words and pseudowords elicit similar modulations in the P200 ERP component would genuinely indicate not only that the syllable is activated at the early stages of visual word processing but also that the effect is not lexical in nature. It is also worth remarking that although the vast majority of the ERP studies tracking syllable effects in visual word recognition have reported syllable effects in the P200 component, modulations in earlier time-windows have also been reported. For example, Ashby (2010) in one of the few ERP studies that have used both CV (e.g., PONY) and CVC (e.g., PONDER) English words, preceded either by syllable-congruent (e.g., po# – PONY, pon### –PONDER) or syllable-incongruent primes (e.g., pon# – PONY, po#### –PONDER) observed modulations in the N100 component, with both CV and CVC words preceded by syllable-congruent primes producing a reduced amplitude relative to those preceded by syllable-incongruent primes. This was the only component in which modulations were observed, however, though it is also important to point out that evidence for syllable effects in the English language remains a matter of intense debate (e.g., Álvarez et al., 2016; Taft, 1979, 1992).

In the present study, we used the colour-congruency paradigm to investigate the electrophysiological correlates of syllable effects in the processing of EP words and pseudowords with CV and CVC first-syllable structures, the latter including those in which there is a match (i.e., CVC_{O+P+}) or a mismatch (i.e., CVC_{O+P-}) between their O and P syllable structures to further examine if syllable effects in EP are driven by the activation of P or O information as described above. If the syllable is indeed a sublexical unit for lexical access, we expect to observe a syllable congruent effect modulated in the P200 component for CV and CVC words alike. Furthermore, if the same effect is extended to pseudowords, it would provide support to the view that syllable effects in EP are pre-lexical in nature. Moreover, if phonological information is the driving force of syllable activation, then we would expect that CVC_{O+P-} targets presented in the syllable-congruent condition should not elicit the same neural responses as CVC_{O+P+} and CV targets presented in the syllable-congruent condition, since these targets would appear segmented by their orthographic syllable form in the syllable congruent-condition.

Method

Participants

Twenty-four female undergraduate students from the University of Minho (M_{age} = 19.7; SD_{age} = 1.7) took part in the experiment in exchange for course credits. All the participants were native speakers of EP, with normal hearing and normal or corrected-to-normal vision, and all were right-handed, as assessed by the Edinburgh Handedness Inventory (Oldfield, 1971). None of them reported any prior history of learning disabilities and/or neurological issues. A written informed consent form was obtained from all the participants. This study was approved by the local Ethics Committee (University of Minho, Braga, Portugal, SECSH 028/2018).

Materials

A total of 180 EP dissyllabic words from five to six letters in length and with a lexical frequency ranging from 0.0586 to 48.3894 per million words, were selected from the P-PAL lexical database

(Soares et al., 2014, 2018). Sixty of these words present a CV orthographic and phonological first-syllable (e.g., *ze.bra*– [z'ɛ.bɾɐ]), 60 a CVC orthographic and phonological first-syllable (CVC$_{O+P+,}$ e.g., *ver.bo* – [v'ɛɾ.bu]), and the remaining 60 a CVC orthographic and a CV phonological first-syllable (CVC$_{O+P-,}$ e.g., *can.tor* – [kɐ̃.t'oɾ]). The CV, CVC$_{O+P+}$, and CVC$_{O+P-}$ words were matched in several variables known to affect EP word processing (see Soares et al., 2015, 2019), namely per million-word frequency (*p* = .352), number of letters (*p* = .869), the classic *N* orthographic neighbourhood measure (*p* = .262), number of more frequent orthographic neighbours (*p* = .971), mean frequency of the most frequent orthographic neighbours (*p* = .581), and the orthographic Levenshtein distance (i.e., OLD$_{20}$ measure - Yarkoni et al., 2008; *p* = .175). Moreover, CV, CVC$_{O+P+}$, and CVC$_{O+P-}$ words were also matched in the type (*p* = .373) and token frequency of their first syllable (*p* = .408), the two measures of syllabic neighbourhood provided by P-PAL. Table 8 depicts the psycholinguistic characteristics (means and standard deviations) of the words used in the experiment.

Table 8

Psycholinguistic Variables in Which CV, CVC$_{P+O+}$ and CVCP$_{-O+}$ Words Used in the Present Study Were Matched as obtained from the P-PAL database (Soares et al., 2018)

Psycholinguistic variables	CV words *M* (*SD*)	CVC$_{P+O+}$ words *M* (*SD*)	CVC$_{P-O+}$ words *M (SD)*	*p*
Word length (number of letters)	5.17 (0.38)	5.18 (0.39)	5.27 (0.45)	.869
Word frequency (per million)	7.95 (10.01)	9.01 (12.67)	8.70 (11.56)	.352
Orthographic neighbourhood Size (*N*)	6.00 (4.84)	5.98 (4.45)	7.22 (4.85)	.262
Mean frequency of the orthographic neighbours	16.10 (59.58)	18.05 (42.79)	16.75 (22.52)	.971
Mean frequency of higher frequency orthographic neighbours	33.54 (113.86)	53.79 (109.21)	47.96 (68.78)	.518
Orthographic Levensthein Distance (OLD$_{20}$)	1.60 (0.33)	1.60 (0.35)	1.51 (0.30)	.175
Number of syllabic neighbours sharing the first syllable	40.82 (35.06)	35.65 (19.42)	34.87 (17.33)	.373
Summed frequency of the syllabic neighbours sharing the first syllable	503.51 (674.76)	370.30 (426.99)	485.81 (639.46)	.408

Additionally, 180 pseudowords were created for the purpose of the LDT by replacing one or two letters in the medial positions of other EP words with similar characteristics to the experimental words. For instance, the pseudoword *li.jor* was created from the base EP word *li.cor* [liquor] by replacing the letter <c> with a <j> while respecting the orthographic and phonotactic restrictions of EP. As with word targets, 60 pseudowords had a CV first-syllable structure (e.g., *fó.pio* [f'ɔ-pju]), 60 a CVC$_{O+P+}$ first-syllable structure (e.g., *vul.ma* [v'uɫ-mɐ]), and the 60 a CVC$_{O+P-}$ first-syllable structure (e.g., *pen.va* [p'ẽ-vɐ]). This method followed many other studies conducted in EP (e.g., Campos et al., 2018; Perea et al., 2013; Soares et al., 2019, 2020, 2021) and in other languages as well (e.g., Balota et al., 2004, 2007;

Cuetos et al., 2011; Ferrand et al., 2010; Yap et al., 2010), as research tools supporting the generation of legal pseudowords are not available for EP. Nevertheless, extreme caution was taken to ensure that the pseudowords resembled real EP words and conform to the orthographic rules of EP.

Each of the words and pseudowords was segmented according, or not, to its syllable boundary following the orthographic syllabic rules of EP by using the black and grey colours. Thus, a CV word as *zebra* [zebra] was presented as *zebra* in the syllable-congruent condition and as *zebra* in the syllable-incongruent condition, as a CVC_{O+P+} word as *verbo* [verb] or a CVC_{O+P-} word as *cantor* [singer] were presented as *verbo* and *cantor* in the syllable-congruent condition and as *verbo* and *cantor* in the syllable-incongruent condition, respectively. Although in the original study of Carreiras et al. (2005), the authors used red and green to segment the targets, we opted to use black and a dark grey instead because participants are used to see printed words in these colours, therefore creating a more ecological experimental setting. Furthermore, we have opted to use black and grey to avoid potential positive/negative effects related to the use of red and green colours, which are commonly linked to positive and/or negative connotations in several contexts (e.g., Buechner et al., 2014; Elliot & Maier, 2007, 2012, 2014). Words and pseudowords were presented twice to the participants, once in the syllable-congruent condition and another in the syllable-incongruent condition, in two separate blocks. Thus, in one block, half of the words and half of the pseudowords were presented in the syllable-congruent condition while in the other half were presented in syllable-incongruent condition evenly distributed across the three types of words/pseudowords (CV, CVC_{O+P+}, and CVC_{O+P-}). In the other block, the reverse would happen, i.e., the words/pseudowords that were presented in the syllable-congruent condition in the first block were presented in the syllable-incongruent condition in the second block and the other ones the other way around. To prevent order effects, the presentation of the first and second blocks was counterbalanced across participants.

Procedure

Participants were tested individually in a light- and sound-attenuated electrically shielded room, a meter away from the computer screen. They were asked to decide as quickly and accurately as possible if the letter string presented at the centre of a 22-inch computer screen was a real EP word or not, by pressing the key "1" of the keyboard for a "word" response and the key "2" for a "nonword" response (i.e., to perform the classic lexical decision task). The task comprised 720 trials presented in two blocks of 360 trials each. Trials in each block began with the presentation of a fixation cross (+) at the centre of the computer screen for 2,500 ms. Subsequently, a word or a pseudoword was presented in 36-point Courier New, in the same stimulus position for 1,000 ms - or until a response (word/nonword) was produced - with a variable interstimulus interval (ISI) from 1000 to 1500 ms. Also, an additional ISI of 3,000 ms was presented every four trials to avoid fatigue. Trials in each block were presented randomly for each participant.

Prior to the experimental task, participants responded to 12 practice trials to familiarize them with the task. The task was programmed using the Psychopy software (Pierce, 2007). The whole procedure lasted approximately 45 minutes per participant.

EEG Data Acquisition and Processing

The EEG data were recorded while participants performed the LDT by 64 channels BioSemi Active-Two system (BioSemi, Amsterdam, The Netherlands) organised according the 10/10 system and sampled at a rate of 512 Hz. Electrode impedances were kept below 20 kΩ and they were filtered online at a rate of 0.1-100 Hz band-pass filter (zero phase shift Butterworth). Vertical and horizontal electro-oculogram activity was recorded to monitor eye movements and blinks.

The EEG data were processed with the Brain Vision Analyzer, version 2.1.1. (Brain Products, Munich, Germany). It was digitally filtered offline with a 0.1-70 Hz band-pass filter (8 dB/octave). Stereotyped noise, which was mostly ocular movements and blinks, was removed by independent component analysis (ICA). The signal was re-referenced off-line to the algebraic average of the mastoids and segmented in epochs from -200 to 1,000 ms. Epochs that exceeded ±80 µV at any scalp electrode were rejected. Before averaging, a baseline correction was applied (from -200 to 0 ms).

Data Analysis

EEG and behavioural data were analysed with the IBM-SPSS software (Version 27.0. Armonk, NY, USA: IBM Corporation). Incorrect responses (13.6% of the responses in the word data and 22.2% of the responses in the pseudoword data) were removed from the analyses. Furthermore, RTs that were bellow and above three standard deviations from the mean of each participant per experimental condition were also excluded (2.9% of word data and 0.69% of pseudoword data), following common procedures in psycholinguistic research (e.g., Campos et al., 2018; Soares et al., 2020).

Individual ERPs were averaged separately for the correct responses per experimental condition over a 1,200 ms epoch. Grand average waveforms were then calculated across individuals for each type of word/pseudoword (CV, CVC_{O+P+}, and CVC_{O+P-}) both in the syllable-congruent and syllable-incongruent conditions. Based on previous literature, mean amplitudes in the fronto-central (Fz, FCz, FC1, FC2, and

Cz) and parieto-occipital (Pz, POz, PO3, PO4, and Oz) regions were calculated for three time-windows: 80-120 ms (N100), 130-170 ms (P200), and 350-450 ms (N400).

