Universidade do Minho
Escola de Psicologia

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On the nature of the inhibitory neighborhood effect: A masked priming study with European Portuguese-English bilinguals

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Mestrado em Cognição Humana

Trabalho efetuado sob a orientação da
Professora Doutora Montserrat Comesaña
e coorientação do
Professor Doutor Ton Dijkstra

junho de 2024

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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.

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Braga, 6th of June 2024



(Ana Fernandes)

Sobre a natureza do efeito inibitório de vizinhança:
um estudo de *priming* mascarado com bilingues de Português Europeu-Inglês

Resumo

Modelos computacionais de reconhecimento de palavras em bilingues como o Multilink+ (Dijkstra et al., 2023) assumem que o acesso lexical é não-seletivo à língua. Ante a apresentação de uma palavra alvo, palavras que compartilham forma e/ou significado são co-ativadas independentemente da língua e competem pelo acesso lexical. Este postulado foi testado em estudos de decisão lexical combinados com *priming* mascarado usando vizinhos ortográficos por substituição (palavras que partilham todas as letras exceto uma). Embora os resultados são inconsistentes, estes mostram um efeito inibitório de vizinhança ortográfica, i.e., tempos de decisão mais longos quando o alvo é primado por um vizinho mais frequente do que por uma palavra não-relacionada (beau-BEAM > donc-BEAM; Bijeljac-Babic et al., 1997). No entanto, a natureza e *locus* do efeito não estão definidos. O objetivo do presente estudo de decisão lexical com *priming* mascarado foi examinar estas questões, manipulando o tamanho de vizinhos ortográficos e fonológicos dos *primes*. 152 bilingues de Português Europeu (L1)-Inglês (L2) que variam na sua proficiência e no uso diário da L2 participaram. O efeito inibitório foi replicado, mas modulado pelo tamanho de vizinhos e pelo uso diário da L2 mostraram, revelando que o efeito ocorre em estádios precoces do reconhecimento.

Palavras-Chave: bilinguismo, *priming* mascarado, efeito de vizinhança, consistência entre códigos, fonologia.

On the nature of the inhibitory neighborhood effect:
A masked priming study with European Portuguese-English bilinguals

Abstract

Computational models of bilingual word recognition, such as the Multilink+ (Dijkstra et al., 2023) assume that lexical access is language non-selective. When presented with a target word, words that share form and/or meaning are coactivated independently of the language they belong to and compete for lexical access. This assumption was tested in several masked priming lexical decision studies using orthographic substitution neighbors (words that share all letters but one). Although results are inconsistent, an inhibitory effect of orthographic neighborhood is often shown, i.e., decision latencies are longer when a target is primed by a higher-frequency neighbor than when primed by an unrelated word (beau-BEAM > donc-BEAM; Bijeljac-Babic et al., 1997). However, the nature and locus of the effect are not clear. The aim of the present masked priming lexical decision study was examining these questions, while manipulating orthographic and phonological neighborhood size of the prime words. In all, 152 European Portuguese (L1)-English (L2) bilinguals that varied in their L2 proficiency and daily use of L2 took part in the experiment. The inhibitory effect was replicated, but it was modulated by neighborhood size and daily use of L2, showing it occurs in early stages of word recognition.

Keywords: bilingualism, masked priming, neighborhood effect, cross-code consistency, phonology.

Table of Contents

DIREITOS DE AUTOR E CONDIÇÕES DE UTILIZAÇÃO DO TRABALHO POR TERCEIROS ii

Agradecimentos iii

Financiamento iii

STATEMENT OF INTEGRITY iv

Resumo v

Abstract vi

List of Figures viii

List of Tables viii

List of Acronyms ix

Introduction 10

Method 17

- Participants 17
- Materials 17
- Procedure 23

Results 24

- Results for Error Percentages (E%) 26
- Results for Response Times (RTs) 28

Discussion 30

References 33

Appendix A. List of Selected Words 37

Appendix B. Approval of the Ethics Committee 39

List of Figures

Figure 1. *Effect of Prime Relatedness on E%* 27

Figure 2. *Triple Interaction Between Prime Condition, Prime Relatedness, and Daily Use of English on E%* 28

Figure 3. *Triple Interaction Between Prime Relatedness, Prime Condition, and Daily Use of English on RTs* 30

List of Tables

Table 1. *Mean Values (and Standard Deviations) of the Controlled Variables for the Related European Portuguese Prime Words to the Target Words in Each Condition* 19

Table 2. *Mean Values (and Standard Deviations) of the Controlled Variables for the English Target Words in Each Condition* 20

Table 3. *Mean Values (and Standard Deviations) of the Controlled Variables for Unrelated European Portuguese Prime Words to the Target Words in Each Condition* 21

Table 4. *Mean Values (and Standard Deviations) of the Controlled Variables for Related and Unrelated European Portuguese Prime Words to the Target Words* 22

Table 5. *Mean Values (and Standard Deviations) of the Controlled Variables for Related and Unrelated European Portuguese Primes to the Target Nonwords* 23

Table 6. *Mean and Standard Deviations for Variables Related to the Participants' Linguistic History and Knowledge of English (L2)* 25

Table 7. *Mean E% and Standard Error (SE) for Each Experimental Condition* 26

Table 8. *Mean RTs (in ms) and Standard Error (SE) for Each Experimental Condition* 29

Table A1. *List of English Target Words and Corresponding Related (i.e., Orthographic Substitution Neighbors) and Unrelated Portuguese Prime Words* 37

List of Acronyms

L1: first language

L2: second language

N-size: neighborhood size

+: large N-size

-: small N-size

O+: many orthographic neighbors

O-: few orthographic neighbors

P+: many phonological neighbors

P-: few phonological neighbors

O+P+: many orthographic neighbors and many phonological neighbors

O-P-: few orthographic neighbors and few phonological neighbors

O+P-: many orthographic neighbors but few phonological neighbors

O-P+: few orthographic neighbors but many phonological neighbors

N-frequency: neighborhood frequency

N-frequencies: neighborhood frequencies

AoA: age of acquisition

EP: European Portuguese

RTs: response times

E%: error percentages

SE: standard error

CI: confidence intervals

Introduction

Computational models for bilingual word recognition generally consider lexical access to be *language non-selective* (BIA, Van Heuven et al., 1998; BIA+, Dijkstra & Van Heuven, 2002; Multilink, Dijkstra et al., 2019; Multilink+, Dijkstra et al., 2023). This entails that word representations from the bilinguals' languages that share form and/or meaning with a visually presented target word are automatically co-activated during processing. As a consequence, lexical representations engage in cross-language competition during the recognition process and/or at a post-lexical level during response selection (see Comesaña, 2024, for more detail). In order to explore these postulates, studies have often applied a lexical decision task in combination with a masked priming paradigm.

In the lexical decision task, participants decide as quickly and accurately as possible whether or not a sequence of letters is a word in a given language. In the masked priming variant, the target is preceded by a briefly presented prime word, for around or under 60 ms. Usually, primes are presented in lowercase and targets in uppercase to avoid visual continuity. In language combinations that share the same alphabet, researchers usually employ orthographic substitution neighbor words as prime-target pairs. These are words that share all letters with a particular target word but one (e.g., Bijeljac-Babic et al., 1997; Commissaire, 2022; Commissaire et al., 2019; Dijkstra et al., 2010a; Dirix et al., 2017; Midgley et al., 2008; van Heuven et al., 1998). In a bilingual context, stimuli are therefore either within- or cross-language neighbors. Examples are, respectively, the Portuguese words *gato* ["cat" in English] and *pato* ["duck"], and the Portuguese word *gato* and the English word *gate*. When examining issues of language non-selectivity and competition during lexical access with neighbor words, researchers have generally observed that decision latencies in a second language (L2) are longer when a target word is primed by a higher-frequency neighbor in the first language (L1) rather than by an unrelated L1 word of the same frequency. Said differently, an inhibitory neighborhood effect is obtained (e.g., beau-BEAM > donc-BEAM with French-English bilinguals; Bijeljac-Babic et al., 1997). Overall, available studies appear to support the notion of cross-language competition.

Cross-language competition can be accounted for in terms of three possible mechanisms during the recognition process (see Dijkstra et al., 2023), two of which are taking place in early stages of the recognition process (a and b) and one post-lexically (c):

a. Competition may occur between lexical candidates through *lateral inhibition* during the recognition process (a *structural* form of competition). In computational models such as the Multilink+ (Dijkstra et al., 2023), at every time cycle of activation, each activated item suppresses other items depending on its activity.

b. Competition may occur at the time of item selection and identification (when the recognition phase ends). When other items are also active at that time, this may complicate the selection of the correct input item, i.e., the target. Thus, competition should be understood here in terms of *item selection* during the decision process.

c. Competition may occur during responding, i.e., *motor response competition*. This may happen when activated items are linked to different responses and, thus, at a post-access and post-lexical level. Consider, for instance, an English lexical decision task performed by European Portuguese (EP)-English bilinguals who are asked to press a button when the item is an English word ("yes" response) and another button when the item is not an English word ("no" response). Items requiring a negative response can be EP words or nonwords. Whereas nonwords are linked to the "no" response, both English and EP words are linked to different responses (the former to "yes, the latter to "no"), increasing the difficulty to decide whether to press one button or the other. The difficulty increases even further when the presented words are very similar in form across languages (e.g., cognate and neighbor words; see Comesaña, 2024 and Dijkstra et al., 2023 for more detail).

