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Early processing of orthographic language membership information in bilingual visual word recognition: Evidence from ERPs

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Abstract

For successful language comprehension, bilinguals often must exert top-down control to access and select lexical representations within a single language. These control processes may critically depend on identification of the language to which a word belongs, but it is currently unclear when different sources of such language membership information become available during word recognition. In the present study, we used event-related potentials to investigate the time course of influence of orthographic language membership cues. Using an oddball detection paradigm, we observed early neural effects of orthographic bias (Spanish vs. English orthography) that preceded effects of lexicality (word vs. pseudoword). This early orthographic pop-out effect was observed for both words and pseudowords, suggesting that this cue is available prior to full lexical access. We discuss the role of orthographic bias for models of bilingual word recognition and its potential role in the suppression of nontarget lexical information.

Keywords

bilingualism; visual word recognition; language membership; orthography; bigram frequency

1. INTRODUCTION

For successful language production and processing, bilinguals need to determine which of their languages is relevant in a given context and select representations that belong to the appropriate language. During comprehension, this requires identification of the language to which the input belongs. Some evidence suggests that this language membership information may guide the word recognition process toward representations belonging to the target language to improve the efficiency of lexico-semantic processing (Casaponsa, Carreiras, & Duñabeitia, 2014; Casaponsa & Duñabeitia, 2016; Hoversten, Brothers, Swaab, & Traxler, 2015). For this process to occur, language membership information must be available very early during lexical access. Therefore, it is critical to establish the precise

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timing of the availability of language membership information for a complete understanding of the bilingual word recognition system.

The Bilingual Interactive Activation Plus (BIA+) model of bilingual visual word recognition includes sublexical, lexical, and semantic units as well as language nodes that represent language membership information (Dijkstra & van Heuven, 2002). These language nodes are activated via lexical representations. However, recent studies suggest that bilinguals are sensitive to language membership information from other sources as well. Several studies have proposed that phonological cues that differ across languages can help bilinguals identify the appropriate language during spoken language processing (e.g., Gonzalez & Lotto, 2013). Prior experience with a particular speaker may provide cues to help identify the language membership of incoming input as well (e.g., Martin, Molnar, & Carreiras, 2016).

During reading, bilinguals have also shown sensitivity to *orthographic* regularities, which differ systematically across languages (Vaid & Frenck-Mestre, 2002). For language pairs such as Chinese and English, the languages can be distinguished based on low-level visual features (e.g., logographic vs. alphabetic script), but languages that share scripts can contain orthographic language membership information as well. Many languages that use the same basic script contain language-specific letters (e.g., æ, ø, and å in Norwegian) that can aid in language attribution. Even for overlapping orthographies, the frequency of different letter combinations (i.e., bigram frequency) differs across languages (Oganian et. al., 2016).

1.1 Orthographic Language Membership Information

Converging evidence has demonstrated that orthographic language membership cues are used in a variety of behavioral tasks including lexical and language decisions. Stimuli that contain language-specific letters or bigrams that are illegal or improbable in the other language (marked stimuli) reduce language decision response times compared to orthographically unmarked stimuli (Casaponsa et. al., 2014; Oganian et. al, 2016; Vaid & Frenck-Mestre, 2002; van Kesteren, Dijkstra, & de Smedt, 2012). For example, van Kesteren and colleagues (2012) tested the effects of orthographic markedness in language and lexical decision tasks in Norwegian-English bilinguals. While they found robust effects in the language decision task, these effects depended on stimulus list composition for their lexical decision tasks. When participants performed an English lexical decision on a list of English words and pseudowords that could be marked for either language, markedness effects were only found for Norwegian pseudowords. Similarly, when the task was a Norwegian lexical decision on a list of Norwegian words and pseudowords marked for either language, markedness effects were only found for English pseudowords. The authors argued that this pattern of results demonstrates that orthographic language membership cues are only used when they are a reliable indicator of the correct response and that the locus of these effects is in post-lexical task/decision processes.

Orthographic markedness has been found to predict language decision latency even when factors such as orthographic neighborhood density are controlled, suggesting that these effects do not depend on co-activation of near neighbors (Casaponsa et. al, 2014; Oganian et al., 2016; van Kesteren et. al., 2012). Moreover, unique effects of continuous sublexical

(bigram frequency) and lexical (orthographic neighborhood) statistics have been found in language decision tasks using languages with overlapping orthographies (Oganian et. al., 2016). Because these markedness effects have been observed for both words and pseudowords (Lemhöfer & Dijkstra, 2004; Lemhöfer & Radach, 2009; van Kesteren et. al., 2012), it is possible that these effects operate at a pre-lexical processing stage. However, to our knowledge, the time course of access to orthographic language membership information has not yet been directly tested.