Repeated-measures ANOVAs were conducted on the behavioural (RT and accuracy) and EEG data (mean amplitudes in each ERP component) based on a within-subject design, which included the factors lexicality (2: words vs. pseudowords), syllable structure (3: CV, CVC_{O+P+}, CVC_{O+P-}), and syllable congruency (2: congruent vs. incongruent). In both analyses, only main or interaction effects that reached statistical or marginal significance in comparisons of interest are reported. The Greenhouse–Geisser correction for nonsphericity was used when appropriate. Posthoc tests for multiple comparisons were adjusted with Bonferroni correction. Measures of effect size (η^2_p) and observed power (*pw*) for a single effect are reported in combination with the main effects of the condition.

Results

Behavioural Data

The mean and standard deviations of the RTs for correct responses and the percentage of errors for the CV, $CVC_{O+P+,}$ and CVC_{O+P-} words and pseudowords in each syllable colour boundary conditions (congruent and incongruent) are presented in Table 9.

Table 9

Mean and SD (in brakets) of Response Times (RTs) and Percentage of Errors (%E) per Condition

Lexicality	Target type	Prime type			
		Congruent		Incongruent	
		RT	%E	RT	%E
Words	CV	652 (40)	12.4 (7.9)	655 (46)	14.5 (10)
	CVC_{O+P+}	653 (42)	12.6 (7.6)	662 (45)	14.3 (7.7)
	CVC_{O+P-}	653 (41)	15.3 (8.9)	655 (46)	14.3 (6.9)
Pseudowords	CV	721 (62)	23.5 (18.7)	717 (56)	24.4 (18.7)
	CVC_{O+P+}	716 (62)	22.0 (15.6)	708 (64)	20.5 (16.6)
	CVC_{O+P-}	703 (62)	22.1 (16.1)	715 (55)	21.0 (16.5)

On the latency data, the ANOVA showed a significant main effect of lexicality, $F(1, 23) = 38.845$, $MSE = .246$, $p < .001$, $\eta^2_p = .628$ indicating, unsurprisingly, that participants were faster at recognizing words than pseudowords. A syllable structure main effect was also was also observed, *F*(2,

46) = 3.219, *MSE* = .001, p = .049, η^2_p = .123. Pairwise comparisons revealed, however, that the contrasts were not significant since there was only a tendency for participants to be faster at recognizing CVC_{O+P-} words and pseudowords than CV words and pseudowords (p = .061). Furthermore, the two-fold lexicality x syllable structure interaction reached statistical significance, F(2, 46) = 3.931, *MSE* = .001, p = .027, η^2_p =.146. This interaction revealed that the effect of syllable structure reported above (faster responses to CVC_{O+P-} than CV stimuli) was only significant for pseudowords (p = .002). Moreover, the interaction revealed that participants were faster at recognizing CVC_{O+P+} pseudowords than CV pseudowords (p = .036). For words, no differences reached statistical significance (all p's > .631). The three-fold lexicality x syllable structure x syllable congruency boundary interaction was also significant, F(2, 46) = 5.638, *MSE* = .001, p = .006, η^2_p = .197. Pairwise comparisons revealed that participants were faster at rejecting pseudowords with a CVC_{O+P-} structure presented in the syllable-congruent condition than in the syllable-incongruent condition (p = .003). No other differences were significant.

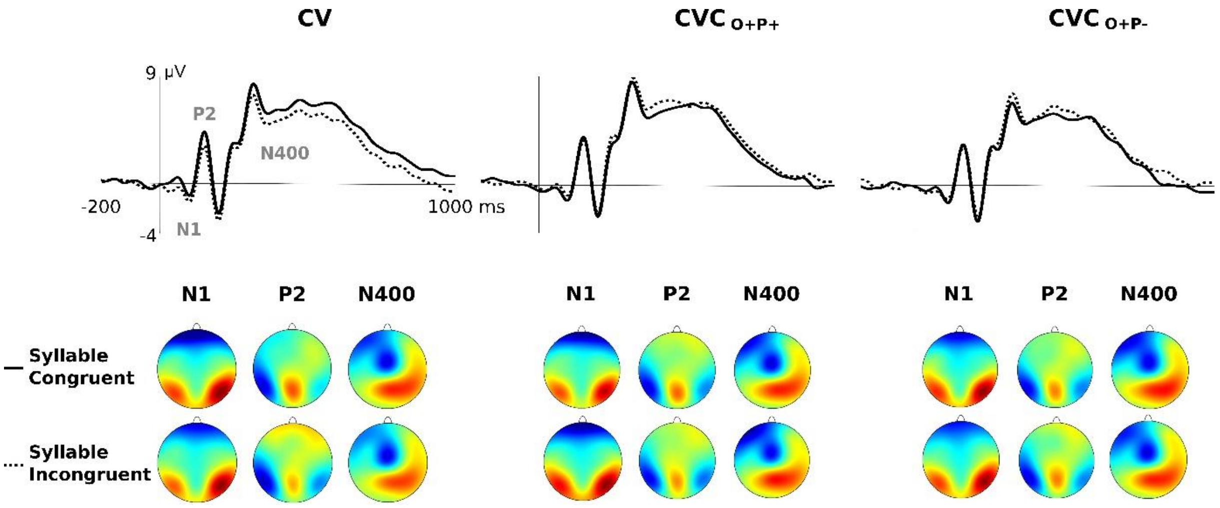
In the accuracy data, the ANOVA revealed a main effect of lexicality, F(1, 23) = 6.803, *MSE* = .503, p = .016, η^2_p = .228, showing that participants were more accurate at recognizing words than pseudowords, as expected. The interaction lexicality x syllable structure was also significant, F(2, 46) = 3.231, *MSE* = .009, p = .049, η^2_p = .123. This effect revealed that participants produced more mistakes when responding to CV pseudowords than to CVC_{O+P+} pseudowords (p = .020). For words, no differences were observed (all p's > .282). No other effects reached statistical significance.

ERP Data

Figure 6 presents the grand average waveforms and the scalp distributions for the syllable-congruent and syllable-incongruent conditions for the CV, CVC_{O+P+}, and CVC_{O+P-} words and pseudowords at POz in the N100, P200, and N400 time-windows.

Figure 6.

Grand average waveforms and scalp distributions for the syllable-congruent and syllable-incongruent condition, presented for the three different first-syllable structure target types, at POz in the three time-windows at which significant effects were found, 80-120 ms (N100), 130-170 ms (P200), and 350-450 ms (N400)

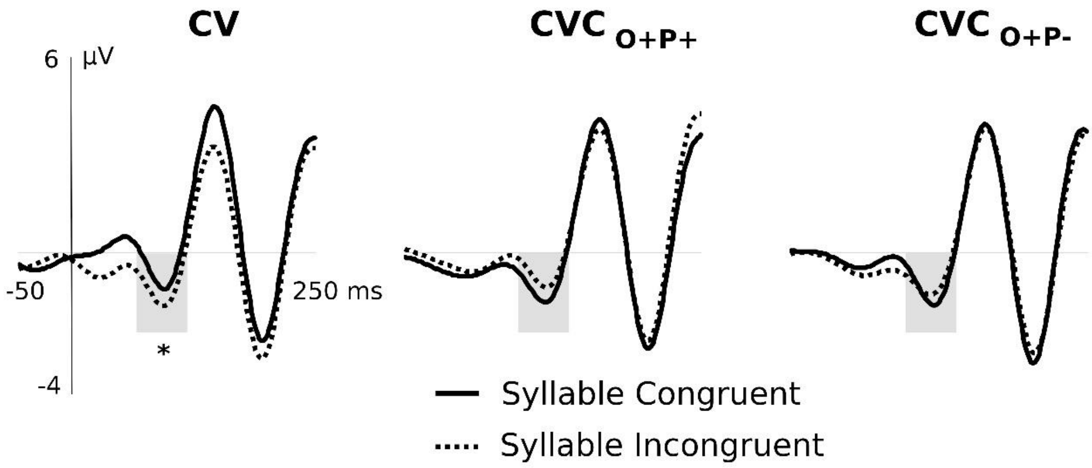


N100.

The ANOVA revealed that the syllable structure x syllable-congruency interaction effect in the parieto-occipital region was significant, $F(2, 46) = 3.296$, $MSE = 8.622$, $p = .046$, $\eta^2_p = .332$. Pairwise comparisons showed that words and pseudowords with a CV first-syllable structure elicited reduced amplitudes in the syllable-congruent condition when compared to the syllable-incongruent condition (p = .028). No other main or interaction effects reached statistical significance. In Figure 7, the N100 is represented across the three types of syllable structure targets.

Figure 7.

Grand average waveforms for CV, CVC$_{O+P+}$ and CVC$_{O+P-}$ at POz in the 80-120 ms time-window (N100)

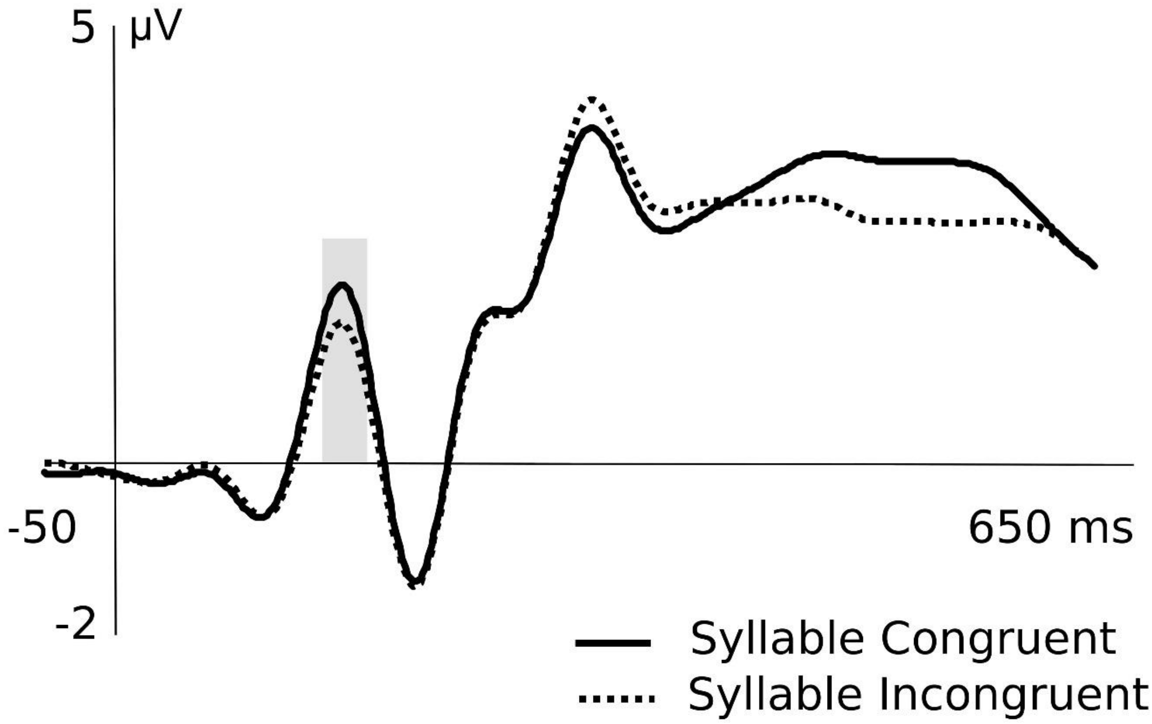


P200.