Various studies have already explored the neighborhood effect, but as yet leave many questions unanswered. For instance, the seminal study by Bijeljac-Babic et al. (1997) aimed to explore the effect of orthographic neighbors on cross-language competition. In their first experiment, highly proficient French-English bilinguals were asked to perform a masked priming lexical decision task in English. Primes were four- to five-letter French (i.e., between-language condition) and English (i.e., within-language condition) words of higher frequency than the targets. The primes (presented for 57 ms) were either orthographically related or unrelated to the target word. Orthographically related primes were orthographic neighbors of the targets. An inhibitory priming effect that was stronger between languages than within language was obtained: an effect of 28 ms in the within-language condition and an effect of 54 ms in the between-language condition. However, participants were overall slower to respond in the between- than in the within-language condition. In addition, according to the authors, participants' L2 proficiency differences might have influenced the inhibition effect.

These issues motivated a second experiment, involving a masked priming lexical decision task in French (participants' L1). Three groups of French speakers who differed in their L2 proficiency participated in the experiment: proficient French-English bilinguals, beginning French-English bilinguals, and native speakers of French without knowledge of English. While a similar procedure and manipulation were used as in Experiment 1, the same targets were now presented within- and between-language.

Again, there was an inhibitory priming effect of relatedness on response times and accuracy. The effect was statistically larger between languages than within language. Besides, the inhibitory priming effect was modulated by the degree of L2 proficiency, because it was restricted to the group of proficient bilinguals, and to the between-language condition only. Despite design differences between the two experiments, both showed a between-language inhibitory effect, supporting the assumptions of language non-selectivity and cross-language competition at an early stage of lexical access. However, the strong inhibition effect observed by the authors has not been replicated, and more recent studies even cast a shadow of doubt on the existence of the effect, i.e., they observe modulations as a function of sub-lexical variables.

For instance, Dijkstra et al. (2010a) observed a similar inhibitory tendency of orthographic neighbors while exploring within- and cross-language competition, but only in the first block of experimental stimuli. The authors tested the effects of target repetition and neighborhood size on visual word recognition with Dutch (L1)-English (L2) bilinguals in two masked priming lexical decision experiments. In Experiment 1, the task was carried out within-language (lowercase primes and uppercase targets presented in Dutch), and in Experiment 2 between-language (lowercase primes in English and uppercase targets in Dutch). In Experiment 1, participants were presented with Dutch target words with low frequencies per million and a small neighborhood size that could be preceded by related or unrelated prime words of higher frequency. In order to guarantee that each target would be presented to each participant once, the selected 160 pairs of prime-target were divided in four blocks. In each block, 40 prime-target pairs were presented. In each of the four blocks, the same five target words and the same five target nonwords were presented but in a counterbalanced way; they were preceded by four different primes according to the prime conditions (i.e., related prime word, unrelated prime word, related prime nonword, and unrelated prime nonword). After a mask consisting of hash signs (#), a prime word was presented for 60 ms, followed by the target word. A non-significant within-language inhibition effect of 11 ms arose, but only for the first block of trials. For the following three blocks, the inhibition effect turned into a facilitation effect. The authors commented that the observed within-language inhibitory effect was weaker than the one observed by Bijeljac-Babic et al. (1997).

The second experiment used the same procedure and manipulation as the first experiment but involved another group of Dutch (L1)-English (L2) bilinguals. Because this experiment had the goal of examining the between-language priming effect, the main experimental difference was that primes now were English words. A non-significant between-language inhibition effect of 21 ms was found, again restricted to the first block, turning into a facilitation effect for the next three blocks. Note that the

presentation of four blocks implied repeated presentation of the target words; as a consequence, the target was assumed to be more active in later blocks and participants profited more from the overlap of the target with the prime. Together, these findings suggest that lexical competition and inhibition neighborhood priming effects occur early during recognition and similarly within- and between-language. Comparing their results to earlier studies, the researchers observed that the effect was weaker than that observed by Bijeljac-Babic et al. (1997). Recently, Dijkstra et al. (2023) explored interactions of orthography and semantics during visual word recognition in Dutch (L1)-English (L2) bilinguals in a L1-to-L2 masked priming lexical decision task and obtained weak non-significant inhibitory neighborhood effects (3 ms in Experiment 1 and 9 ms in Experiment 2), supporting the observations by Dijkstra et al. (2010a).

Due to the scarce literature on the inhibitory neighborhood effect in bilinguals and due to some inconsistency in the robustness of the effect (null effects vs. significant inhibitory effects), a more detailed examination of the nature of within- and cross-language lexical competition effects has been brought forward (e.g., Commissaire, 2022; Commissaire et al., 2019; Mulder et al., 2018). In particular, Commissaire and colleagues (2019) carried out a study on the neighborhood effect considering a variable that may be responsible for the discrepancies observed in the existing literature, namely, *markedness*. This variable refers to words with language-specific orthographic patterns such as particular letters (e.g., letter ø in Norwegian when compared to English; Van Kesteren et al., 2012), letter combinations (i.e., bigrams or trigrams) that are only legal in one of the two languages spoken by bilinguals (e.g., the bigram "tx" in the Basque word "etxe" when compared to Spanish; Casaponsa et al., 2014) or letter combinations that are more frequent in one language than in the other (e.g., "oa" is legal in French and English but is much more frequent in English; Commissaire, 2022; Commissaire et al., 2019). Words with these sub-lexical markers are generally termed *marked*.

Therefore, Commissaire and colleagues' (2019) goal was to assess the effect of the sub-lexical variable markedness and of the L2 proficiency levels on L2 visual word recognition. To do so, an English lexical decision task was carried out with two groups of French (L1)-English (L2) bilinguals: low proficiency and high proficiency bilinguals. For the L2 lexical decision task, monosyllabic English words were selected and allocated to three conditions, (1) marked targets with small cross-language orthographic neighborhood size, (2) unmarked targets with small cross-language orthographic neighborhood size, and (3) unmarked targets with large cross-language orthographic neighborhood size. Markedness was defined as a low French bigram frequency. Besides, stimuli were controlled for a range of other within- and between-language variables. The procedure followed was that of a standard lexical decision task: After

the presentation of a fixation point for 500 ms, a target was shown on the screen for 3000 ms or until a response was given. Markedness, but not cross-language neighborhood size, was found to influence L2 visual word recognition. Indeed, markedness facilitated lexical decisions, because target words of the marked condition yielded faster responses and lower error percentages than the target words of the unmarked conditions. The opposite effect was, however, observed for target nonwords. The target nonwords of the marked condition led to slower responses and higher error percentages than those of the unmarked conditions, in line with an inhibition effect of markedness for nonwords. L2 proficiency did not show any effect. Previous research on markedness supports these results, as studies have shown that marked words are responded to faster than unmarked words in lexical decision (e.g., Casaponsa et al., 2014; Van Kesteren et al., 2012). These findings suggest that orthographic word patterns may contribute to a rapid identification of language membership. They imply that bilinguals rely not only on lexical characteristics to identify language membership, but also on sub-lexical features. If this is the case, orthographic markedness should be controlled for in studies investigating orthographic neighborhood effects in bilingual word recognition (Commissaire et al., 2019, p. 358).

However, the study by Commissaire et al. (2019) involved a lexical decision task without priming. Therefore, it is of interest to also consider studies using a priming paradigm. To our knowledge, the only study that examined the impact of markedness on cross-language neighborhood priming effects was conducted by Commissaire in 2022. The author explored the relationship between orthographic neighborhood size and markedness to further our understanding of lexical orthographic coding in bilingual visual word recognition. In the first experiment, French (L1)-English (L2) bilinguals performed a masked priming lexical decision task in L1 with monosyllabic French target words. Each target was associated with a related and marked English word (wrap-DRAP), a related but unmarked English word (trap-DRAP), and an unrelated English prime word (gift-DRAP). Participants were allocated to two groups according to the markedness of the presented primes. First, by having a *marked prime* group and an *unmarked prime* group, markedness was a between-subjects factor by-participant and a within-subjects factor by-item. Markedness was defined as a low bigram frequency of English primes in terms of French orthotactics. To assure that each target was presented with its corresponding related and unrelated 57-ms prime, each participant completed two sessions: The same list of targets was repeated twice, preceded by one or the other of the two corresponding primes. Prime words were controlled for frequency per million words as well as for within- and cross-language neighborhood size, mean neighborhood frequency (the mean frequency of a word's neighbors), and frequency of the most frequent neighbor. The procedure was similar to that in the previously mentioned studies. A significant interaction effect was found between

relatedness and markedness, in the sense that the inhibition priming effect was restricted to the marked condition (wrap-DRAP > gift-DRAP).

However, given that the author applied a between-subjects design, individual differences in the participants' profiles could alternatively account for the observed results. Consequently, in Experiment 2, a similar procedure was followed, but markedness was operationalized as a within-subjects factor by-participant and as a between-subject by-item. Additionally, unrelated primes were controlled for markedness. Again, the author observed a significant inhibition priming effect that was restricted to the marked condition, especially, in the first session. This was consistent with the results found by Dijkstra et al. (2010a). However, in this experiment, a triple interaction between session, relatedness, and markedness occurred, reflecting that the markedness effect was stronger in the first session.