1.2 Architecture of the Bilingual Word Recognition System

To accommodate their results, van Kesteren and colleagues (2012) proposed an extension to the BIA+ model of visual word recognition, which includes separate sets of lexical and sublexical language nodes that receive activation from lexical and sublexical units respectively. Both sets of nodes feed information on to the task decision system that controls responses for a particular task. According to the current BIA+ model, “language information becomes available rather late during bilingual visual word recognition, usually too late to affect the word selection process” (Dijkstra & van Heuven, 2002, p. 186). Therefore, the language nodes do not have interactive feedback connections to the word recognition stream and hence cannot affect word identification processes directly. In this way, bilingual word recognition proceeds without regard to the language membership of a word (i.e., access is non-selective).

The extended version of the model proposed by van Kesteren and colleagues successfully accounts for the evidence that bilinguals are sensitive to orthographic language membership cues. It is also consistent with the body of evidence that bilingual word recognition is fundamentally non-selective (Kroll, Bobb, & Wodniecka, 2006). While this model is a promising step forward, it does not accommodate the growing body of evidence suggesting that the nontarget language may be less active than the target language (i.e., access is at least partially selective), at least under certain conditions (Elston-Güttler, Gunter, & Kotz, 2005; Hoversten & Traxler, 2016; Titone et. al, 2011). For example, using a dual categorization task, Hoversten and colleagues (2015) showed event-related potential (ERP) evidence that language membership information is available prior to semantic information. Additionally, the N400 frequency effect was reduced for the nontarget compared to the target language. These results support the hypothesis that, contrary to the BIA+, the relatively early availability of language membership information contributes to subsequent suppression of nontarget language representations.

Furthermore, a series of studies by Casaponsa and colleagues has indicated that orthographic language membership cues in particular may play a critical role in restricting cross-language activation. In one study, markedness of Basque words decreased reaction times for Spanish-Basque bilinguals in a progressive demasking task, even though markedness was not a reliable indicator of the correct response (Casaponsa et. al., 2014). In another study, bilinguals showed evidence for reduced top-down feedback from lexical to sublexical levels of representation for marked compared to unmarked Basque stimuli in a forced choice letter detection task. In a second experiment, the same participants showed robust masked translation priming effects for unmarked Basque primes on lexical decision for Spanish

target words, whereas no translation priming effect was found for marked Basque primes (Casaponsa & Duñabeitia, 2016). Finally, a third study compared the effects of Spanish and Basque masked primes on processing of subsequent Spanish targets during electroencephalogram (EEG) recording. Switch costs on the N250 and N400 ERP components were found for target Spanish words preceded by marked Basque primes, but no switch costs were found when targets were preceded by unmarked Basque primes (Casaponsa, Carreiras, & Duñabeitia, 2015). Together, these studies suggest that orthographic language membership information may participate directly in word identification processes by narrowing the search space to a single language.

1.3 The Current Experiment

Although one of the key predictions of the BIA+ model is that language membership information arrives late and cannot directly affect the word recognition process, these recent studies show evidence to the contrary. We hypothesized that the time course of sublexical language membership information could explain how orthographic markedness constrains cross-language activation and how language membership information modulates the depth of processing of target and nontarget languages. If orthographic language membership information is available early enough, it could influence subsequent lexico-semantic processing. In other words, orthographic cues may uniquely permit these early effects of language membership specifically because they are used early during word recognition. If, on the other hand, orthographic language membership information is not available until later during word recognition- as proposed by the BIA+ model- it would not have time to influence ongoing lexico-semantic processing in real time and may instead operate on post-lexical task/decision processes (van Kesteren et. al., 2012).

Therefore, this study was designed to test different hypotheses about the mechanisms of bilingual word recognition by establishing precisely *when* orthographic language membership information is first available. To do so, we recorded EEG in a group of Spanish-English bilinguals during an oddball task in which participants saw frequent nontarget words in one language and infrequent target words in the other language. Rare task-relevant oddball stimuli are known to elicit N2 and P3 effects, which index the amount of time required to perform the necessary categorization task (Luck, 2005). In order to elicit these pop-out effects, we chose words typical of the language to which they belonged according to their orthographic regularities. This orthographic typicality was captured in an *orthographic bias* measure of the ratio between Spanish and English mean bigram frequencies for a given stimulus. Using this measure, we chose a set of Spanish and English words across a broad range of orthographic bias values. While some stimuli contained bigrams that are illegal in the other language (e.g., “sk” in *skipper*), other stimuli contained bigrams that were moderately biased toward one language (e.g., “qu” in *queso* is much more common in Spanish than in English) or weakly biased (e.g., “in” in *inner* is slightly more common in English).