In this time window, the ANOVA showed two significant main effects in the parieto-occipital regions: a main effect of lexicality, $F(1, 23) = 11.452$, $MSE = 39.511$, $p = .003$, $\eta^2_p = .332$, indicating that words elicited larger P200 amplitudes than pseudowords; and a main effect of syllable congruency, $F(1, 23) = 4.729$, $MSE = 20.280$, $p = .040$, $\eta^2_p = .171$, showing that CV, CVC$_{O+P+}$, and CVC$_{O+P-}$ words and pseudowords produced larger P200 amplitudes in the syllable-congruent condition than in the syllable-incongruent condition (see Figure 8). No other effects reached statistical significance.

Figure 8.

Grand average waveforms for the syllable -congruent boundary condition and the syllable-incongruent condition at POz in the 130-170 ms time-window (P200)

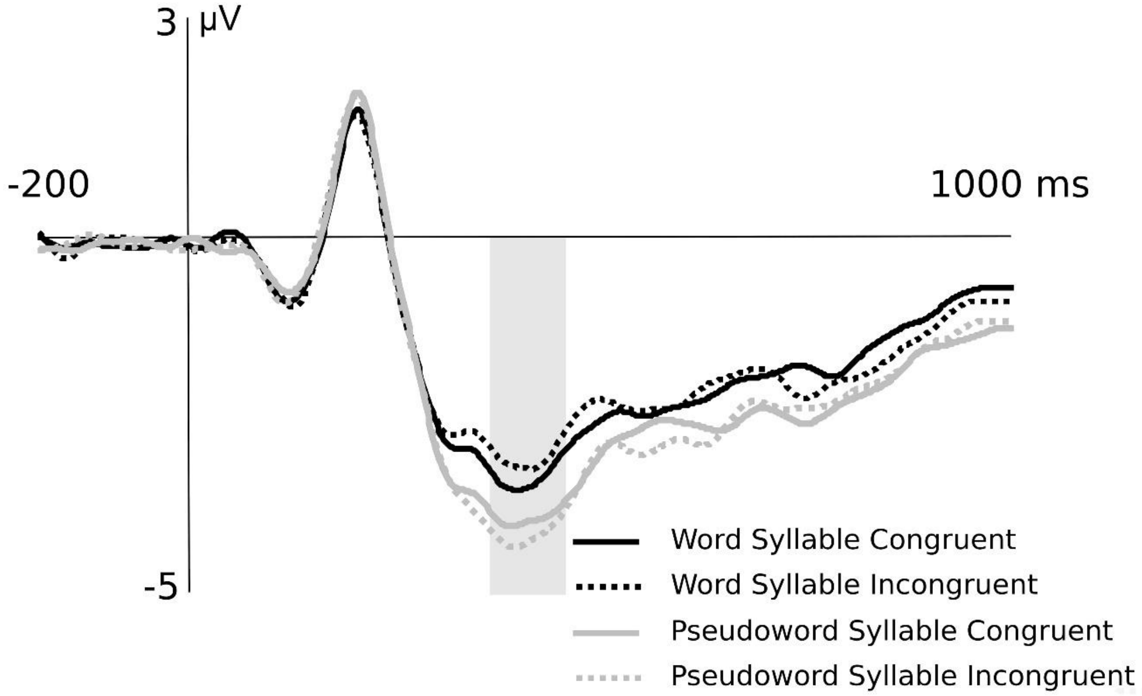


N400

A main effect of lexicality was observed in this time window in the fronto-central electrodes, $F(1, 23) = 47.265$, $MSE = 205.316$, $p < .001$, $\eta^2_p = .673$, indicating that words produced reduced N400 amplitudes when compared to pseudowords. A significant lexicality x syllable congruency interaction was also found in the same fronto-central region, $F(1, 23) = 4.701$, $MSE = 10.360$, $p = .041$, $\eta^2_p = .170$. Pairwise comparisons however failed to reach significance and there was only a tendency for words with a CV, $CVC_{O+P+,}$ and CVC_{O+P-} structure to produce a larger N400 amplitude in the syllable-congruent than in the syllable-incongruent condition ($p = .056$). Figure 9 depicts the graphic representation of this two-fold interaction.

Figure 9.

Grand average waveforms showing the interaction between lexicality and the syllable congruency condition (congruent vs. incongruent) in the 350-450 ms time-window (N400) at FOz



Furthermore, in the parieto-occipital region, a marginal syllable structure x syllable-congruency effect was also observed, $F(2, 46) = 3.104$, $MSE = 11.208$, $p = .054$, $\eta^2_p = .119$. Pairwise comparisons revealed that CV words and pseudowords produced a larger N400 amplitude in the syllable-congruent than in the syllable-incongruent condition ($p = .029$). No other significant effects were found in this time window.

Discussion

The role of the syllable in visual word recognition has been widely studied in the psycholinguistic literature, though several questions remain unanswered. This study was designed to address some of these issues, namely the largely overlooked syllable structure effect observed in EP, as well as in other languages. In addition, we have also analysed whether syllable effects in EP are driven by phonological and/or orthographic information, as the results of Campos et al. (2021) left open phonology as a possible factor contributing to the syllable structure effect observed in EP. We have explored this issue by taking advantage of a particular feature of the EP language that encompasses the fact that words with a CVC orthographic first syllable may present either a CVC (CVC_{O+P+}) or a CV (CVC_{O+P-})

phonological first syllable. If phonological information was driving syllable activation at early stages of visual word recognition, CVC_{O+P-} targets presented in the syllable-congruent condition should differentiate from CVC_{O+P+} and CV targets presented in the syllable-congruent condition. Moreover, by comparing the neural responses elicited by the processing of words and pseudowords, we also aimed to shed light on the pre-lexical nature of syllable effects in EP since previous behavioural studies in this language have failed to show syllable effects for pseudowords (e.g., Campos et al., 2018, 2021).

Behavioural results showed the expected lexicality effect both in RTs and accuracy data as participants took longer and committed more mistakes when rejecting pseudowords than accepting words, hence demonstrating that the task worked properly. Nonetheless, unlike previous studies manipulating either first syllable frequency (e.g., Álvarez et al., 1998, 2000, 2001; Carreiras et al., 1993; Conrad et al., 2007, 2008; Perea & Carreiras, 1998; Stenneken et al., 2007) or syllable congruency boundary in lexical decision masked priming studies (e.g., Álvarez et al., 2004; Campos et al., 2018, 2020, 2021; Chetail & Mathey, 2009), no signs of syllable effects were observed for word targets in our data. Although the result might seem unexpected, it is consistent with previous findings in the literature that also failed to show reliable syllable effects using the colour-congruency paradigm (e.g., Carreiras et al., 2005; Katz & Baldasare, 1983). As Katz and Baldasare (1983) suggested, the absence of significant syllable effects in this paradigm might stem from the fact that presenting stimuli in two different colours might not suffice to disrupt word recognition in skilled adult readers, at least as captured by behavioural measures. Moreover, the fact that in our study targets were also presented in black and dark grey, colours that most readers are used to encounter in print, could have further contributed to diminishing that disruption.

Evidence for behavioural syllable effects was curiously found for pseudoword targets, as participants were faster and more accurate at rejecting pseudowords presenting a CVC_{O+P-} first syllable in the syllable-congruent condition than in the syllable-incongruent condition. Although this result was not expected, it is possible that because CVC_{O+P-} pseudowords present less syllabic variability than pseudowords with a the CVC_{O+P+} and CV first syllable (note that only when the nucleus of a CVC syllable is followed by an <n> or <m> in the coda position the mismatch between the O and P syllabic structure occurs), this might have contributed to produce some kind of pop-out effect that might make these pseudowords more distinctiveness, hence making participants to quickly reject them as 'words' in the syllable-congruent condition.

Signs of syllable effects for words were nevertheless observed in the ERP data. Specifically, in the N100 component, the results indicated that CV words and pseudowords produced a reduced amplitude in the syllable-congruent condition relative to the syllable-incongruent condition. Although Ashby (2010) observed a reduced amplitude in this ERP component for CV and CVC words, which lead the author to propose that this wave also indexes syllable activation, the fact that in our data the effect was restricted to CV targets prevent us from making such assumption. Rather, our results suggest that this early effect might be indexing syllable complexity instead, as Campos et al. (2020) recently proposed as a possible factor underlying the syllable structure effect in EP. In their work, as mentioned, the authors increased prime durations to test if the greater complexity of CVC syllables could be accounting for the syllable structure effect. Although their results did not seem to support this hypothesis, since reliable syllable effects continued to be restricted to CV words even when giving participants greater prime exposure, the ERP data presented here does seem to show that this factor should not be neglected. It is possible that the influence of syllable complexity during visual word recognition occurs at very early stages of visual word recognition, hence making it that behavioral paradigms would not be able to capture them. In any case, although syllable complexity might not be sufficient to explain the syllable structure effect found in masked priming lexical decision studies, it can nonetheless contribute to its emergence at later stages of visual word recognition, favoring syllable effects for words with less complex first-syllable structures such as the CV as they could be easier to segment and process – i.e., having only two letters and not having a coda unit - consequently making syllable effects easier to emerge.

Evidence of genuine syllable effects was nevertheless found in the P200 component, and, importantly, for CV, CVC_{O+P+}, and CVC_{O+P-} targets alike. These findings not only support previous studies showing modulations in this ERP component for syllable manipulations (e.g., Barber et al., 2004; Carreiras et al., 2005; Chetail et al., 2012; Hutzler et al., 2004), but critically extend them by demonstrating, for the first time, that the effect found in this waveform for CV targets were also observed for other syllable types, hence providing strong support to take this ERP component as the neural signature of syllable activation. Note that because Carreiras et al. (2005) have only used CV targets prevented them from claiming the effect stemmed from a genuine syllable activation and not from syllable complexity per se, as we have previously mentioned for the result obtained in the N100 component. Furthermore, the fact that here, using a more time-sensitive technique we have observed syllable effects across different first-syllable structure words, does seem to show that the syllable structure effect found in masked priming lexical decision studies (e.g., Álvarez et al., 2004; Campos et al., 2018, 2020, 2021; Chetail & Mathey, 2009) might be emerging from the particular characteristics of the task at use and does not reflect a genuine effect. Moreover, it is also worth noting that syllable effects were observed at this time window for words and pseudowords, regardless of their syllable structure, as shown by the main syllable congruency effect. This is a crucial result since it shows for the first time, evidence of syllable effects in EP not only for words with different first-syllable structures, but also for pseudowords, reinforcing the view that syllable effects in EP are pre-lexical in nature, as observed in other studies conducted in different languages (e.g., Carreiras et al., 2005; Chetail et al., 2012; Hutzler et al., 2004; Kwon et al., 2011).