Considering these findings, it is difficult to account for the non-significant inhibition effect in the unmarked condition by models that assume the presence of structural lateral inhibition within the word recognition system (BIA, BIA+, inhibition variant of Multilink). To further examine this issue, a third experiment was conducted in which markedness was manipulated as a within-subjects variable by-participant and by-item. Shorter and less frequent prime words in English were also included in order to obtain a larger set of stimuli. In the first session, a general inhibition priming effect arose that was independent of markedness. In the second session, the effect was restricted to targets preceded by marked primes. In spite of some differences across experiments, the effect of priming was stronger overall in the marked condition. On the basis of all results, Commissaire (2022) concluded that markedness is a crucial variable in bilingual word recognition that deserves further examination.

As the impact of markedness on the inhibitory neighborhood effect is not quite clear, the effect might not be exclusively orthographic in nature. Indeed, another variable that was neglected in the studies on the orthographic neighborhood effect above mentioned is *phonology*. Even when the number of orthographic neighbors between prime and target pairs from different conditions is the same, that of phonological neighbors can vary and influence the results (see Comesaña et al., 2012, 2015; Dijkstra et al., 1999, 2010b; Grainger et al., 2005; Tiffin-Richards, 2024, for evidence concerning the interplay of orthography and phonology in visual word recognition).

Of particular relevance for the present study are unprimed studies in which effects of neighborhood were observed that were observed and modulated by cross-code (in)consistency, i.e., the degree of compatibility between coactivated orthographic and phonological representations during word recognition (see Grainger et al., 2005). When orthographic neighborhood size is held constant at a small value, increasing the phonological neighborhood size increases the inconsistency across the activated

orthographic and phonological representations, which is shown to impact word recognition. For instance, Grainger et al. (2005) pointed out that *type* has various phonological neighbors such as *wipe*, *ripe*, and *time*. As these phonological neighbors are not orthographic substitution neighbors of *type*, the consequence is a high inconsistency between activated representations. The authors examined the impact of cross-code (in)consistency in native speakers of French. They conducted three experiments, involving two lexical decision tasks and one perceptual identification task using a progressive demasking paradigm. Keeping the experiments very similar in design and controlling for phonological neighborhood size, responses to target words were inhibited when they had few orthographic neighbors and many phonological neighbors, i.e., when they were cross-code inconsistent. Conversely, facilitation effects in the lexical decision tasks and null effects in the perceptual identification task occurred for words from the consistent condition (see also Event-Related Potential studies such as Carrasco-Ortiz et al., 2017).

Considering the literature reviewed this far, neither the nature nor the locus of the neighborhood effect is clarified in the empirical literature; hence, the aim of the present research was to further explore this effect to take on the existing debate of how and when cross-language interactions occur. EP-English bilinguals were asked to perform a masked priming lexical decision task in English. In this task, only English words were presented and linked to "yes" response whereas nonwords were linked to "no" response in order to avoid competition at a post-lexical level (see Comesaña et al., 2015, who applied the same rationale). Markedness was controlled, while the number of orthographic and phonological neighbors of prime words was manipulated in an orthogonal way in an attempt to explore whether or not the effect is (only) orthographic in nature. Given that word frequency depends on word usage and may also impact the effect (Bijeljac-Babic et al., 1997), the degree of L2 proficiency and the L2 daily use of European Portuguese (L1)-English (L2) bilinguals was also considered.

EP prime – English target pairs were assigned to one of four conditions as a function of the number of orthographic and phonological neighbors that the EP prime words had. Words in the four conditions could either have (a) many orthographic neighbors and many phonological neighbors (O+P+), (b) few orthographic neighbors and few phonological neighbors (O-P-); (c) many orthographic neighbors but few phonological neighbors (O+P-); or, finally, (d) few orthographic neighbors but many phonological neighbors (O-P+). To maximize

any priming effect, primes were of higher frequency than targets. Considering the studies reviewed above, modulations of the inhibitory neighborhood priming effect as a function of number of phonological neighbors are expected; its impact should be higher the lower the number of orthographic neighbors (Grainger et al., 2005). In addition, consistent with the observations made by Bijeljac-Babic et

al. (1997), the higher the level of participants' L2 proficiency, the stronger the cross-language inhibitory effect should be. In other words, proficiency might work as modulator of effect size. The obtained pattern of findings will enable us to explore the nature of cross-language competition and clarify whether cross-language competition is due to structural mechanisms or due to more strategic mechanisms in post-lexical stages. Additionally, results may help, for instance, the authors of the Multilink model (Dijkstra et al., 2019) to refine or adjust their postulates regarding the nature of cross-language interactions that take place during the early steps of visual word recognition.

Method

Participants

In total, 152 European Portuguese (L1)-English (L2) bilinguals (24 males; M_{Age} = 21.4, SD_{Age} = 3.9) were recruited through the institutional email of the University of Minho (Braga, Portugal). Participants also had the option to access the study through the accreditation platform of the School of Psychology at the University of Minho. As compensation for their participation, participants could win a 50-euro voucher and/or earn course credit for the on-going semester. As criteria for inclusion, they (1) must be fluent in EP and English, and (2) must give their informed consent before starting the tasks involved in the current study. Their daily use of English (and of any other languages) as well as their age of L2 acquisition were assessed through a sociodemographic questionnaire (adaptation of the Language History Questionnaire, LHQ 3.0; Li et al., 2020) that was presented right after the informed consent. In order to objectively assess participants' L2 proficiency levels, a lexical decision task in English was presented to each participant, based on stimuli used in the DIALANG Vocabulary Size Placement Test (Alderson, 2005).

Materials

The sociodemographic questionnaire contained questions about age, sex, gender, education level, native language, knowledge, daily use, and age of acquisition (AoA) of any L2 to accurately characterize the bilinguals' linguistic history (adaptation of the LHQ 3.0; Li et al., 2020).

For the L2 lexical decision task, 75 isolated sequences of letters were presented and bilinguals were asked to decide whether each of the sequences was an existing word in the L2. To do so, the DIALANG Vocabulary Size Placement Test was used (Alderson, 2005). As the DIALANG test uses solely verbs, the presented words were verbs in English. Eight items were added for the training phase – i.e., four existing English verbs, and four non-existing sequences of letters.

The main task was an online masked primed lexical decision task in English. In total, 40 three-to-five letters long English (L2) target words and 80 three-to-five letters long European Portuguese (L1) prime words were selected. Forty prime words were related and the other 40 were unrelated to the targets, so that each English target word was preceded by a specific prime neighbor word or by an unrelated prime word in European Portuguese. For a short training phase, eight additional targets were selected, four target words and four target nonwords. Two target words and two target nonwords were primed by related prime words and the other two target words and two target nonwords were primed by unrelated prime words.

As a manipulation of orthographic and phonological neighborhood sizes and code-consistency of the EP primes, four types of related prime words were identified along with their respective unrelated primes. These had many orthographic neighbors and many phonological neighbors (O+P+); few orthographic neighbors and few phonological neighbors (O-P-); many orthographic neighbors but few phonological neighbors (O+P-); and few orthographic neighbors but many phonological neighbors (O-P+). In the selection process, EP words from the Procura-PALavras lexical database were selected first (P-PAL; Soares et al., 2018). Words were preferentially singular nouns. A neighborhood size (N-size) of under four neighbors was considered as a "small N-size" (-) and a N-size of over four neighbors as a "large N-size" (+), in order to make conditions statistically different in their orthographic and phonological N-size.

The difference in orthographic and phonological N-size across conditions was indeed statistically significant, *p*s < .001. Post Hoc Tests showed that the conditions O+P- and O+P+ had comparable orthographic N-sizes ($p = 1$). This was also the case for the conditions O-P+ and O-P- ($p = .343$). However, when comparing conditions of O+ with conditions of O-, statistically significant differences arose (*p*s < .001). For phonological N-size, Post Hoc Tests showed that conditions O+P- and O-P- were similar in their phonological N-size ($p = .431$), as were also the conditions O-P+ and O+P+ ($p = 1$). A comparison of P- conditions with P+ conditions led to statistically significant differences (*p*s < .001). Additionally, word length, per-million and logarithmic word frequencies, and orthographic neighborhood frequencies (N-frequencies; mean frequencies of the words' orthographic neighbors) were obtained from P-PAL (Soares et al., 2018). Differences across conditions were non-significant (*p*s > .203). Additionally, logarithmic frequency values were selected from the SUBTLEX-PT (Soares et al., 2015) and they did not differ across conditions, $F(3,36) = .589$, $p = .626$. EP prime words were unmarked. Markedness was measured in terms of cross-language bigram frequencies available at the Clearpond database (Marian et al., 2012). As can be seen in Table 1, related prime words obtained comparable bigram frequencies across conditions with all *p*s > .252. Besides, cross-language orthographic N-sizes (number of English neighbors

of the EP word) and N-frequencies (mean frequency of English neighbors of the EP word) were acquired at the Clearpond database (Marian et al., 2012). To do so, EP prime words were analyzed with respect to English statistics. No significant differences across conditions were observed, *p*s > .426. Mean concreteness values for Portuguese prime words were obtained from the Minho Word Pool (Soares et al., 2017) and were controlled between conditions, $F(3, 23) = 1.638$, $p = .208$.

