

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

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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.

Public Significance 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 article with the masked priming paradigm.

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

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 & Rodríguez, 2004, for evidence in Spanish; or Soares et al., 2014, 2018; Soares, Lages, et al., 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, Stenken, & Jacobs, 2006), or Portuguese (e.g., Campos,

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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 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, Lages, et al., 2019) as word frequency (per million words), word length (in number of letters), neighborhood size (N), orthographic Levenshtein distance (OLD₂₀), 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, Macedo, et al., 2019; Soares, Lages, 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 1 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.

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 × Prime Type interac-

Table 1
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)

Note. CV = consonant-vowel; CVC = consonant-vowel-consonant.



tion 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 con-

stant 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 \times Target Type \times 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 Readout mode model (MROM; Grainger & Jacobs, 1996) and the Dual Route Cascaded model (DRS; 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 suitable to

provide valuable data on the locus of the syllable structure effect observed in EP and in several other languages.

Résumé

Bien qu'il ait été démontré que les syllabes jouent un rôle important aux stades précoces de la reconnaissance visuelle des mots, plusieurs études utilisant des mots dont la première syllabe combine une consonne et une voyelle (CV) ou une consonne, une voyelle et une consonne (CVC) ont aussi démontré que des effets fiables sont observés pour les mots CV, mais pas pour les mots CVC. Plusieurs propositions ont été formulées pour rendre compte de cet effet de la structure des syllabes. Or, les études visant à aborder directement cette question sont peu nombreuses. Dans la présente étude, nous avons examiné si la complexité des syllabes pourrait être à l'origine de l'effet de la structure des syllabes observé dans diverses langues en reproduisant l'étude de décision lexicale par amorçage masqué menée par Campos, Oliveira, et Soares (2018) auprès de lecteurs adultes de langue portugaise utilisant des pseudo-mots amorces de 50 ms mais avec des durées d'amorce plus longues (67 ms et 82 ms). Si l'effet de la structure des syllabes est régi par la complexité des syllabes, l'augmentation de la durée des amorces devrait favoriser l'émergence d'effets facilitateurs de l'amorce syllabique pour les mots CVC. De plus, en manipulant la durée des amorces, nous pouvons aussi jeter un nouvel éclairage sur la dynamique temporelle des effets des syllabes aux stades précoces de la reconnaissance visuelle des mots. Les résultats d'analyses de modèles non linéaires intégrés à effets mixtes ont démontré que, même en accroissant la durée des amorces, les effets fiables des syllabes se limitaient toujours aux mots CV. Le fait d'augmenter la durée de 67 à 82 ms ne faisait que renforcer les effets d'amorçage des mots CVC. De plus, la magnitude des effets d'amorçage pour les mots CV demeurait relativement constante parmi l'ensemble de ces durées d'amorçage, ce qui donne à penser que l'avantage CV sur la reconnaissance visuelle des mots n'est pas un effet éphémère. Ces résultats sont abordés au regard des constatations actuelles formulées dans la documentation.

Mots-clés : effet de la structure des syllabes, durée des amorces, complexité des syllabes, effet d'amorce d'une syllabe CV.

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