It is also worth noting that the absence of differences between the processing of CV, CVC_{0+P+}, and CVC_{0+P-} targets in the P200 ERP component does not support the notion that phonology is the main source driving syllable effects in EP, unlike what has been observed in other languages, though using different paradigms (e.g., Álvarez et al., 2004; Chetail & Mathey, 2009; Conrad et al., 2007; Kwon et al., 2011, 2011). In fact, for CVC_{0+P-} targets participants were presented with the orthographic first-syllable form in the syllable-congruent condition, but with the phonological first-syllable form in the syllable-incongruent condition. The fact that - analogous to what happened for CV and CVC_{0+P+} targets- it was in the syllable-congruent condition that evidence of a syllable effects was found, suggests that it was the orthographic syllable form of CVC_{0+P-} targets that was activated during word recognition. Consequently, our results support the view that orthography is the driving force behind syllable effects at the first stages of visual word recognition, which is also consistent with the results observed by Chetail et al. (2012) in a study using ERPs in French, which, as EP, is also an intermediate-depth language. These findings seem to suggest that in languages where there is not a direct mapping between orthography and phonology, unlike what is observed in transparent languages such as Spanish, phonology might have a less prominent role in syllable activation at least at the early stages of visual word recognition, which is also consistent with many studies suggesting that while, in more transparent languages, readers rely more on the use of phonological codes, in more opaque languages, readers rely more on alternative strategies that are based on visual and orthographic cues (see Harm & Seidenberg, 2004; Katz & Frost, 1992 and also Soares et al., 2019 for an extended discussion). Lastly, in the N400 component, besides the unsurprising lexicality effect showing that EP words produced a reduced amplitude when compared to EP pseudowords, a result also observed in previous studies (e.g., Carreiras et al., 2005; Vergara-Martínez & Swaab, 2012), the lexicality and syllable-congruency interaction effect revealed a tendency (p = .056) for CV, CVC_{0+P+}, and CVC_{0+P-} words in the syllable-congruent condition to produce larger N400 amplitudes than words in the syllable-incongruent condition. Importantly, the same result was not observed for pseudowords since no differences in the N400 component were found between pseudowords presented in the syllable-congruent condition and those in the syllable-incongruent condition regardless of their first-syllable structure. This result seems to suggest that syllable effects at later stages of visual word recognition are only maintained for words, and that this is likely happening due to a top-down activation generated by words containing this first syllable. It is also important to mention that the larger N400 amplitude for words presented in the syllable-congruent condition closely reproduces previous findings with CV words presented in the syllable-congruent condition in the study by Carreiras et al. (2005), and also in studies manipulating syllable frequency in a standard lexical decision task where CV words with a high-frequent first syllable also elicited larger N400 amplitudes when compared to CV words with a low-frequent first syllable (e.g., Barber et al., 2004; Hutzler et al., 2004; Goslin et al., 2006; Chetail et al., 2012). The larger N400 amplitude has been taken as indexing an effect that emerges as a consequence of the lexical competition between lexical candidates that share the same first syllable (i.e., syllabic neighbours) and that compete with the target for recognition (see Conrad et al., 2010 but see also Chetail et al., 2012 for more details). Additionally, results observed in parieto-occipital areas showed that this competition between lexical candidates tended to be greater for CV words when compared to CVC_{O+P+} and CVC_{O+P-} words suggesting that CV words produce a larger top-down activation of CV syllables, as shown by the tendency observed for CV targets in the syllable-congruent condition to produce larger N400 amplitudes than CV targets in the syllable-incongruent condition. Note also that posthoc analyses revealed that only for CV words was the effect observed in the N400 significant (p = .023; for pseudowords, it does not reach significance, p = .203), further supporting the view that this latter syllable effect is produced from top-down activation.

Although as mentioned, the stimuli used in the present paper were controlled for in several important psycholinguistic variables including the number of syllabic neighbours (i.e., type frequency of the first syllable) and their summed frequency (i.e., token frequency of the first syllable), the tendency observed in our results related to modulations in the N400 seem to suggest that the CV skeletal structure (i.e., the combination of consonants and vowels) and not only the syllable per se, is also being activated. Indeed, recent studies have highlighted the importance of the CV skeletal structure of words during visual word recognition, showing that they are activated at early stages (e.g., Blythe et al., 2014; Chetail & Drabs, 2014; Chetail et al., 2016; Perea et al., 2018). The fact that words containing a CV combination, both when it forms a syllable such in the word *ba.nho* [bath - CVCCV] or when it is only a letter cluster but not a syllable, as in the word *bal.de* [bucket – CVCCV] – note that most CVC words in the EP language contain a CV syllable embedded within them, but the contrary does not typically occur - are more common, might explain why even when CV and CVC words are matched on their number of syllabic neighbours, such as recently done by Campos et al. (2021), is there still an advantage of CV words over CVC words. Thus, this larger number of lexical candidates activated by the CV skeletal structure of CV words is likely indexed by the larger N400 amplitudes relative to CVC words with a match and mismatch, showing that there is a higher level of competition.

Conclusions

In sum, the present study highlights that early syllable activation, as indexed by the P200 component, is not restricted to CV first-syllable structure words and that these early modulations also emerge for CVC first-syllable structure words. Moreover, the same pattern of neural activation was found for the two types of CVC targets, those with a match (CVC_{O+P+}) or a mismatch (CVC_{O+P-}) between their O and P form, with both producing larger P200 amplitudes in the syllable-congruent than in the syllable-incongruent condition. This result seems to suggest that, in EP, syllable effects at early stages of visual word recognition are not driven by phonological but rather by orthographic information. Additionally, modulations in the P200 component were found for words and pseudowords, which extended previous studies in EP regarding syllable effects, by demonstrating that syllable activation is not dependent on the lexical status of the target thus making the effect pre-lexical. Moreover, at later stages of visual word recognition, as observed in the N400 component, our results seem to show that syllable effects are only maintained in word targets, likely being produced from the top-down activation sent from the lexical entries to the syllable. Furthermore, the fact that the effect tends to be more pronounced in CV words can stem from the fact that in EP a larger number of words not only have a CV syllable, but also a CV skeletal structure, which would generate greater competition between lexical entries, as indexed by larger amplitudes in the N400 component, even when the number of syllabic neighbours is matched between CV and CVC words.

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General Discussion

The main goal of the studies presented in this thesis was to investigate the role of the syllable at the early stages of visual word recognition in EP, an intermediate-depth stress-timed language, where no previous studies on this issue had been conducted. Furthermore, with this thesis we also aimed to shed light on the factors that might underlie the syllable structure effect, previously observed in other languages, using the well-known lexical decision task combined with the masked priming paradigm (e.g., Álvarez et al., 2004; Chetail & Mathey, 2009). To that purpose, four behavioral experiments (see Papers 1, 2, 3, and 4) and an event-related potentials (ERPs) experiment (see Paper 5) were conducted using skilled and non-skilled (developing) EP readers.

Specifically, in Paper 1, we tested for the first time the role of the syllable as a sublexical unit during visual word recognition with EP adult skilled readers by replicating the paradigm used by Álvarez et al. (2004) with Spanish adult skilled readers, but adding an unrelated condition, as used in the study of Chetail and Mathey (2009) with French skilled readers, to test if syllable effects at early stages of EP visual recognition were facilitative. Additionally, we have also opted to use shorter (50 ms) prime durations than the ones used by Álvarez et al. (2004) but also by Chetail and Mathey (2009) - 64 ms and 67 ms, respectively - since many studies have shown that a shorter priming duration of 50 ms is enough not only to allow the emergence of orthographic effects (see Ferrand & Grainger, 1993; Grainger et al., 2006; Perfetti & Tan, 1998) but also phonological effects (see for instance Frisson et al., 2014; Frost et al., 2003; but also, Rayner et al., 2006 for a review). The results obtained from Paper 1 showed evidence of syllable activation at early stages of visual word recognition as participants were faster at recognizing dissyllabic EP words preceded by syllable-congruent primes than preceded by both syllable-incongruent and unrelated primes. Critically, however, this syllable facilitation effect was only observed when the dissyllabic EP words had a CV first-syllable structure. For the CVC dissyllabic EP words, no differences were found between the syllable-congruent, syllable-incongruent, and unrelated conditions, thus showing the syllable structure effect (i.e., advantage of the CV over the CVC words) previously observed in Spanish (Álvarez et al., 2004) and French (Chetail & Mathey, 2009). Moreover, the results also showed that syllable effects were restricted to words as the previous presentation of syllable-congruent, syllable-incongruent, and unrelated primes had no effects on the processing of pseudowords.

Paper 2 further examined the developmental trajectory of syllable effects in EP, in particular of the syllable structure effect, using beginning (third-grade students) and intermediate (fifth-grade students) EP developing readers. To that purpose, we have resorted to a sandwich masked priming lexical decision (go/no-go) paradigm, instead of the standard masked priming lexical decision paradigm used in Paper 1, as previous studies had shown that the brief presentation of the target (33 ms) prior to the prime increases priming effects that are usually of small size, especially with developing readers, and attenuates the influence of orthographically similar words, such as orthographic and syllabic neighbors, boosting priming effects (see Perea et al., 2014; Stinchcombe et al., 2012). Furthermore, the use of the go/no-go variation of the lexical decision task follows current practices in the literature with younger readers (e.g., Moret-Tatay & Perea, 2011; Soares et al., 2014, 2019) as it makes the task easier for them, decreasing RTs and increasing accuracy (see Moret-Tatay & Perea, 2011 for more details). Besides, we have also added an extra identity-prime condition to the syllable-congruent, syllable-incongruent, and unrelated conditions used in Paper 1, to assure that the task was working adequately, even when no other priming effects were obtained, another common practice. Results showed that reliable syllable priming effects were only observed for intermediate EP readers and, importantly, for CV and CVC EP words alike. For EP beginning readers, besides the expected identity priming effect, no evidence of a syllable effect was found since, although they were faster in recognizing EP words preceded by syllable-congruent and syllable incongruent primes when compared to unrelated primes, the fact that no differences were found between the two conditions suggests that the facilitation effects were due to the orthographic overlap between prime and targets instead of a genuine syllable activation.

Papers 3, 4, and 5 focused on examining the factors that could account for the syllable structure effect observed in EP adult skilled readers, a subject which had been largely overlooked in past research. Note that in EP the advantage of the CV over the CVC syllable was not expected, not only because Morais et al. (1989) had previously observed with EP literate and illiterate adults that syllable effects in speech recognition occurred for CV and CVC words alike, but, importantly, because EP did not show the unbalanced distribution of CV and CVC words observed in the Spanish and French languages. Indeed, the main account put forward to explain the syllable structure effect has been the differences between the number of CV and CVC words since CV words constitute about three times the number of CVC words in Spanish (see Álvarez et al., 2004) and French (see Colé et al., 1999). Nonetheless, in EP these estimates are 38% of occurrences for CV first-syllable words and 30.2% for CVC first-syllable words, making it unlikely, based on this hypothesis, that an advantage of CV over CVC syllables should be observed.

Alternatively, Paper 3 examined if syllable complexity could underlie the syllable structure effect observed in EP adult skilled readers. In fact, CVC syllables when compared to CV syllables are not only longer, having one extra letter, but they also contain another syllabic segment, the coda, which has been shown to be the hardest syllabic segment to process (see Content et al., 2001; Treiman & Danis, 1988). Hence, it would be possible that the brief (50 ms) presentation of the primes, would not give enough time for the system to segment CVC primes and for CVC syllables to be fully activated in the system, giving rise to the syllable structure effect. To directly test this hypothesis, in Paper 3, we have replicated the experiment in Paper 1 using the same paradigm and materials but increasing prime durations to 67 ms and 82 ms. Still, reliable syllable priming effects were once again only observed for CV EP words, thus ruling out syllable complexity as the main cause of the syllable structure effect observed with EP skilled readers, at least as tested in this work by increasing priming durations.