Table 1

Mean Values (and Standard Deviations) of the Controlled Variables for the Related European Portuguese Prime Words to the Target Words in Each Condition

Related Primes	**O+P-**	**O-P+**	**O-P-**	**O+P+**	***p***
Within-language Variables					
Letters	4.0 (6.7)	4.0 (1.1)	4.3 (0.8)	4.2 (0.8)	n.s.
Log frequency	4.1 (0.7)	3.9 (0.8)	3.9 (0.7)	4.2 (0.7)	n.s.
O N-size	6.8 (2.4)	3.3 (1.1)	2.3 (1.5)	6.9 (1.9)	< .001
P N-size	2.7 (0.7)	7.2 (2.4)	2.0 (1.2)	7.3 (1.6)	< .001
Cross-language Variables					
Bigram 1	13.3 (13.6)	9.6 (4.7)	10.2 (7.8)	7.4 (4.3)	n.s.
Bigram 2	9.2 (6.5)	7.0 (7.7)	9.6 (5.6)	13.0 (6.4)	n.s.
Bigram 3	4.8 (2.4)	7.2 (1.7)	7.0 (4.6)	7.2 (5.5)	n.s.
Bigram 4	1.9 (1.7)	9.5 (6.0)	7.1 (4.5)	10.8 (8.9)	n.s.

Note: Word length in letters, logarithmic (log) frequency, orthographic (O) and phonological (P) neighborhood size (N-size) and cross-language bigram frequencies are listed. Standard deviations are presented in parentheses. To ensure greater clarity, bigram frequencies were multiplied by 1000.

* The *p*-value was not significant (n.s.) with $p > .05$, or significant with $p < .05$, $p < .01$ or $p < .001$

In order to facilitate the selection of target items, orthographic substitution neighbors in English were obtained through the Clearpond database (Marian et al., 2012). For each related prime word in EP, an English word with lower frequency was selected that preferentially was also a singular noun. SUBTLEX frequencies (per million and logarithmic), orthographic and phonological N-sizes, mean lexical decision response time (RTs in ms) and mean accurate responses (excluding errors and outliers) were obtained from the English Lexicon Project (Balota et al., 2007). English targets showed no significant differences in frequencies across conditions, *p*s > .510. The same was found for orthographic N-size and phonological N-size, *p*s > .410. No significant differences were shown for RTs as well as for Accuracy, *p*s > .828.

Orthographic N-frequencies and bigram frequencies were taken from the Clearpond database (Marian et al., 2012). Differences across conditions were non-significant, *p*s > .154. Concreteness values were obtained from the study by Brysbaert et al. (2014) and were shown to be comparable across conditions, $F(3,36) = .567$, $p = .640$. Word prevalence values were taken from the word prevalence database by Brysbaert et al. (2019) and no differences were observed either, $F(3,36) = 1.751$, $p = .174$. Mean values are shown in Table 2. Also, because it has recently been shown that orthographic neighborhood priming effects are influenced by the position of the modified letter in the neighbor word (Lupker et al., 2020), the position of the changed letter of the target and length of words were controlled between conditions (*p*s > .814).

Table 2

Mean Values (and Standard Deviations) of the Controlled Variables for the English Target Words in Each Condition

Target words	**O+P-**	**O-P+**	**O-P-**	**O+P+**	***p***
Letters	4.0 (0.7)	4.0 (1.1)	4.3 (0.8)	4.2 (0.8)	n.s.
Log frequency	2.8 (0.6)	2.6 (0.7)	2.5 (0.3)	2.8 (0.5)	n.s.
O N-size	8.9 (5.5)	6.3 (4.2)	5.4 (5.3)	7.3 (4.0)	n.s.
P N-size	15.1 (9.1)	16.9 (11.4)	13.1 (14.0)	14.4 (4.8)	n.s.
Bigram 1	13.9 (13.7)	10.0 (4.7)	7.2 (3.9)	7.8 (4.6)	n.s.
Bigram 2	10.8 (7.3)	7.1 (7.6)	10.6 (6.1)	11.8 (7.2)	n.s.
Bigram 3	7.8 (2.6)	6.5 (2.1)	7.2 (4.7)	8.0 (5.1)	n.s.
Bigram 4	6.2 (7.8)	5.0 (4.1)	6.2 (3.7)	12.0 (5.2)	n.s.

Note: Word length in letters, logarithmic (log) frequency, orthographic (O) and phonological (P) neighborhood size (N-size) and bigram frequencies are listed. Standard deviations are presented in parentheses. To ensure greater clarity, bigram frequencies were multiplied by 1000.

* The *p*-value was not significant (n.s.) with $p > .05$ or significant with $p < .05$, $p < .01$ or $p < .001$

Afterward, unrelated Portuguese prime words were selected from P-PAL (Soares et al., 2018). They were mainly singular nouns. Differences across conditions for frequency values, orthographic neighborhood frequency (N-frequency), length, concreteness, cross-language orthographic N-size and N-frequency, and cross-language bigram frequencies were not statistically significant (see Table 3), all *p*s > .067. Equal to what was observed for related prime words, significant differences across conditions were shown for orthographic and phonological N-size (*p*s < .001). Post Hoc Tests confirmed that significant

differences were solely caused by differences between O+ and O- conditions for orthographic N-size (all *p*s < .005) and by differences between P+ and P- conditions for phonological N-size (all *p*s < .001).

Table 3

Mean Values (and Standard Deviations) of the Controlled Variables for Unrelated European Portuguese Prime Words to the Target Words in Each Condition

Unrelated Primes	**O+P-**	**O-P+**	**O-P-**	**O+P+**	***p***
Within-language Variables					
Letters	4.0 (0.7)	4.0 (1.1)	4.3 (0.8)	4.2 (0.8)	n.s.
Log frequency	4.3 (0.8)	3.6 (0.9)	4.2 (0.6)	4.2 (0.7)	n.s.
O N-size	6.3 (1.8)	3.0 (0.8)	2.6 (1.1)	7.7 (2.2)	< .001
P N-size	3.8 (0.6)	7.3 (2.2)	2.2 (1.2)	7.3 (2.6)	< .001
Cross-language Variables					
Bigram 1	8.3 (4.1)	4.6 (4.4)	9.3 (7.6)	9.6 (8.1)	n.s.
Bigram 2	6.9 (4.8)	5.3 (4.8)	9.7 (7.8)	12.6 (7.6)	n.s.
Bigram 3	11.1 (6.1)	5.1 (4.1)	7.8 (5.1)	5.0 (3.1)	n.s.
Bigram 4	12.4 (8.5)	5.2 (3.3)	8.7 (5.6)	4.9 (2.9)	n.s.

Note: Word length in letters, logarithmic (log) frequency, orthographic (O) and phonological (P) neighborhood size (N-size) and cross-language bigram frequencies are listed. Standard deviations are presented in parentheses. To ensure greater clarity, bigram frequencies were multiplied by 1000.

* The *p*-value was not significant (n.s.) with $p > .05$ or significant with $p < .05$, $p < .01$ or $p < .001$

Unrelated primes showed similar frequency values, bigram frequencies, orthographic and phonological N-size, and concreteness values to the values of the related prime words with all *p*s > .195 (see Tables 3 and 4). Similarly, no statistically significant difference was obtained for cross-language orthographic N-size and N-frequency for related and unrelated primes, *p*s > .074. Given that it was a selection criterion, the length of targets and primes in letters was the same. Mean values for related and unrelated primes are listed in Table 4 for better comparison.

Table 4

Mean Values (and Standard Deviations) of the Controlled Variables for Related and Unrelated European Portuguese Prime Words to the Target Words

	Related Primes	Unrelated Primes	*p*
Within-language Variables			
Letters	4.1 (0.8)	4.1 (0.8)	n.s.
Log frequency	4.0 (0.7)	4.1 (0.8)	n.s.
O N-size	4.8 (2.7)	4.9 (2.6)	n.s.
P N-size	4.8 (2.9)	5.2 (2.9)	n.s.
Cross-Language Variables			
Bigram 1	10.1 (8.4)	7.9 (6.4)	n.s.
Bigram 2	9.7 (6.7)	8.6 (6.8)	n.s.
Bigram 3	6.5 (4.0)	7.5 (5.2)	n.s.
Bigram 4	8.1 (6.2)	7.1 (5.0)	n.s.

Note: Word length in letters, logarithmic (log) frequency, orthographic (O) and phonological (P) neighborhood size (N-size) and cross-language bigram frequencies are listed. Standard deviations are presented in parentheses. To ensure greater clarity, bigram frequencies were multiplied by 1000.

* The *p*-value was not significant (n.s.) with $p > .05$ or significant with $p < .05$, $p < .01$ or $p < .001$

Importantly, per million and logarithmic frequencies of the English target words were significantly different from those for related and unrelated Portuguese primes (*p*s < .013), as expected. Note that under the assumption of language non-selectivity, this discrepancy in frequencies should enhance cross-language competition, leading to a stronger inhibition priming effect. Comparisons in terms of SUBTLEX-PT logarithmic frequencies were also made, yielding a significant difference between prime words and English target words (*p*s < .001). Both English target words and Portuguese prime words were unmarked. Furthermore, Portuguese prime words had comparable bigram frequencies with their corresponding English target words when tested for English statistics to guarantee that they were unmarked primes. Indeed, bigram frequencies yielded no significant differences between targets and primes (all *p*s > .352; see Tables 2 and 4). When comparing related and unrelated primes with targets, no significant differences were observed for bigram frequencies, all *p*s > .274.

In line with the requirements of the lexical decision task, 80 non-words were also made. Non-words were created by running the forty English target words and forty additional base English words

through the Wuggy non-word generator (Keuleers & Brysbaert, 2010). Non-words were preceded by related Portuguese prime words or by unrelated Portuguese prime words (preferably singular nouns). Similarly, to the target words, related and unrelated prime words for the non-words were matched for length, frequency (from the P-PAL database and the SUBTLEX-PT database), and orthographic and phonological neighborhood size (see Table 5). No statistically significant differences between them were obtained, all *p*s > .509.