Critically, we also included pseudowords with orthography that resembled either the target or the nontarget language. Although these pseudowords did not require a response, we used ERPs to determine whether participants would initially categorize target-like pseudowords

as task-relevant based on orthographic information (as indicated by oddball N2 and P3 effects). If bilinguals are indeed sensitive to orthographic bias information even in the absence of lexical information, target-like pseudowords should produce oddball ERP effects similar to those of the infrequently presented target words. Nontarget-like pseudowords, on the other hand, should not produce the same effects because they resemble the nontarget category. Since pseudowords were fully counterbalanced across target-like and nontarget-like conditions, any ERP difference between the two pseudoword conditions would thus indicate that the brain differentiated these stimuli based on their orthographic language membership properties and identified target-like pseudowords as potentially belonging to the target language. Moreover, if orthographic information is available early during lexical access, we would expect orthographic bias to modulate ERPs in an early time window, perhaps even earlier than ERP effects distinguishing words and pseudowords.

2. METHODS

2.1 Participants

Thirty-two Spanish-English bilinguals participated in the study and provided written informed consent. All participants were undergraduates at the University of California, Davis and received course credit as compensation for their participation. An additional six participants completed the experiment but were excluded from analyses due to an excessively low number of trials per condition after artifact and error rejection (> 50% missing data). These participants were replaced to balance the lists for a final sample of thirty-two participants. All participants had normal or corrected-to normal vision and were right-handed according to the Edinburgh Handedness Inventory (Oldfield, 1971). None of the participants had a history of neurological or psychiatric impairment.

Each participant completed the Language History Questionnaire 3.0 (Li, Zhang, Tsai, & Puls, 2014) to provide self-reported measures of proficiency and information about their acquisition and current use of each language. Participants also completed the Boston Naming Test in each language (Kaplan, Goodglass, & Weintraub, 1983) and extended versions of the LexTALE (Lemhöfer & Broersma, 2012) and LexTALE-Esp (Izura, Cuetos, & Brysbaert, 2014) lexical decision tasks. We created these extended versions in order to equate the difficulty of items across languages and compare English and Spanish proficiency in our participants. We added 100 words and 50 pseudowords to the original versions of these tests to match word length and frequency across English and Spanish versions of the test for a total of 300 stimuli (33% pseudowords). Pseudowords were created with the Wuggy software program (Keuleers & Brysbaert, 2010) and chosen by at least three native speakers of each language to be pronounceable in that language. In addition to proficiency scores for the original versions for comparison to other studies, d' scores on the extended versions are also provided in Table 1 to compare relative language dominance.

Most participants were heritage speakers of Spanish who had learned Spanish in the home. Others had immigrated to the U.S. as young children from Latin American countries. Although all participants learned Spanish first, most of their education had been completed in English in the U.S. Participants reported that they used English more than Spanish in their daily lives, and they were found to be significantly more proficient in English than in

Spanish according to their d' scores on the extended lexical decision tasks ($t(31) = 9.89$; $p < .001$). Proficiency scores on the various measures were in line with norms for this population of Spanish-English bilinguals (Casillas & Simonet, 2016; Kohnert, Hernandez, & Bates, 1998).

2.2 Stimuli

To assess the degree to which the letter combinations in a stimulus resemble one language or the other, we calculated an orthographic bias measure using bigram frequency statistics from the Leipzig Corpora Collection (Goldhahn, Eckart, & Quasthoff, 2012). We first calculated the ratio of bigram frequency between English and Spanish for each possible bigram combination. We then calculated the log of this ratio to create a bias measure for each bigram combination. To measure the bias of a given stimulus, we calculated the mean of the bias of all the bigrams in the stimulus. This gave us a single measure of the ratio of English to Spanish bias for each stimulus, with positive values reflecting an English bias and negative values reflecting a Spanish bias. While most words that belong to one language are more orthographically biased toward that language, some words are more orthographically biased toward the other language. For example, the English word *knight* has a mean English bias of 1.06 according to the measure, indicating that it contains bigrams that appear more frequently in English than in Spanish. The English word *trapeze*, on the other hand, has a mean English bias of $-.29$, meaning that it resembles Spanish more than English according to its orthographic bigram frequency. The English word *lobster* has a neutral bias at $-.001$ on this measure, meaning it has bigrams that are approximately equally frequent in both languages.