In Paper 4, we have explored another hypothesis related to the role syllabic neighbors could play in the advantage of CV syllables. Following the most recent proposal of Chetail and Mathey (2011), syllabic neighbors are defined as words with the same syllabic length that shared the same (first) syllable in the same position between themselves (e.g., the syllabic neighbors of the word *rumor* [rumor] would be all disyllabic words that have <ru> as a first syllable, which would include words such as *rugas* [wrinkles], *rubro* [red], *rural* [rural], and *rubor* [flush]). It is important to mention that, although in Paper 1, special care was taken to assure that CV and CVC words were controlled in as many psycholinguistic variables as possible, including the summed frequency of words sharing a first syllable with the target (i.e., token frequency), a post-analysis of the stimuli revealed that, still, CV words presented a higher number of words sharing the first syllable with the targets than CVC words, which could have also accounted for the syllable structure effect. It is possible that because CV words came from a larger syllabic neighborhood than CVC words, the threshold needed for word recognition (i.e., to produce a 'yes' response) would be lower, making it that a CV congruent prime would produce more facilitation than a CVC congruent prime, justifying the syllable structure effect. To examine the role of syllabic neighborhood density on the syllable structure effect, in Paper 4 we have matched CV and CVC words on their number of syllabic neighbors in a masked priming lexical decision task. While it would have been ideal to manipulate the number of syllabic neighbors of CV and CVC words rather than match them, due to constraints in EP, such a manipulation was not possible as we could not find a sufficient number of CVC words with a high enough number of syllabic neighbors nor a sufficient number of CV words with a sufficiently low number of syllabic neighbors, while avoiding differences between them on several crucial psycholinguistic variables known to affect word processing such as length (i.e., number of letters), frequency, number and frequency of orthographic neighbors, just to name a few. Nevertheless, the results obtained in Paper 4 still showed that even with a strict control of stimuli, including the number of words of the same syllabic length sharing the same first syllable in the same position, reliable syllable priming effects were only observed for CV words, once again, replicating the syllable structure effect observed in Papers 1 and 3. Additionally, in Paper 4 we have also analyzed the data with pseudowords, as we had in Paper 1, and once again, no evidence of a syllable activation was observed with pseudowords regardless of their first syllable structure.

Nonetheless, it is worth noting that the measure of syllabic neighborhood in which CV and CVC words were controlled for was the orthographic syllable measure. Contrary to what is observed in transparent languages such as Spanish, in EP there is no direct correspondence between phonology (P) and orthography (O). Consequently, orthographic and phonological variables will vary making it extremely difficult to achieve a simultaneous control in both. Given that our studies were conducted in the visual domain, we have opted to match CV and CVC words on their orthographic variables. Still, in EP, when phonology is considered, the difference between the number of CV and CVC words becomes much more pronounced, with CV words totaling around 43.9% and CVC words around 15.3%. The main reason towards this difference is due to the fact that while for the most part, CV syllables have a direct correspondence between O and P (i.e., one of the only cases being when the consonant is an <h> since in EP the <h> at the beginning of a word is silent making it that in a word such as *hóquei* [hockey - ˈɔkwɐj], the first orthographic syllable <hó> is CV but the first phonological syllable [ˈɔ] is V), when CVC words are considered, a considerable number of them contain nasal vowels (e.g., *cantor* [singer - kɐ̃tˈoɾ]) that are represented in print by three letters, making them orthographically CVC (e.g., the first syllable of <cantor> is <can>), but in speech are composed of only two phonemes, making them phonologically CV instead (e.g., the first syllable of [kɐ̃tˈoɾ] is [kɐ̃]). Therefore, it is possible that the greater salience observed, when phonology is considered, between the number of CV and CVC words, might be explaining the syllable structure effect. Indeed, in an a posteriori analysis conducted in Paper 4 where we have divided the CVC words used into those with a match between their P and O forms (i.e., CVC_{O+P+}) and those with a mismatch (i.e., CVC_{O+P-}), adding another level to the factor Target type for a total of three possible types (CV | CVC_{O+P+} | CVC_{O+P-}), seemed to show that CV and CVC_{O+P-} words both tended to be responded faster in the syllable congruent-condition than in the syllable-incongruent and unrelated conditions, while the same was not observed for the CVC_{O+P+} words. Even though the result did not reach statistical significance, likely due to the low statistical power as only 14 words of each type were used in the analyses, it presented an interesting clue towards a potential cause for the syllable structure effect.

As such, to gain further insights into the role the phonological factors could play in the syllable structure effect, but also to investigate if syllable effects could emerge with CVC words, in Paper 5 we resorted to a high-temporal resolution technique, the event related potentials (ERPs), combining them with the use of a color congruency paradigm used in previous studies examining the electrophysiological correlates of syllable processing (e.g., Carreiras et al., 2005). To that purpose, EP words and pseudowords presenting a CV (e.g., *zebra* [zebra]) and two types of CVC structures - those with a match (CVC_{O+P+} - e.g., *verbo* [verb]) and those with a mismatch between the P and O syllable forms (i.e., CVC_{O+P-} - e.g., *cantor* [singer]) - were presented segmented either according to their syllable boundary (e.g., *zebra*, *verbo*, and *cantor*), or not (e.g., *zebra*, *verbo*, and *cantor*) through the use of two different colors (black and grey), while participants performed a lexical decision task. Although reliable evidence of syllable effects was not obtained with the behavioral data (curiously, only for the pseudowords with CVC_{O+P-} first-syllable structure was there an advantage of the syllable-congruent when compared to the syllable-incongruent condition), the ERP data showed significant syllable effects in the N100 and P200 ERP components in parieto-occipital areas, and in the N400 ERP component in fronto-central and parieto-occipital areas. In the N100, the results showed that CV words and pseudowords elicited reduced amplitudes in the syllable-congruent condition when compared to the syllable-incongruent condition, suggesting not a genuine syllable effect, but rather an effect that seemed to be indexing syllable complexity. Note that CV syllables have one less letter to be processed in the syllable-congruent condition than CVC syllables do, making them easier to be visually segmented, and thus, easier to be activated. Subsequently, results in the P200, a component typically associated with syllable activation, showed neural evidence of syllable activation for CV, $CVC_{O+P+,}$ and CVC_{O+P-} first-syllable structure targets alike as indexed by an enhanced amplitude of the P200 component in the syllable-congruent condition when compared to the syllable-incongruent condition. Furthermore, the fact that the effect was observed for words and pseudowords alike supported the notion that syllable activation precedes lexical activation, hence making syllable effects in EP pre-lexical. Moreover, the fact that CVC_{O+P-} first-syllable structure targets produced the same neural responses in the syllable-congruent condition as did the CV and CVC_{O+P+} targets, suggested that it is the orthographic and not the phonological syllable form that is activated at first stages of visual word recognition. Lastly, the modulations observed in the N400 component for CV, CVC_{O+P+}, CVC_{O+P-} words, in centro-frontal areas, showed an increased amplitude in the syllable congruent condition when compared to the syllable incongruent condition. Similar to what has been observed, in previous studies for CV words (see for instance Carreiras et al., 2005) this larger amplitude in the syllable-congruent condition has been suggested to be indexing the competition that emerges as a result of the activation of lexical entries containing the same first syllable as the target, that will generate competition (see Chetail et al., 2012 and Conrad et al., 2010) sending top-down activation to the syllable. Nonetheless, this competition appeared to be greater for CV words since there was a tendency for modulations in the N400 component in parieto-occipital areas, to be restricted to word targets with a CV first-syllable structure which produced slightly larger N400 amplitudes in the syllable-congruent condition than in the syllable-incongruent condition. As the CV, CVC_{O+P+}, CVC_{O+P-} words used were matched in their number and summed frequency of syllabic neighbors however, it is unlikely that this variable is explaining the larger competition observed for CV words. Instead, it is possible that this competition observed only for CV words emerges from the activation of the CV skeletal structure (i.e., combination of consonants and vowels) of CV syllables that is spread to the lexical entries containing it, and that in turn will also compete with the CV target word for activation.

Taken together, the results obtained from the five papers presented in this thesis provided evidence of the role the syllable plays at the early stages of visual word recognition in EP, suggesting, as observed in other languages (Spanish: Álvarez et al., 1998, 2000, 2001, 2004, 2016; Barber et al., 2004; Carreiras et al., 1993, 2005; Carreiras & Perea, 2002; Conrad et al., 2008; Perea & Carreiras, 1998; French: Chetail & Mathey, 2009; Conrad et al., 2007; Goslin et al., 2006; Mathey & Zagar, 2002; German: Conrad et al., 2006; Conrad & Jacobs, 2004; Stenneken et al., 2007; Korean: Kwon et al., 2011, 2011), that the syllables does act as a sublexical unit for lexical access. These results extend previous findings in the EP language, namely those observed by Morais et al. (1989) in a speech recognition task, which found evidence of syllable effects. Importantly however, in spoken word recognition, Morais et al. (1989) found virtually the same results for CV and CVC EP words, while here across Papers 1, 3, and 4, syllable effects were only observed for words with a CV first-syllable structure, thus showing the syllable structure effect previously found in other languages.

Furthermore, the findings from Paper 2, which have only shown evidence of syllable effects for intermediate readers, suggest that the syllable only emerges as an access unit in visual word recognition as exposure to print and reading skills increases, and, importantly, for both CV and CVC words alike. Even though this result contrasted with the data obtained in Paper 1 with EP adult expert readers, which showed a syllable structure effect (later replicated in Papers 3 and 4), the fact that syllable effects observed in the intermediate readers were found for both word types (CV and CVC) replicated the finding of Chetail & Mathey (2012) with French intermediate readers, who also observed syllable effects for CV and CVC words alike. Therefore, this would suggest that syllable effects are not immediately developed as we learn how to read, emerging later at more intermediate stages of reading acquisition, and furthermore, that as exposure to print increases and we become proficient readers, syllable activation does become more pronounced for words with a CV first-syllable structure. It is possible that as we master our reading skills, our visual word recognition system learns how to extract regularities in a language – in this case the fact that CV syllables tend to be shared amongst a larger number of words, and that the CV skeletal structure of CV syllables tend to occur not only in CV words but also in CVC words making it more frequent – and take advantage of them to make the reading process faster and more efficient. While results from Paper 4 suggest that this bias is not due to the number of syllabic neighbors, results from Paper 5 support that it can be due to the CV skeletal structure of CV syllables, which is more common in EP occurring for both CV and CVC words alike. Consequently, the system might be more efficient and quicker at activating CV syllables due to the greater frequency of the combination of a consonant and a vowel, found in an extensive number of EP words.

Another important result worth mentioning is the fact that not only in Papers 1, 3, and 4, a syllable structure effect was observed, but also in Papers 1 and 4 the results showed that besides syllable effects being restricted to targets with a CV first-syllable structure, they were also restricted to words, as no evidence of syllable effects was obtained with pseudowords. While this result could suggest not only that syllable activation is dependent on lexical activation, but also that lexical factors might be behind the syllable structure effect, the ERP data in Paper 5 showed evidence of an early syllable activation in the P200 for CV, CVC_{O+P+}, and CVC_{O+P-} words and pseudowords, showing, indeed, that syllable effects in EP appear to emerge prior to lexical activation, in line with what previous studies in other languages have shown (e.g., Spanish: Carreiras et al., 2005; French: Chetail & Mathey, 2012; German: Hutzler et al., 2004; Korean; Kwon et al., 2011). Furthermore, and critical towards the main goals of this thesis, the ERP data has also revealed that syllable effects are not restricted to CV first-syllable structure words since modulations in the P200 component, but also in the N400, were also observed for CV, CVC_{O+P+}, and CVC_{O+P-} words alike, showing that, through the use of a more time-sensitive measure, syllable activation can be observed for CVC targets.