Table 5

Mean Values (and Standard Deviations) of the Controlled Variables for Related and Unrelated European Portuguese Primes to the Target Nonwords

	Related Primes	**Unrelated Primes**	***p***
Letters	4.1 (0.8)	4.1 (0.8)	n.s.
Log frequency	3.5 (0.9)	3.5 (0.9)	n.s.
O N-size	6.3 (4.7)	6.3 (4.4)	n.s.
P N-size	6.2 (4.9)	6.1 (5.0)	n.s.

Note: Word length in letters, logarithmic (log) frequency, orthographic (O) and phonological (P) neighborhood size (N-size). Standard deviations are presented in parentheses.

* The *p*-value was not significant (n.s.) with $p > .05$ or significant with $p < .05$, $p < .01$ or $p < .001$

Procedure

All participants were asked to complete all tasks mentioned above: the sociodemographic questionnaire, the main masked and primed lexical decision task, and the L2 proficiency assessment. The tasks were performed online and individually on a computer with a screen and a keyboard. Before starting their participation in the study, each participant signed the informed consent by checking a box that substituted their manual signature. Afterward, participants were first solicited to respond to the adapted LHQ 3.0 questionnaire (Li et al., 2020) containing questions about the participant's age, sex, gender education level, L2 daily use and AoA, and knowledge about any other languages. Both the informed consent and the LHQ 3.0 questionnaire were presented on Qualtrics (Qualtrics, Provo, UT).

After completing the sociodemographic questionnaire, participants were asked to open the link to the main task. The main masked and primed lexical decision task was run using the OpenSesame software (Mathôt et al., 2012; Mathôt & March, 2022). Here, participants were asked to decide as fast and accurately as possible whether the sequences of letters on the screen were words in English or not.

In order to give a response, participants were instructed to press one of two buttons ("M" for when it is a word and "C" for when it is not a word) of the keyboard that were defined beforehand. Prior to starting the task, participants were provided with a short practice phase containing eight words. Each trial started off with a fixation cross "+" for 500 ms. Afterward, a forward mask consisting of five hashtags "#####" was presented for 500 ms. Following the mask, a prime word appeared in lowercase letters for 60 ms. Finally, the target was presented in capital letters until a response was given or until 2000 ms had elapsed. Words were presented in the default font type on OpenSesame (mono) and in font size 38. In order to guarantee that each target was presented with its corresponding related and unrelated prime word, two lists were created in which half of the targets were presented with their corresponding related prime and the other half with the unrelated prime word. Participants were randomly distributed across lists.

Right after finishing the masked and primed lexical decision task, participants were redirected automatically to the third task, run on the OpenSesame software (Mathôt et al., 2012; Mathôt & March, 2022) as well. The purpose of this isolated-word lexical decision task was to assess the participants' L2 proficiency. Instructions were similar to the ones of the main task. A practice trial of eight words was presented so that the participant could get familiarized with the task. At the beginning of each trial, a fixation cross "+" appeared for 500 ms at the center of the screen. Right after the cross, a target stimulus was presented and remained on the screen until the participant's response or after 2000 ms had elapsed.

Results

The applied experimental design was a 4 (prime type: O+P-; O-P+; O-P- or O+P+) x 2 (prime-target relatedness: related vs. unrelated) factorial design. As dependent variables, response times (RTs) and error percentages (E%) were considered. These were analyzed using linear mixed models (e.g., Baayen, 2008; Baayen et al., 2008), more specifically by means of the lme4 package of R (Bates et al., 2015). A series of fixed-structure models were created to examine the hypotheses with E% and RTs as dependent variables. Variables related to participants entered the analyses as covariables, i.e., objective proficiency levels, L2 AoA, subjective proficiency levels, and proportions of daily use. For the DIALANG test, participants could obtain a maximum punctuation of 75 points in each language. For the evaluation of the subjective proficiency levels, participants evaluated their proficiency for four language skills (reading, writing, speaking, and listening) on a 7-point Likert scale. The mean across competencies was calculated and used in the analyses. Thus, subjective L2 proficiency could vary between 1 and 7. Daily L2 use was operationalized by the proportion of the total sum of hours the participant uses the language

for various activities (i.e., listening to radio/watching TV, reading for fun, reading for school/work, reading on the internet, using social media and internet, writing for school/work, and other activities) in a day (i.e., 24 hours) and could vary between 0 and 1.

Table 6

Mean and Standard Deviations for Variables Related to the Participants' Linguistic History and Knowledge of English (L2)

Individual variables	Mean	SD
DIALANG score	64.1	6.5
DIALANG RTs in ms	757.7	121.8
Age of acquisition (AoA) in years	8.4	2.7
Subjective proficiency (7-point scale)	5.7	1.0
Daily use (proportion of hours per day)	.43	.30

For RTs and E%, analyses were started with the model considering the interaction between prime relatedness and prime condition (RTs or E% ~ prime_condition * prime_relatedness + dialang_eng + aoa_eng + subjective_prof_eng + daily_use_eng). Afterward, the above-mentioned participant variables (covariates) were introduced one by one to this interaction model (e.g., RTs or E% ~ prime_condition * prime_relatedness * dialang_eng + aoa_eng + subjective_prof_eng + daily_use_eng). Participants and items were introduced as random effects, with a random slope of prime relatedness by items (e.g., RTs or E% ~ prime_condition * prime_relatedness + dialang_eng + aoa_eng + subjective_prof_eng + daily_use_eng + (1 | participant) + (prime_relatedness | item). Log-likelihood ratio tests determine the significance of main effects and interactions, using the R anova function. For statistically significant effects, degrees of freedom of the denominator were approximated with Satterthwaite's method (see Satterthwaite, 1941). P-values for determining statistical significance were estimated by the lmerTest package (see Kuznetsova et al., 2017).

Data from participants with a higher E% of 50% were eliminated. A total of 19 participants were excluded, leaving a final number of 133 participants. Additionally, observations that exceeded the mean RTs of each participant by 2.5 *SD* were eliminated, so that 110 observations were excluded. All continuous variables were converted to standardized values ($M = 0$, $SD = 1$). When running pairwise comparisons with continuous variables, those variables were categorized into three levels according to the mean and *SD* of the variable in question. The three levels were the following: (1) *low* corresponds to values one *SD*

or more below the mean; (2) *medium* corresponds to values from one *SD* below the mean until one *SD* above the mean; (3) *high* corresponds to values one *SD* or more above the mean.

Results for Error Percentages (E%)

In Table 7, mean E% and standard error (*SE*) for primes related and unrelated to the target words in each prime condition are listed.

Table 7

Mean E% and Standard Error (SE) for Each Experimental Condition

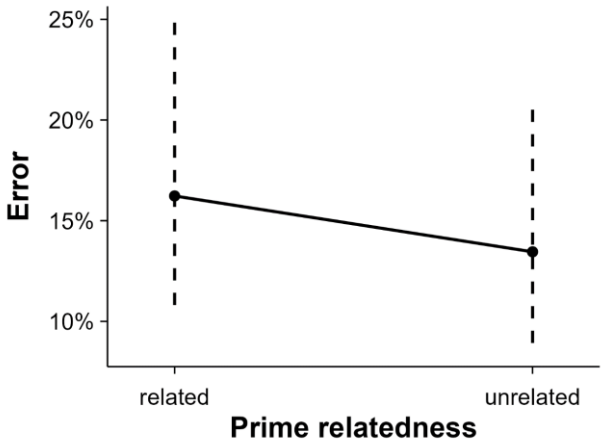
Prime Condition	Prime Relatedness	Mean E%	SE	Effect
O-P-	related	26.1	1.7	-1.1
	unrelated	25.0	1.7	
O-P+	related	28.1	1.8	-3.4
	unrelated	24.7	1.7	
O+P-	related	34.4	1.9	-5.6
	unrelated	28.8	1.8	
O+P+	related	20.7	1.6	-4.7
	unrelated	16.0	1.4	

Note: Effect represents the difference between related and unrelated prime conditions by subtracting the mean of the related prime from the mean of the unrelated prime.

When considering the model with the interaction between relatedness and prime condition, a statistically significant effect of relatedness is found, *estimate* = 0.78, *SE* = 0.06, CI [0.67 – 0.91], t = 3.16, p = .002, $\chi^2(1) = 9.80$, p = .002. As can be seen in Figure 1, participants committed more errors for targets that were preceded by related primes than for targets that were preceded by unrelated primes, replicating the inhibitory neighborhood effect for E%.

Figure 1

Effect of Prime Relatedness on E%

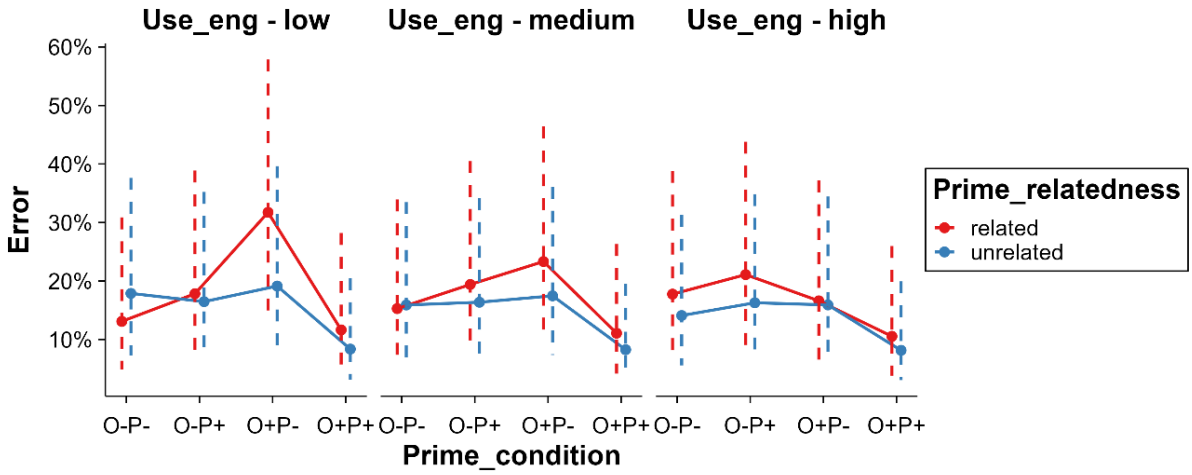


Note: Error refers to error percentages (E%). Dashed bars represent the confidence intervals.

The associated model showed a significant triple interaction between prime relatedness, prime condition, and daily use of L2 (English), $\chi^2(3) = 8.18$, $p = .042$. Participants with infrequent and medium daily use of English had a higher E% for targets that were preceded by related primes than for targets that were preceded by unrelated primes for the O+P- condition (inconsistency condition), *estimate* = 0.63, *SE* = 0.23, $z = 2.72$, $p = .007$, *estimate* = 0.34, *SE* = 0.17, $z = 2.00$, $p = .045$, respectively, as can be seen in Figure 2.

Figure 2

Triple Interaction Between Prime Condition, Prime Relatedness, and Daily Use of English on E%



Note: Daily use of English is abbreviated to Use_eng. Error refers to error percentages (E%). Dashed bars represent the confidence intervals.

Results for Response Times (RTs)

In the RTs analyses, additional participant variables were considered as covariables, in particular, the mean RTs taken from the lexical decision task based on the DIALANG test (e.g., RTs ~ prime_condition * prime_relatedness + mean_rt_dialang_eng + dialang_eng + aoa_eng + subjective_prof_eng + daily_use_eng (1 | participant) + (prime_relatedness | item). Mean RTs and standard error (*SE*) for primes related and unrelated to the target words in each prime condition are shown in Table 8.

Table 8

Mean RTs (in ms) and Standard Error (SE) for Each Experimental Condition

Prime Condition	Prime Relatedness	Mean RTs	SE	Effect
O-P-	related	770	10.3	-19
	unrelated	751	9.0	
O-P+	related	751	9.7	-5
	unrelated	746	9.6	
O+P-	related	762	11.4	-5
	unrelated	757	10.0	
O+P+	related	763	10.0	-18
	unrelated	745	9.0	

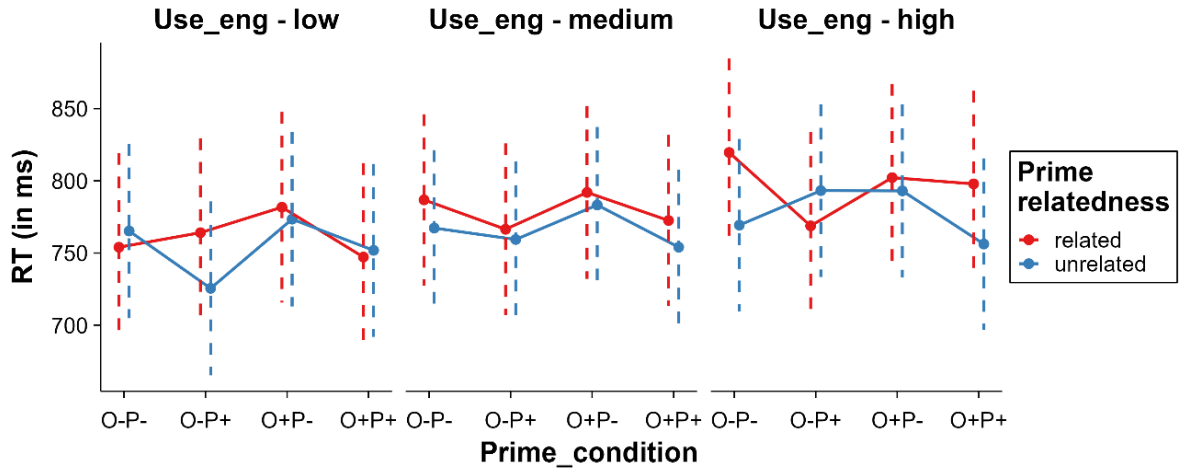
Note: Effect represents the difference between related and unrelated prime conditions by subtracting the mean of the related prime from the mean of the unrelated prime.

For the fixed model with the interaction between relatedness and prime condition, a marginal effect of prime relatedness was observed, *estimate* = 13.89, *SE* = 7.54, CI [-0.90 – 28.68], $t = 1.84$, $p = .066$, $\chi^2(1) = 3.33$, $p = .068$. This effect suggests that participants tended to need more time to respond to targets that were preceded by related primes than to targets that were preceded by unrelated primes, which would signal the inhibitory neighborhood effect.

In the model with involving prime relatedness, prime condition, and proportion of daily use of English (L2), a triple interaction between these factors was observed, $\chi^2(3) = 22.66$, $p < .001$. Participants with infrequent daily use of English showed longer RTs for targets that were preceded by related rather than unrelated primes for the O-P+ condition, *estimate* = 38.25, *SE* = 18.9, $z = 2.02$, $p = .043$. Therefore, the neighborhood effect was found in an inconsistency condition. In contrast, participants with frequent daily use of English showed longer RTs for targets that were preceded by related rather than unrelated primes for the O-P-, *estimate* = 50.47, *SE* = 18.8, $z = 2.68$, $p = .007$, and O+P+ conditions, *estimate* = 42.43, *SE* = 18.1, $z = 2.35$, $p = .019$. Here, the effect was significant for the consistency conditions, see also Figure 3.

Figure 3

Triple Interaction Between Prime Relatedness, Prime Condition, and Daily Use of English on RTs



Note: Daily use of English is abbreviated to Use_eng. Dashed bars represent the confidence intervals.

To further explore possible effects of (in)consistency between orthography and phonology, O+ with O- conditions, P+ with P- conditions and consistency with inconsistency conditions were compared. Consistency conditions correspond to O+P+ and O-P- and inconsistency conditions correspond to O+P- and O-P+ conditions. However, neither significant main effects nor significant interactions with prime relatedness were obtained (all *p*s > .05).

Discussion

The current study aimed at a detailed exploration of cross-language interactions during the early stages of visual word recognition by manipulating the number of lexical neighbors in a masked primed lexical decision task in English (participants' L2). In particular, the nature of the neighborhood effect was investigated through the manipulation of the orthographic and phonological neighborhood size of the EP primes. Individual variables like objective and subjective L2 proficiency, L2 daily use, and L2 AoA were also considered to assess their contribution to the cross-language neighborhood effect.

Overall, an inhibitory neighborhood effect was only significant for E%, i.e., participants committed more mistakes in responding to targets that were preceded by related rather than unrelated primes. Yet, it is important to mention that participants also needed more time to respond to targets that were preceded by related rather than unrelated primes, although depending on their daily use of L2. However, L2 proficiency as measured by the DIALANG test did not impact the inhibitory neighborhood effect. In

other words, the subjective measurement of L2 proficiency in terms of daily use modulated the effect, while the objective measurement of L2 proficiency, the DIALANG test, did not. Modulations of the effect due to L2 proficiency are in line with expectations and with the findings of Bijeljac-Babic et al. (1997). Importantly, Bijeljac-Babic et al. (1997) defined proficient bilinguals as participants that were exposed to the L2 since early childhood and that indicated to use their L2 daily.

Furthermore, modulations of the effect were observed as a function of the primes' orthographic and phonological neighborhood size. Although participants with an infrequent language use in both languages showed a stronger inhibition effect in cases the inconsistency between orthographic and phonological neighborhood size was larger, participants with a frequent language use showed the opposite (i.e., the effect was greater the lower the inconsistency). To clarify this unexpected effect, several comparisons were run involving two paired conditions each rather than four: O+ and O- conditions; P+ and P- conditions; and consistency and inconsistency conditions. However, these comparisons did not show any significant effects and do not allow drawing any firm conclusions. Further studies should examine this issue in further detail to assess the robustness of the results and the relative contribution of the different stimulus dimensions involved.

In comparison to other studies, the obtained effect size in error percentages between target words preceded by unrelated and related primes was similar to those of Bijeljac-Babic et al. (1997; 4.4% in the between-language condition for proficient bilinguals) and Commissaire (2022; 6.8% for session 1 in the marked condition for Experiment 2). For RTs, similar effect sizes were obtained to Commissaire (2022; 20 ms overall for Experiment 1 and 17 ms overall for Experiment 2), Dijkstra et al. (2010a; 11 ms for word primes to word targets in block 1 for Experiment 1 and 21 ms for word primes to word targets in block 1 for Experiment 2) and Dijkstra et al. (2023; 3 ms in Experiment 1 and 9 ms in Experiment 2). Although similar effect sizes in RTs arose in the present study, the effect of the related prime we found appears to be slightly weaker than that reported in previous studies. In particular, Bijeljac-Babic et al. (1997) found an effect of 28 ms in the within-language condition and an effect of 54 ms in the between-language condition for Experiment 1, as well as an effect of 28 ms within-language and of 43 between-language in proficient bilinguals for Experiment 2. In the present study, we were unable to replicate such a strong effect. A potential explanation could be sought in methodological differences between our experiment and those by Bijeljac-Babic et al. (1997). For example, the primes used in our study were slightly less frequent in terms of frequency per million compared to the primes used by Bijeljac-Babic et al. (1997). However, measures of logarithmic frequency are not given in either of the two experiments by Bijeljac-Babic and colleagues (1997). Additionally, our sample size was much larger than the samples

used in the experiments by Bijeljac-Babic and colleagues (1997), an aspect that is known to influence the overall statistical power of results (Brysbaert, 2019).