Regarding to the factors that might underlie the syllable structure effect observed in masked priming lexical decision tasks, two factors were advanced in Papers 3 and 4 as potential driving forces: syllable complexity and syllabic neighborhood density. Although behavioral data did not support the notion that either factor could fully account for the syllable structure effect, ERP data has shown that both of these variables do interfere with syllable activation. In fact, concerning the modulations observed in the N100 component, it is unlikely that they are indexing a genuine syllable activation, but syllable complexity instead. Note that CV syllables have one letter less in the syllable-congruent condition (e.g., <ze> in *zebra*) when compared to CVC syllables (e.g., <ver> in *verbo* and <can> in *cantor*), making them visually less complex and probably easier to process. Although the behavioral results in Paper 3 did not seem to show that syllable complexity could be accounting for the advantage of CV syllables, it is possible that because this factor comes into play at very early stages of visual word recognition (around 100 ms after the onset of the stimulus) the masked priming paradigm is not sensitive enough to capture these very early effects. However, with a highly-sensitive temporal technique, such as the ERPs, it was possible to observe the influence of syllable complexity during word processing. Concerning the number of syllabic neighbors and how it can potentially influence the syllable structure effect, although the results in Paper 4 seemed to refute this factor as a possible account for the advantage of CV syllables - since even when matching CV and CVC words on their number of syllabic neighbors still a syllable structure effect was observed – in Paper 5 we did observe ERP evidence of the competition that takes place between the targets and lexical entries. Since in this study we also matched CV and the two types of CVC words in their number and frequency of their syllabic neighbors, however, the potential influence of this factor would not be easily captured. In fact, ideally, it would have been better to manipulate rather than control the number of syllabic neighbors. Past studies that have manipulated the number of syllabic neighbors, measured as the type frequency of the first syllable, have observed that those words with a higher number of syllabic neighbors are recognized faster, when keeping the summed frequency of the neighbors constant, than those with a low type frequent first syllable (see Conrad & Jacobs, 2004). It is important to mention that while usually the effect of syllable frequency is inhibitory, since a high type frequency is usually linked to a high token frequency (see Conrad & Jacobs, 20014), in masked priming lexical decision tasks this is not usually the case due to the fact that the primes used are pseudowords, which having no lexical representation do not compete directly with the target for activation (see Carreiras & Perea, 2002 but also Mathey et al., 2013 for a more detailed account). Nonetheless, due to the characteristics of EP, such a manipulation for CV and CVC words was not possible, so they were matched instead on their number of syllabic neighbors, and the three first-syllable structure types of words showed evidence of syllable activation in the N400 component, which according to previous studies reflects the influence of syllabic neighbors over the target, especially of those with higher frequencies of occurrence that compete with the target for activation via a later-inhibition mechanism (see Conrad et al., 2010, but also Chetail et al., 2012 for more details).

Nevertheless, modulations in the N400 component tended to be more pronounced for CV targets, in particular words, since in parieto-occipital areas they were restricted to CV words. Since the CV, CVC_{O+P+}, and CVC_{O+P-} words had a very strict control, including in the number and frequency of their syllabic neighbors, the greater magnitude in the N400 component observed for CV targets, in particular words, led us to propose that the CV skeletal structure of CV syllables (i.e., the combination of consonants and vowels) could be an advantage of CV words relative to CVC words. It is important to mention here that, for their majority, CVC syllables in EP have a CV syllable embedded (e.g., the first syllable of *forno* [oven] is the CVC syllable <for> that contains the CV syllable <fo>), the contrary never happens though, and only in some cases do the first three letters of a CV word contain a level CVC syllable (e.g., the first syllable of *zebra* [zebra] is the CV syllable <ze> but <zeb> is not a permissible CVC syllable in EP). Consequently, the CV skeletal structure of CV syllables would occur more frequently, which could make CV syllables easier to be activated, contributing towards the syllable structure effect observed in masked priming lexical decision tasks. Moreover, the fact that most CVC syllables have a CV syllable embedded could produce some competition between the two permissible syllables, making CVC syllables harder to activate and syllable effects harder to emerge for CVC first-syllable structure words, especially through the use of a behavioral paradigm. Likewise, it is also possible to consider that phonological factors could potentially influence later stages of visual word recognition, and that the activation of the phonological syllable form could still occur and confer an additional advantage to CV syllables.

From the studies reported in this thesis, we are able to argue that in EP the syllable does play a relevant role in visual word recognition, both for expert and also for developing readers at intermediate stages of reading acquisition. Moreover, although the syllable structure effect was observed for expert readers when a masked priming lexical decision task was employed, when using ERPs, we were able to observe significant evidence of an early syllable activation for CV and CVC words alike. Thus, while several factors at both early and later stages of visual word recognition influence how the syllable is activated, including syllable complexity and the CV skeletal structure of CV syllables as previously highlighted, syllable effects still emerge for CVC words, though these are not easily captured in behavioral paradigms when compared to what is observed for CV words. Furthermore, the ERP data presented here showed that this influence is pre-lexical, as it is observed for words and pseudowords, and, importantly, that, in EP, just as in French (see Chetail et al., 2012), the driving force of the syllable activation appears to be orthography.

Turning now to the current models of visual word recognition, it is possible to consider how they could potentially relate to the results obtained in the present work, especially regarding the syllable structure effect and its underlying factors. As mentioned in the Introduction, even though the syllable has been widely studied in the current Psycholinguistic literature, its inclusion in computational models of visual word recognition has largely been overlooked. The three models we have previously presented are, to the best of our knowledge, the only ones that have taken the syllable into account though this sublexical unit has been implemented in different ways. While the model for polysyllabic word reading of Ans et al., (1989) and the Connectionist Dual-Process (CDP++) model of Perry et al. (2010) have implemented a syllabification stage during silent reading – though of the two only the CDP++ postulates a syllabification principle – the Multiple Read-Out model with a syllable layer (MROM-S) of Conrad et al. (2010), a revised version of the original MROM model of Grainger and Jacobs (1996), implemented a syllable layer that mediates between the letter and lexical layers instead. Although these models include syllable activation in their architecture, and the MROM-S (Conrad et al., 2010) was specifically built to account for the syllable frequency inhibitory effect (i.e., the fact that words with a high first-syllable token frequency produce larger RTs than words with a low first-syllable token frequency), none make any specific predictions regarding the syllable structure effect and how words with different first-syllable structures could be processed differently.

Considering the MROM-S, the only one of the models that was specifically created to account for visual word recognition (i.e., note that the model of Ans et al. (1998) and the CDP++ are reading-aloud models), a similar mechanism to the one employed in the graphemic of the CDP++ should be implemented to explain the effects of syllable complexity. According to this proposal, when words are being processed, they will enter a graphemic buffer and their constituent letters would be assigned to individual slots for the first and second syllables, corresponding to their syllable segment (i.e., onset, nucleus, or coda) according to a left-to-right principle. Thus, CV syllables would be faster to activate both because they have a smaller number of letters, but also because the second consonant of CVC syllables can either be assigned as the coda of the first syllable or the onset of the second syllable, which would difficult the segmentation process (see Taft et al., 2017). In contrast, the consonant and vowel that constitute a CV syllable would automatically be assigned to the role of onset and nucleus, making them faster to be segmented and subsequently activated, which would explain the early effect of syllable complexity, as seen in Paper 5.

Regarding now the competition between lexical entries, the MROM-S does propose that activation not only occurs bottom-up, being sent from the letter layer to the syllable and lexical layers, but also top-down as lexical entries would compete with the target for activation via a lateral-inhibition mechanism. To account for the influence of the CV skeletal structure, however, a CCCVCCCC structure alike the one existing in the slot-based system of the CDP++, should be implemented in the letter layer of the MROM-S, to take into account the different roles assumed by the letters as either consonants or vowels. Furthermore, as the reading system matures, regularities found in the language would be extracted such as the fact that most words in EP begin with a combination of a CV structure, found not only in CV but also in CVC words as well. Consequently, as this structure would be shared amongst many lexical entries, the threshold needed for the activation of this CV skeletal structure, found in CV syllables, would be lower, which in turn could make CV syllables to also be activated more quickly.

While it is important to mention here that the MROM-S was not set up as a developmental model of visual word recognition, it would be possible to suggest that as reading skills are established, similar mechanisms to the ones implemented in this model for expert readers – including the changes suggested here - could also be implemented for developing readers. Still, an important difference between the two types of readers could be related with the time needed for syllables to be activated in the syllable layer, which could be greater for developing readers, as for them, syllables would take longer to reach a threshold needed for activation, hence why syllable effects would emerge at later stages of visual word recognition. Additionally, it is also possible that because in developing readers the system has yet to learn some of the regularities found in languages, such as the greater frequency of the CV letter combination both as a syllable structure but also as a CV skeletal structure in EP, less activation would be generated towards CV words than what is observed with adult readers. Potentially, this could mean that CV and CVC syllables would have a similar threshold for activation in intermediate readers, thus explaining why no differences would be observed between the two in behavioral paradigms, and why no syllable structure effect would emerge.

In conclusion, the present thesis not only established syllable effects in a new language, EP, but importantly also highlighted how different factors such as syllable complexity, but also the CV skeletal structure of syllables, come into play during visual word recognition, and affect the recognition of CV and CVC words in different ways. Consequently, these results are important, and it would be relevant for current computational models of visual word recognition to take them into account.

Limitations and Future Directions

Some noteworthy considerations should be made regarding the findings of the studies presented in this thesis, as well as some suggestions for future research. Although due to the strict control imposed in our studies only CV and CVC words were used, it would be interesting for future studies to investigate syllable effects with other types of syllable structures (e.g., CVV, CCV, V, VC), particularly in EP, which is a language with a more varied number of first-syllable structure words, especially when compared to other Romance languages such as Spanish and French. Another important step in future research would also entail investigating syllable effects with developing readers using a more time-sensitive measure such as the ERPs, as used in this work for expert readers. It is important to point out that due to the age of our beginning and intermediate readers, some changes to the paradigm employed were introduced, such as using the sandwich as opposed to the standard masked priming paradigm and opting for the go/no-go variation of the standard lexical decision task. Consequently, we cannot discard that differences in the behavioral results of expert and developing readers, especially concerning the syllable structure effect and its underlying factors, could be due to those methodological options. Moreover, while syllable effects in developing readers do appear to emerge at later stages of visual word recognition, it would be important to investigate if potentially syllable complexity, and also the CV skeletal structure, could come into play for these younger readers. Furthermore, another issue worth exploring would be the pre-lexical nature of syllable effects in developing readers, by using pseudowords, as done in this thesis with expert readers.

From the data presented here, we can conclude that the syllable does have an important role during reading, guiding lexical access. It would be relevant for these findings to help guide future research, not only in experimental areas but also in more applied areas of knowledge. Potentially, a more syllable-based teaching method of reading could be beneficial for beginning readers, even for those with some language-related disorders, such as dyslexia, particularly since our results do appear to show that syllable activation, at least in an intermediate-depth language such as EP, is guided by orthographic information.

To finalize, we hope that the collective evidence gathered in this thesis can be considered for future studies and contributed to a better understanding of syllable effects and of the syllabic factors that come into play during visual word recognition.

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Appendixes

Appendix A. Stimuli Used in the Study "The role of syllables in intermediate-depth stress-timed languages: masked priming evidence in European Portuguese"

The items are arranged in triplets in the following order: syllable-congruent prime, syllable-incongruent prime, and unrelated prime for the word and nonword targets.

Words

babur; babpa; dudot; BABEL; bagra; bagmo; dopur; BAGOS; batur; batco; debro; BATOM; bazum; bazco; vefra; BAZAR; bifur; bifto; gatra; BIFES; bocor; bocte; dupre; BOCAL; cabel; cabco; netro; CABRA; cetar; cetpo; mujis; CETIM; curir; curnu; mazem; CURAS; dicre; dicta; pijer; DICAS; dunir; dunve; bivel; DUNAS; facur; facte; lovre; FACAS; farot; farfu; dixor; FAROL; febum; febco; colur; FEBRA; fedum; fedno; lefor; FEDOR; fezom; fezco; gevra; FEZES; figor; figna; lapra; FIGAS; forur; forlo; buzit; FORAL; funat; funti; lenar; FUNIL; furim; furne; toviz; FUROR; gater; gatpe; vaber; GATIL; jejar; jejco; delom; JEJUM; latre; latca; facri; LATIM; licem; licta; gotro; LICOR; luver; luvco; baver; LUVAS; murer; murze; namor; MURAL; natre; natco; zales; NATAS; nudam; nudco; velis; NUDEZ; nuvro; nuvca; vuvis; NUVEM; pirir; pirva; rusco; PIRES; polum; polno; jadro; POLAR; pudur; pudca; tefas; PUDIM; pudas; pudno; febos; PUDOR; pulis; pulzo; fande; PULOS; remer; rembe; vonar; REMOS; robir; robta; zorlo; ROBES; ruble; rubco; nitus; RUBRA; rumum; rumpi; niver; RUMOR; sinai; sinra; nacro; SINOS; sobur; sobpu; befro; SOBRA; tiqro; tiqta; lapos; TIQUE; tirer; tirjo; larel; TIRAS; tutro; tutca; fazir; TUTOR; vapel; vapca; nejus; VAPOR; varom; vardo; norei; VARIZ; visim; visca; nunva; VISOR; vogur; vogma; pazer; VOGAL; zebor; zebno; dalim; ZEBRA; barto; barel; lerto; BARBA; berno; beram; losvo; BERMA; casra; casim; veiza; CACO; calba; catle; nebta; CALDO; cenza; cenur; raica; CENSO; cerma; ceros; mosce; CERNE; cinle; cinor; zerda; CINTO; cinvo; cinum; vismo; CINZA; corbe; corim; surbo; CORDA; corzo; corum; zasna; CORVO; cosna; cosai; sesna; COSMO; dergo; deros; lasno; DERME; farne; farer; lerzo; FARSA; forve; foris; tunzo; FORCA; forza; forau; tusge; FORNO; funja;funer; tespa; FUNGO; gampe; gamor; fesdo; GAMBA; garda; garel; prela; GARFO; genfa; genom; jarce; GENRO; gosvo; gosim; pinzo; GOSMA; lasve; lasom; benve; LASCA; lesro; lesum; tarco; LESMA; manvo; manul; vormo; MANGA; morza; morum; craze; MORNO; mosro; moser; ninzo; MOSCA; nesco; nesur; vrapo; NESGA; ninte; ninel; mirlo; NINFA; percor; parost; grobot; PARDAL; parme; parus; gerpa; PARGO; parbe; parim; gonfe; PARTO; pasna; pasem; genza; PASMO; perme; peram; foszo; PERSA; porma; porus; jesva; PORCO; rambe; ramei; drojo; RAMPA; rusmo; rusil; varpe; RUSGA; sarge; sarim; zesgo; SARJA; surbe; surer; crala; SURTO; talna; talum; bilva; TALCO; tambe; tamou; fesgo; TAMPO; tanju; tanes; larxa; TANGO; tarbo; tarer; bonfo; TARTE; tesbo; tesur; larfe; TESTA; tosdo; toclo; forfe; TOSTA; turde; turom; disda;

TURBO; vervo; verer; creco; VERME; verma; veris; masva; VERSO; vesda; vesam; zesje; VESGO; vesmo; vesou; crago; VESPA;

Nonwords

bager; bagma; dajul; BAGIL; begul; begno; jonha; BEGRA; bepui; bepco; lanus; BEPRA; bevur; bevda; magur; BEVOL; bicel; bicte; fopra; BICRA; bodus; bodpo; terol; BODIO; bubra; bubpo; lapta; BUBIM; budei; budco; ravra; BUDIA; bupei; bupco; sigue; BUPLA; cadul; cadpo; rogul; CADRE; conel; conve; ficro; CONUL; dapul; dapco; bujro; DAPIL; datur; datca; tibro; DATRO; facum; facta; mucra; FACIZ; fanur; fanvo; defar; FANOL; fetra; fetco; bidro; FETOM; fonem; fonve; denus; FONUS; foter; fotco; gonua; FOTAI; gedum; gedmo; pisor; GEDRA; gomua; gompo; tucre; GOMER; gotre; gotce; pegro; GOTAM; jedem; jedca; panir; JEDUR; letro; letca; puler; LETOM; lezum; luzco; vernu; LUZAR; nefer; nafte; zejro; NAFEM; nager; nagmo; capra; NAGAM; nagum; nagco; zaqua; NAGIA; nague; nagma; nomui; NAGOU; natei; natpa; cogra; NATUO; necal; necte; xuzre; NECRU; pabpa; pabre; tomul; PABRO; pafum; pafca; vezul; PAFIR; paner; panjo; jacro; PANOL; pebut; pebpa; gafus; PEBIL; pogro; pogme; zapau; POGUA; ridre; ridmo; xadal; RIDAR; sabar; sadca; reces; SADRIL; satas; satpa; pofir; SATIO; tagre; tagma; verpo; TAGIO; tezil; tezca; zada; TEZUE; timis; timbo; fenus; TIMAO; vatra; vatpo; somus; VATAU; venil; venfe; lagro; VENOI; zebim; zebpa; nigua; ZEBIO; zenos; zenja; xixas; ZENAL; zevar; zevga; mefro; ZEVOU; zilom; zilxe; cocra; ZILAM; zunim; zunxa; rozou; ZUNUR; barxa; barum; fosma; BARMO; basda; basur; rilfo; BASFO; biscu; bisom; tosxo; BISZA; bolfa; bolus; palna; BOLDA; bolxe; bolil; dosgo; BOLPA; carmi; carum; xenco; CARCA; dande; damum; brifo; DAMBU; dempo; demul; bofus; DEMPA; desfe; desum; valca; DESPO; dolza; dolui; xalca; DOLCO; fapco; fapre; brapo; FAPSA; fesxu; fesim; derxo; FESMO; forpe; forer; lanja; FORGO; fosje; fosel; dorpe; FOSGO; galba; galui; palne; GALFA; gasfu; gasul; proce; GASPO; ginva; ginus; palso; GINCA; gonfo; gonal; jenel; GONTA; gunsa; gunis; zasne; GUNZO; jorxa; jorum; nesfa; JORZA; josdo; josir; feica; JOSCE; julza; juler; valro; JULTE; larne; larom; venco; LARFA; mulxo; mulir; goute; MULSA; nasto; nasil; xonim; NASTRE; nolbu; nolai; nalfa; NOLTE; palfo; palil; loilo; PALDE; pesfu; pesis; jarca; PESMO; pesza; pesoi; vospe; PESTAR; pisja; pisau; jisca; PISMO; porja; porul; ponja; PORPO; permo; peril; dalba; PURNA; rolxo; rolus; reica; ROLRO; sanvre; sanaol; frana; SANTRA; segmo; seguo; lisvo; SEGNA; sonza; sonis; roumo; SONCE; texva; texol; busbo; TEXFO; tinzo; tiner; bulma; TINDA; tornu; torui; falno; TORMA; valta; valus; fengo; VALBO; vanza; vaner; nouma; VANCE; vaszu; vasum; verzo; VASMO; verjo; velor; junro; VERFA; vigmo; viguo; grofo; VIGNA; vosfe; vosur; xerla; VOSMA; zalva; zalum; crofo; ZALCO; zalne; zaler; rispo; ZALMO; zermu; zerar; lasba; ZERCE;

Appendix B. Prime-target pairs from the Study "On the Role of Syllabic Neighbourhood Density in the Syllable Structure Effect in European Portuguese"

The items are arranged in triplets in the following order: syllable-congruent prime, syllable-incongruent prime, and unrelated prime for the word and nonword targets.

Words

bicro; bicte; dugue; BICAS; bicla; bicta; dales; BICHO; bifco; bifor; tunha; BIFES; bilhos; biltro; gelaos; BILHAR; cetar; cetca; ricra; CETIM; cidos; cidto; rasal; CIDRA; cunol; cunvo; nitra; CUNHA; dadal; dadpa; xucos; DADOR; dicor; dicto; vobro; DICAS; diqua; diqta; zicre; DIQUE; ducar; ducta; tunho; DUCHE; dunim; dunca; bides; DUNAS; duqua; duqta; renho; DUQUE; febas; febga; degue; FEBRE; fedim; fedma; lelha; FEDOR; fetor; fetpo; lefro; FETAL; feves; fevco; dinho; FEVRA; furis; furva; vosas; FUROR; genil; genva; piror; GENES; gomer; gompa; noque; GOMOS; gotir; gotco; jecor; GOTAS; jagro; jagma; gulher; JAGUAR; judor; judco; gorai; JUDEU; jural; jurga; pucar; JUROS; lonor; lonvo; docal; LONAS; lotim; lotca; tilhe; LOTES; luces; lucta; tinho; LUCRO; murim; murvo; noses; MURAL; naral; narjo; vinza; NARIZ; natim; natco; cacra; NATAL; nator; natmo; raler; NATAS; negul; negmo; midel; NEGRA; ninal; ninca; varol; NINHO; nobas; nobta; munho; NOBRE; nozal; nozfo; vicos; NOZES; nudal; nudma; ronho; NUDEZ; nuvar; nuvco; sunos; NUVEM; pudes; pudta; focol; PUDIM; punaos; punjo; fobras; PUNHAL; rumal; rumpa; vonas; RUMOR; sigor; signe; cebro; SIGLA; sinar; sinva; recal; SINOS; tumas; tumpa; litra; TUMOR; tutal; tutpa; liles; TUTOR; vocer; vocto; muter; VOCAL; vogor; vogmo; naque; VOGAL; xadins; xadtar; palhos; XADREZ; zebes; zebco; conhe; ZEBRA; balto; balor; torfa; BALDE; borbo; borim; lanto; BORLA; canco; canol; mosce; CANJA; carfo; carel; mesme; CARGA; carsa; carom; mesca; CARNE; carlho; carous; mesbro; CARTAZ; casgo; casor; morgo; CASPA; ceril; cerma; zinva; CERCO; cinro; cinos; mesco; CINZA; confro; conaos; vintra; CONCHA; conra; conus; vinva; CONDE; confa; conar; vinge; CONTO; culbo; culor; vongo; CULPA; curno; curom; misno; CURVA; cusfa; cuser; varfe; CUSPO; farne; farir; linge; FARSA; forve; forul; tesvo; FORCA; forse; forim; tesma; FORNO; funfe; funir; laspa; FUNGO; linva; linas; basmo; LINCE; manva; manal; vesca; MANSO; marpa; maral; cosbra; MARFIM; marba; marol; sosca; MARTE; mesfro; mesois; narlho; MESTRE; monfa; monul; vaspa; MONGE; morma; moriz; nasva; MORNO; parpes; parous; gostro; PARDAL; parna; paril; gosve; PARVO; pasca; paser; ferno; PASMO; penlo; penom; farlo; PENTE; paraus; perbal; finvas; PERDIZ; perce; perel; fince; PERNA; permo; peril; finvo; PERSA; pinvas; pinaus; jastos; PINCEL; pinfa; piner; jaspa; PINGO; pulfo; pulor; gampo; PULGA; pulma; puler; garta; PULSO; salro; salim; corme; SALSA; surba; surar; cosla; SURDO; surla; sures; cosja; SURTO; tanca; tanes; bisfa; TANGO; tarbo; taral; borfa;