Whatever may be the reason for the discrepancy across studies, our findings indicate the existence of cross-language competition in the early stages of visual word recognition (Comesaña, 2024; Dijkstra & Peeters, 2023). Yet, this competition might be due to cross-language competition in form of *lateral inhibition* at the pre-lexical level (as assumed by the BIA and BIA+) or due to competition during *response selection* in a "post-access" stage. This latter explanation predicts greater competition between similarly activated items when a decision has to be made. Given that the used prime words differ in their number of orthographic and phonological neighbors, the response selection might be made more difficult by inconsistency in activated representations with respect to both orthography and phonology. The observed combination of effects in terms of orthographic and phonological neighborhood size in E% and RTs complicates a differentiation of these two possibilities in our study. A follow-up lexical decision study was therefore carried out, in order to further validate the obtained effects and implement a useful baseline condition for assessing the processing of the target words in non-priming context conditions. In this study, a subset of the same participants conducted a lexical decision task on the same English targets, but without any masked primes. In addition, a questionnaire was added in which participants evaluated the subjective frequency of the 40 English targets and the 80 Portuguese prime words (73 participants responded to the follow-up request). Data from the follow-up study will be analyzed and may permit more definite conclusions.

However, the found inhibition effect is unlikely to be due to *response competition* in post-lexical stages at the motor response level, given that the motor response is different for target words (pressing the M button) and for target nonwords (pressing the C button). Note that if the effect occurred exclusively at a post-lexical level, no modulations as a function of consistency should be observed. Furthermore, post-lexical competition could be occurring if one of the conditions was easier to respond to, consistently with fewer errors (E%) and faster responses (RTs). Nevertheless, when comparing the results in E% and in RTs, especially for the participants with frequent daily L2 use, different patterns were observed: in particular, similar E% in all conditions, but an inhibition effect for consistency conditions in RTs.

Importantly, the current results indicate that in future research studying neighborhood effects in bilingual visual word recognition, effects of phonology should seriously be taken into consideration. The present pattern of results necessitates further exploration of the interaction between orthographic and phonological effects in the early stages of word recognition. More specifically, the relative effects of the target words' orthographic and phonological neighborhood size, or of the primes' orthographic and

phonological neighborhood size, could be explored for the target words' language. This would allow for a better understanding of cross-language phonological neighborhood size effects. In addition, databases should invest in adding measures of cross-language phonological neighborhood size or cross-language phonological overlap between words of languages such as Portuguese and English. Finally, the effect should also be explored across modalities, visually and auditorily, because the impact of orthography and phonology seems to be modulated by the modality in which the task is administered (visual vs. auditory word recognition; see Frances et al., 2021, for effects with cognates). As a further exploration of when exactly the cross-language competition occurs is warranted, we suggest carrying out eye-tracking studies, because this research technique allows measurements at finer temporal resolutions (e.g., Dirix et al., 2017). Another possibility would be to manipulate the stimulus onset asynchrony by presenting the prime for less or longer time (e.g., 50 ms vs. 80 ms) and explore possible modulations of the neighborhood effect across stimulus onset asynchronies (see also Dijkstra et al., 2023, for a similar manipulation).

In sum, the present study underlines the presence of cross-language competition in the early stages of bilingual visual word recognition, as proposed by the existing computational models. Future studies should focus on exploring exactly when cross-language competition occurs during the word recognition process in bilinguals. Finally, this study showed effect modulations in error rates and reaction times as a function of cross-code (in)consistency of the primes and L2 proficiency. As such, these findings demonstrate the importance of the interplay between orthographic and phonological N-size for the neighborhood effect and its sensitivity to strength differences between the two languages of a bilingual.

References

Alderson, J. C. (2005). *Diagnosing foreign language proficiency: The interface between learning and assessment*. A&C Black.

Baayen, R. (2008). *Analyzing Linguistic Data: A Practical Introduction to Statistics using R*. Cambridge: Cambridge University Press. https://doi.org/10.1017/CBO9780511801686

Baayen, R. H., Davidson, D. J., & Bates, D. M. (2008). Mixed-effects modeling with crossed random effects for subjects and items. *Journal of Memory and Language, 59*(4), 390–412. https://doi.org/10.1016/j.jml.2007.12.005

Balota, D. A., Yap, M. J., Cortese, M. J., Hutchison, K. A., Kessler, B., Loftis, B., Neely, J. H., Nelson, D. L., Simpson, G. B., & Treiman, R. (2007). The English Lexicon project. *Behavior Research Methods, 39*(3), 445–459. https://doi.org/10.3758/BF03193014

Bates, D., Mächler, M., Bolker, B., & Walker, S. (2015). Fitting linear mixed-effects models using lme4. *Journal of Statistical Software, 67*(1). https://doi.org/10.18637/jss.v067.i01

Bijeljac-Babic, R., Biardeau, A., & Grainger, J. (1997). Masked orthographic priming in bilingual word recognition. *Memory and Cognition, 25*(4), 447–454. https://doi.org/10.3758/BF03201121

Brysbaert, M. (2019). How many participants do we have to include in properly powered experiments? A tutorial of power analysis with reference tables. *Journal of Cognition, 2*(1), Article 16. https://doi.org/10.5334/joc.72

Brysbaert, M., Mandera, P., McCormick, S. F., & Keuleers, E. (2019). Word prevalence norms for 62,000 English lemmas. *Behavior Research Methods, 51*(2), 467–479. https://doi.org/10.3758/s13428-018-1077-9

Brysbaert, M., Warriner, A. B., & Kuperman, V. (2014). Concreteness ratings for 40 thousand generally known English word lemmas. *Behavior Research Methods, 46*(3), 904–911. https://doi.org/10.3758/s13428-013-0403-5

Carrasco-Ortiz, H., Midgley, K. J., Grainger, J., & Holcomb, P. J. (2017). Interactions in the neighborhood: Effects of orthographic and phonological neighbors on N400 amplitude. *Journal of Neurolinguistics, 41,* 1–10. https://doi.org/10.1016/j.jneuroling.2016.06.007

Casaponsa, A., Carreiras, M., & Duñabeitia, J. A. (2014). Discriminating languages in bilingual contexts: The impact of orthographic markedness. *Frontiers in Psychology, 5,* Article 424. https://doi.org/10.3389/fpsyg.2014.00424

Comesaña, M. (2024). Procesamiento léxico en bilingües: revisión sobre su estado de cuestión. In E. Álvarez García (Ed.), *Dos lenguas, un cerebro: el procesamiento lingüístico en hablantes bilingües*. Peter Lang. ISBN: 978-3-631-89416-3

Comesaña, M., Ferré, P., Romero, J., Guasch, M., Soares, A. P., & García-Chico, T. (2015). Facilitative effect of cognate words vanishes when reducing the orthographic overlap: The role of stimuli list composition. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 41*(3), 614–635. https://doi.org/10.1037/xlm0000065

Comesaña, M., Sánchez-Casas, R., Soares, A. P., Pinheiro, A. P., Rauber, A., Frade, S., & Fraga, I. (2012). The interplay of phonology and orthography in visual cognate word recognition: An ERP study. *Neuroscience Letters, 529*(1), 75–79. https://doi.org/10.1016/j.neulet.2012.09.010

Commissaire, E. (2022). Do both WRAP and TRAP inhibit the recognition of the French word DRAP? Impact of orthographic markedness on cross-language orthographic priming. *Quarterly Journal of Experimental Psychology (2006), 75*(6), 1094–1113. https://doi.org/10.1177/17470218211048770

Commissaire, E., Audusseau, J., & Casalis, S. (2019). Disentangling cross-language orthographic neighborhood from markedness effects in L2 visual word recognition. *Psychonomic Bulletin & Review, 26*(1), 353–359. https://doi.org/10.3758/s13423-018-1518-6

Dijkstra, T., & Peeters, D. (2023). *The New Psychology of Language: From Body to Mental Model and Back*. Routledge. https://doi.org/10.4324/9781003326274

Dijkstra, T., & Van Heuven, W. J. B. (2002). The architecture of the bilingual word recognition system: From identification to decision. *Bilingualism: Language and Cognition, 5*(3), 175–197. https://doi.org/10.1017/S1366728902003012

Dijkstra, T., Grainger, J., & van Heuven, W. J. B. (1999). Recognition of cognates and interlingual homographs: The neglected role of phonology. *Journal of Memory and Language, 41*(4), 496–518. https://doi.org/10.1006/jmla.1999.2654

Dijkstra, T., Hilberink-Schulpen, B., & van Heuven, W. J. B. (2010a). Repetition and masked form priming within and between languages using word and nonword neighbors. *Bilingualism: Language and Cognition, 13*(3), 341–357. https://doi.org/10.1017/S1366728909990575

Dijkstra, T., Miwa, K., Brummelhuis, B., Sappelli, M., & Baayen, H. (2010b). How cross-language similarity and task demands affect cognate recognition. *Journal of Memory and Language, 62*(3), 284–301. https://doi.org/10.1016/j.jml.2009.12.003

Dijkstra, T., Peeters. D., Hieselaar, W., & van Geffen, A. (2023). Orthographic and semantic priming effects in neighbour cognates: Experiments and simulations. *Bilingualism: Language and Cognition 26*(2), 371–383. https://doi.org/10.1017/S1366728922000591

Dijkstra, T., Wahl, A., Buytenhuijs, F., Van Halem, N., Al-Jibouri, Z., De Korte, M., & Rekké, S. (2019).

Multilink: A computational model for bilingual word recognition and word translation. *Bilingualism: Language and Cognition, 22*(4), 657–679. https://doi.org/10.1017/S1366728918000287

Dirix, N., Cop, U., Drieghe, D., & Duyck, W. (2017). Cross-lingual neighborhood effects in generalized lexical decision and natural reading. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 43*(6), 887–915. https://doi.org/10.1037/xlm0000352

Frances, C., Navarra-Barindelli, E., & Martin, C. D. (2021). Inhibitory and facilitatory effects of phonological and orthographic similarity on L2 word recognition across modalities in bilinguals. *Scientific Reports*, *11*(1), 12812. https://doi.org/10.1038/s41598-021-92259-z

Frost, R. (1998). Toward a strong phonological theory of visual word recognition: True issues and false trails. *Psychological Bulletin, 123*(1), 71–99. https://doi.org/10.1037/0033-2909.123.1.71

Grainger, J., Muneaux, M., Farioli, F., & Ziegler, J. C. (2005). Effects of phonological and orthographic neighbourhood density interact in visual word recognition. *The Quarterly Journal of Experimental Psychology A: Human Experimental Psychology, 58A*(6), 981–998. https://doi.org/10.1080/02724980443000386

Keuleers, E., & Brysbaert, M. (2010). Wuggy: A multilingual pseudoword generator. *Behavior Research Methods, 42*(3), 627–633. https://doi.org/10.3758/BRM.42.3.627

Kuznetsova, A., Brockhoff, P. B., & Christensen, R. H. B. (2017). lmerTest Package: Tests in Linear Mixed Effects Models. *Journal of Statistical Software*, *82*(13), 1–26. https://doi.org/10.18637/jss.v082.i13

Li, P., Zhang, F., Yu, A., & Zhao, X. (2020). Language History Questionnaire (LHQ3): An enhanced tool for assessing multilingual experience. *Bilingualism: Language and Cognition, 23*(5), 938–944. https://doi.org/10.1017/S1366728918001153

Lupker, S. J., Spinelli, G., & Davis, C. J. (2020). Is zjudge a better prime for JUDGE than zudge is?: A new evaluation of current orthographic coding models. *Journal of Experimental Psychology: Human Perception and Performance, 46*(11), 1252–1266. https://doi.org/10.1037/xhp0000856

Marian, V., Bartolotti, J., Chabal, S., & Shook, A. (2012). CLEARPOND: Cross-Linguistic Easy-Access Resource for Phonological and Orthographic Neighborhood Densities. *PloS ONE*, *7*(8), e43230. https://doi.org/10.1371/journal.pone.0043230

Mathôt, S., & March, J. (2022). Conducting Linguistic Experiments Online With OpenSesame and OSWeb. *Language Learning, 72*(4), 1017-1048. https://doi.org/10.1111/lang.12509

Mathôt, S., Schreij, D., & Theeuwes, J. (2012). OpenSesame: An open-source, graphical experiment builder for the social sciences. *Behavior Research Methods*, *44*(2), 314-324. https://doi.org/10.3758/s13428-011-0168-7

Midgley, K. J., Holcomb, P. J., Van Heuven, W. J. B., & Grainger, J. (2008). An electrophysiological investigation of cross-language effects of orthographic neighborhood. *Brain Research*, *1246*, 123–135. https://doi.org/10.1016/j. brainres.2008.09.078

Mulder, K., van Heuven, W. J. B., & Dijkstra, T. (2018). Revisiting the Neighborhood: How L2 Proficiency and Neighborhood Manipulation Affect Bilingual Processing. *Frontiers in Psychology*, *9*, 1860. https://doi.org/10.3389/fpsyg.2018.01860

Qualtrics (2024). Qualtrics (February to May, 2024). Software. http://www.qualtrics.com

Satterthwaite, F. E. (1941). Synthesis of variance. *Psychometrika, 6,* 309–316. https://doi.org/10.1007/BF02288586

Soares, A. P., Costa, A. S., Machado, J., Comesaña, M., & Oliveira, H. M. (2017). The Minho Word Pool: Norms for imageability, concreteness, and subjective frequency for 3,800 Portuguese words. *Behavior Research Methods*, *49*, 1065–1081. https://doi.org/10.3758/s13428-016-0767-4

Soares, A. P., Iriarte, Á., de Almeida, J. J., Simões, A., Costa, A., Machado, J., França, P., Comesaña, M., Rauber, A., Rato, A., & Perea, M. (2018). Procura-PALavras (P-PAL): A Web-based interface for a new European Portuguese lexical database. *Behavior Research Methods, 50*(4), 1461–1481. https://doi.org/10.3758/s13428-018-1058-z

Soares, A. P., Machado, J., Costa, A., Iriarte, Á., Simões, A., de Almeida, J. J., Comesaña, M., & Perea, M. (2015). On the Advantages of Word Frequency and Contextual Diversity Measures Extracted from Subtitles: The Case of Portuguese. *Quarterly Journal of Experimental Psychology, 68*(4), 680-696. https://doi.org/10.1080/17470218.2014.964271

Tiffin-Richards, S. P. (2024). Cognate facilitation in bilingual reading: The influence of orthographic and phonological similarity on lexical decisions and eye-movements. *Bilingualism: Language and Cognition*, 1–18. https://doi.org/10.1017/S1366728923000949

van Heuven, W. J. B., Dijkstra, T., & Grainger, J. (1998). Orthographic neighborhood effects in bilingual word recognition. *Journal of Memory and Language, 39*(3), 458–483. https://doi.org/10.1006/jmla.1998.2584

van Kesteren, R., Dijkstra, T., & de Smedt, K. (2012). Markedness effects in Norwegian–English bilinguals: Task-dependent use of language-specific letters and bigrams. *Quarterly Journal of Experimental Psychology, 65*(11), 2129-2154. https://doi.org/10.1080/17470218.2012.679946

Appendix A

Table A1

List of English Target Words and Corresponding Related (i.e., Orthographic Substitution Neighbors) and Unrelated Portuguese Prime Words

Target Word	Related Prime Word	Unrelated Prime Word
COPE	copo	belo
COCOA	coroa	poste
DICE	doce	anta
EYE	ele	dia
FIN	fio	ler
HIND	hino	arco
NONE	nove	este
PORCH	porco	gosto
TEMP	tema	foco
MESS	mesa	sete
LUG	luz	ida
CHORD	choro	ficha
PAUSE	passe	chave
MOCHA	tocha	louco
SUE	sul	uso
QUILL	quilo	jogar
NOD	nos	jus
PARTY	parte	mundo
PAL	paz	oco
FOG	foz	giz
FLOW	flor	tese
GROVE	greve	sinal
RHINO	reino	lista
PANEL	papel	fonte
VOW	voo	rei
PLANT	plano	geral
PIER	pior	fiel
CRISP	crise	envio
ROT	rol	lei
GRUB	grua	bife
HORN	hora	duro
TASTE	teste	feira
GENIE	gente	longo
SUM	som	lar
FIX	fim	bem

Table A1 Continued

Target Word	Related Prime Word	Unrelated Prime Word
DAMP	dama	figo
MARCH	marca	certo
CURSE	curso	palco
MUSH	musa	remo
CENT	cena	puro

Universidade do Minho

Conselho de Ética

Comissão de Ética para a Investigação em Ciências Sociais e Humanas (CEICSH)

Identificação do documento: CEICSH 181/2023

Título do projeto: *Examining the nature of the neighborhood priming effect with European Portuguese-English bilinguals*

Equipa de Investigação: Ana Isabel Ribeiro Fernandes (IR), Mestrado em Cognição Humana, Escola de Psicologia, Universidade do Minho; Dr.ª Montserrat Comesaña (orientadora), Escola de Psicologia, Universidade do Minho; Dr. Ton Dijkstra (Coorientador), Radboud University Nijmegen

PARECER

A Comissão de Ética para a Investigação em Ciências Sociais e Humanas (CEICSH) analisou o processo relativo ao projeto de investigação acima identificado, intitulado *Examining the nature of the neighborhood priming effect with European Portuguese-English bilinguals.*

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 Comissão de Ética para a Investigação em Ciências Sociais e Humanas (CEICSH) nada tem a opor à realização do projeto nos termos apresentados no Formulário de Identificação e Caracterização do Projeto, que se anexa, emitindo o seu parecer favorável, que foi aprovado por unanimidade pelos seus membros.

O Presidente da CEICSH

Assinado por: **EMANUEL PEDRO VIANA BARBAS DE ALBUQUERQUE**
Num. de Identificação: 07089799

(Emanuel Pedro Viana Barbas Albuquerque)

Anexo: Formulário de identificação e caracterização do projeto