TARTE; tenva; tenos; larna; TENRO; turta; tures; binva; TURBO; tursa; turam; linca; TURCO; verda; verel; cosma; VERBO; verpro; vereil; coster; VERNIZ; verva; veram; cosne; VERSO;

Nonwords

balim; balva; teixo; BALUR; besor; besro; vesur; BESAS; birom; birva; ducra; BIRUS; carem; carca; vocre; CALUS; caner; canva; vemem; CANUS; conur; convo; serus; CONIM; cunor; cunsa; vumar; CUNES; curum; curzo; vecos; CURES; doler; dolsa; boiva; DOLOS; donal; donco; bosxa; DONHE; dorim; dorne; lasne; DORAR; dunel; dunvo; tucel; DUNHA; fisum; fisra; loces; FISIR; focis; focta; lunha; FOCRO; garui; garne; jocus; GARAS; garem; garca; poras; GARIR; gavil; gavco; pusco; GAVAS; giler; gilve; vutas; GILOS; gopos; gopto; joges; GOPRA; goser; gosca; jusro; GOSUM; jenas; jenca; polas; JENHO; jesos; jesna; JESAL; junam; junca; recas; JUNOS; lalem; lalco; tesva; LALOS; lasor; lasmo; bezos; LASES; lesum; lesmo; tivos; LESIR; losar; losce; baror; LOSUS; menca; menar; nures; MENHO; pacia; pacte; jocio; PACLA; paqal; paqma; jofas; PAQUE; pigal; pigma; fucro; PIGUE; ranor; ranvo; juces; RACAS; rapom; rapti; sifes; RAPRA; recam; recda; vecha; RECRO; reron; rerxa; xaxca; RERUS; robas; robca; salga; ROBEL; ronum; ronva; vaves; RONER; serar; serco; caxor; SERUS; silom; silxo; veice; SILAR; vanom; vanva; momos; VANIL; vasas; vasva; coriu; VASOR; vener; venvo; ceror; VENAS; vense; remur; VENOR; veqra; veqpa; fical; VEQUE; verar; verzo; xares; VERUS; vilam; vilna; ruico; VILOR; zeror; zervo; mecer; ZERAS; berna; berur; linve; BERVO; canxe; canor; vervo; CANCA; carim; carlu; misra; CARDE; ceral; cerza; ponco; CERME; cerno; ceros; virna; CERVE; corpe; coril; nempa; CORFO; cusve; cusom; virve; CUSNO; derzo; derim; borve; DERSA; dunso; dunir; birce; DUNVA; firve; firor; lusmo; FIRCA; funva; funus; porva; FUNCE; gasve; gasem; curxe; GASCA; gorzo; gorer; pesze; GORMA; genfo; genhos; verza; GENDA; gilne; gilom; penve; GILCO; gisna; gisum; jurzo; GISMO; jesva; jesur; porma; JESME; jeslo; jesir; vorba; JESTA; junlu; junas; gaslo; JUNFA; jurca; jurim; pisva; JURNO; larfo; laras; firgo; LARTA; lenvo; lenos; binja; LENCA; lorve; lores; tusne; LORCA; lunza; lunes; tirva; LUNCO; merna; meris; nosco; MERVE; munzo; munur; virve; MUNCA; nenvo; nenam; vorve; NENCE; perte; perim; gisla; PERFO; pirva; piral; farca; PIRMO; punxa; punim; jorca; PUNZO; pusno; pusor; jermo; PUSVA; rarmo; raril; nunvo; RARCA; rinze; rinam; xurce; RINCO; risfa; risal; culca; RISJO; sance; sanis; xunre; SANVA; sinvo; sinho; nirmo; SINCA; sisvi; sisil; nirso; SISCA; sunvo; sunos; zerna; SUNCE; tinva; tinos; bunza; TINCO; tirvo; tiror; lesne; TIRSA; turso; turol; dindo; TURZA; vampo; vamir; birjo; VAMBA; vanfa; vanor; corve; VANJO; vasre; vasor; murso; VASCA; verno; verir; mosme; VERVE; vispa; visim; conja; VISGO; vorca; vorus; casza; VORMO; vosme; vosir; mirmo; VOSCA;

Appendix C. A Posteriori Analysis Conducted in the Study "On the Role of Syllabic Neighbourhood Density in the Syllable Structure Effect in European Portuguese"

In the a posteriori analyses, in order to compare the three types of words: CV, CVC with a match between the orthographic and phonologic syllable forms (i.e., CVC_{O+P+}- e.g., TUR.BO), and the CVC words with a mismatch such that they have a CVC orthographic first syllable but a CV phonologic first syllable (i.e., CVC_{O+P-}- e.g., PEN.TE); 14 CV words and 14 CVC_{O+P+} words were selected from our materials to be matched with the 14 existing CVC_{O+P}, keeping all the psycholinguistic variables in which the total pool of stimuli (48 CV and 48 CVC words) were controlled for (see Table 6), except for the number of phonemes (Mcv = 4.86, Mcvc$_{o+p+}$ = 5.07 and Mcvc$_{o+p-}$ = 4.07; $p < .001$). The analyses performed here mimicked the ones conducted with all the CV and CVC words even though the factor Target type has here three levels (CV| CVC_{O+P+}| CVC_{O+P-}) instead of two (CV|CVC).

Regarding reaction times, neither the main effects of prime type, $F(2, 1307.89) = .0196$, $p = .981$, target type, $F(2, 39.35) = 1.4694$, $p = .242$, nor the interaction between prime type and target type $F(4, 1307.91) = 1.7562$, $p = .135$ reached statistical significance. As for the accuracy data, neither the main effects of prime type, $\chi = 1.256$, $p = .534$, target type, $\chi = 1.352$, $p = .509$, nor the interaction between prime type and target type, $\chi = 8.324$, $p = .080$ were statistically significant.
In Table B1, we present the means and standard deviations for the CV, $CVC_{O+P+,}$ and CVC_{O+P-} regarding the reaction times and accuracy data.

Table C1

Mean and Standard Deviations (in Brackets) of Response Times (RTs) and Percentage of Errors (%E) per Prime Condition

Target type	Prime type					
	Congruent		Incongruent		Unrelated	
	RT	%E	RT	%E	RT	%E
CV	710 (219)	4.8 (21)	724 (171)	2.4 (15)	721 (190)	2.4 (15)
$CVCO_{+P+}$	792 (235)	4.2 (20)	768 (240)	3.6 (19)	736 (199)	6.0 (24)
CVC_{O+P-}	734 (183)	2.4 (15)	746 (214)	7.1 (26)	722 (188)	3.0 (17)

Appendix D. Thesis' Etical Approval

The experiments reported in this dissertation received ethical approval for experiments with humans by the Ethics' Subcommittees for Human and Social Sciences of the University of Minho under the references SECHS – 003/2014, SECHS – 005/2014, and SECHS – 028/2018 as presented below.

Universidade do Minho

SECSH

Subcomissão de Ética para as Ciências Sociais e Humanas

Identificação do documento: SECSH – 003/2014

Título do projeto: *Reconhecimento visual de palavras do Português Europeu*

Investigador(a) responsável: Doutora Ana Paula de Carvalho Soares, Escola de Psicologia, Universidade do Minho

Outros Investigadores: Doutora Montserrat Comesaña Vila, Centro de Investigação em Psicologia (CIPsi), Universidade do Minho; Ana Costa, Centro de Investigação em Psicologia (CIPsi), Universidade do Minho

Subunidade orgânica: Escola de Psicologia

PARECER

A Subcomissão de Ética para as Ciências Sociais e Humanas (SECSH) analisou o processo relativo ao projeto intitulado *"Reconhecimento visual de palavras do Português Europeu"*.

Os documentos apresentados revelam que o projeto obedece aos requisitos exigidos para as boas práticas na experimentação com humanos, em conformidade com o guião para submissão de processos a apreciar pela Subcomissão de Ética para as Ciências Sociais e Humanas da Universidade do Minho.

Face ao exposto, a SECSH nada tem a opor à realização do projeto.

Braga, 30 de julho de 2014.

O Presidente

(Paulo Manuel Pinto Pereira Almeida Machado)

Universidade do Minho

SECSH

Subcomissão de Ética para as Ciências Sociais e Humanas

Identificação do documento: SECSH – 005/2014

Título do projeto: *Reconhecimento visual de palavras em crianças*

Investigador(a) responsável: Doutora Ana Paula de Carvalho Soares, Escola de Psicologia, Universidade do Minho

Outros Investigadores: Doutor Manuel Perea Lara, Departamento de Metodología, Universitat de València, Espanha.; Doutora Montserrat Comesaña Vila, Centro de Investigação em Psicologia (CIPsi), Universidade do Minho

Subunidade orgânica: Escola de Psicologia

PARECER

A Subcomissão de Ética para as Ciências Sociais e Humanas (SECSH) analisou o processo relativo ao projeto intitulado *"Reconhecimento visual de palavras em crianças"*.

Os documentos apresentados revelam que o projeto obedece aos requisitos exigidos para as boas práticas na experimentação com humanos, em conformidade com o guião para submissão de processos a apreciar pela Subcomissão de Ética para as Ciências Sociais e Humanas da Universidade do Minho.

Face ao exposto, a SECSH nada tem a opor à realização do projeto.

Braga, 30 de julho de 2014.

O Presidente

(Paulo Manuel Pinto Pereira Almeida Machado)

Universidade do Minho

SECSH

Subcomissão de Ética para as Ciências Sociais e Humanas

Identificação do documento: SECSH 028/2018

Título do projeto: *Correlatos neurodesenvolvimentais dos mecanismos implícitos-explícitos de aprendizagem em crianças com Perturbação Específica de Linguagem: Evidência com potenciais evocados cerebrais*

Investigador(a) Responsável: Ana Paula de Carvalho Soares, Departamento de Psicologia Básica, Escola de Psicologia, Universidade do Minho

Outros Investigadores: Montserrat Comesaña, Centro de Investigação em Psicologia (CIPsi), Escola de Psicologia, Universidade do Minho; Marisa Lobo Lousada, Escola Superior de Saúde, Universidade de Aveiro; David Simões, Escola Superior de Tecnologia da Saúde do Porto, Instituto Politécnico do Porto; Ana Sucena, Escola Superior de Tecnologia da Saúde do Porto, Instituto Politécnico do Porto; Ana P. Patrícia, Faculdade de Psicologia, Universidade de Lisboa

PARECER

A Subcomissão de Ética para as Ciências Sociais e Humanas (SECSH) analisou o processo relativo ao projeto intitulado *"Correlatos neurodesenvolvimentais dos mecanismos implícitos-explícitos de aprendizagem em crianças com Perturbação Específica de Linguagem: Evidência com potenciais evocados cerebrais"*.

Os documentos apresentados revelam que o projeto obedece aos requisitos exigidos para as boas práticas na investigação com humanos, em conformidade com as normas nacionais e internacionais que regulam a investigação em Ciências Sociais e Humanas.

Face ao exposto, a SECSH nada tem a opor à realização do projeto.

Braga, 12 de junho de 2018.

O Presidente

Digitally signed by PAULO MANUEL PINTO PEREIRA ALMEIDA MACHADO
Date: 2018.06.12 16:14:56 +01'00'

Paulo Manuel Pinto Pereira Almeida Machado