Using this measure, we selected 192 words in each language with a mean orthographic bias consistent with their language membership (e.g., English words with bigrams that appear more frequently in English than in Spanish). To include a representative sample of words in each language, we chose words in various word classes and across a range of orthographic bias values, some of which were slightly more biased toward the opposite language but most of which had a bias consistent with their language membership. The full list of stimuli used can be found in the Supplementary Materials. Identical cognates, interlingual homographs, and Spanish words with non-English characters were excluded. Across languages, words were matched on length, number of syllables, orthographic neighborhood density, concreteness, and log frequency per million according to the SUBTLEX-US and SUBTLEX-ESP databases, (Table 2; Coltheart, 1981; Brysbaert, Warriner, & Kuperman, 2014; Cuetos, Glez-Nosti, Barbón, & Brysbaert, 2011; New, Brysbaert, Veronis, & Pallier, 2007). We then used the Wuggy program (Keuleers & Brysbaert, 2010) to create 96 pseudowords resembling each language according to their orthographic bias. Pseudowords were matched to words on length and number of syllables, did not have any single substitution orthographic neighbors in either language, and were chosen by three native speakers of each language to be pronounceable in that language.

The probability of encountering words in each language was manipulated in an oddball paradigm. Standard stimuli occurred most frequently (70% of trials) and consisted of words in one of the two languages (English or Spanish). Three types of deviant stimuli were

presented on 10% of trials each. Target stimuli, which required a button press, consisted of words in the other language (i.e., the language not used as the standard). The other two types of deviant stimuli were pseudowords resembling either the standard (nontarget) or the deviant (target) language category. Each language was presented as the standard and as the deviant category in separate blocks. Stimuli were counterbalanced across lists such that the same stimuli appeared in both target-like and nontarget-like conditions across participants. To exclude the possibility of baseline differences across conditions, only stimuli that were preceded by a stimulus in the standard condition were included in the analyses. This design resulted in 48 trials of each type of deviant condition and 192 trials in the standard condition per participant (see Luck, 2010 for a detailed discussion of comparing ERPs across conditions with different noise levels).

2.3 Procedure

Participants were seated 100cm from a CRT monitor in an electrically shielded, sound-attenuated chamber. Stimuli were presented serially in the center of the screen in white uppercase 20 point Calibri font against a black background. Stimuli appeared between two fixed horizontal lines for 300ms with a jittered inter-stimulus interval of 1750–2100ms. A fixation cross appeared after every third stimulus for 1000ms to allow participants to blink, followed by 1500ms of blank screen before beginning the next trial.

Prior to each of eight blocks, participants were instructed to press a button with either the left or right hand each time they saw an existing word in the deviant language category, although they were not explicitly informed of the probability of encountering these words. Participants were instructed to respond to each word as quickly as possible without making mistakes (i.e., responding to standards or pseudowords). Response hand was counterbalanced within subjects across blocks, and order of presentation of blocks was counterbalanced across participants. Each block began with four practice stimuli belonging to the standard language category to familiarize the participant with the probabilities of encountering each stimulus type for that block.

2.4 Recording

EEG was recorded from 29 tin electrodes mounted in an elastic cap (Electro-Cap International, Eaton, OH). Electrodes were also attached lateral to each eye and below the left eye to monitor horizontal eye movements and blinks. Impedances were kept below 5 k Ω . The signal was amplified using a Synamps Model 8050 Amplifier (Compumedics Neuroscan) with a band pass of 0.05–100Hz and digitally recorded at a sampling rate of 500Hz. Electrodes were referenced to the right mastoid during recording and re-referenced offline to the average of the left and right mastoids.

After recording, independent component analysis (ICA) was used to isolate and remove blink, saccade, and muscle components (Makeig, Bell, Jung, & Sejnowski, 1996). Single-trial epochs with residual artifacts were rejected manually (6.4% of trials). Data were then filtered with a 30 Hz low-pass filter, and 1400 msec epochs were extracted with a 300 msec pre-stimulus baseline. False alarms for nontarget stimuli and omission errors for target stimuli were removed before averaging ERPs.

2.5 ERP Analysis

EEG epochs were averaged to compute ERPs, and statistical analyses were performed on individual subject ERP averages. Time windows were chosen based on prior literature examining the effects of interest (N2 window: 200–275ms; P3 window: 400–700ms; Luck & Hillyard, 1994). Repeated measure ANOVAs were conducted with two levels of Orthographic Bias (target-like vs. nontarget-like) and two levels of Lexicality (word vs. pseudoword). To investigate the topographic distribution of effects, we conducted separate ANOVAs over midline and lateral electrode sites. The midline analysis included a factor of Anteriority with five levels, each representing a single electrode site (AFz, Fz, Cz, Pz, and POz). The lateral analysis included a factor of Anteriority with three levels (anterior: FP1/2, F3/4, F7/8; central: FC1/2, FC5/6, C3/4, CP1/2, CP5/6; posterior: P3/4, T5/6, O1/2) and a two level factor of Hemisphere (left vs. right). The Greenhouse-Geisser correction was used to adjust the reported p -values for analyses with more than one degree of freedom. We report main effects as well as the highest level interaction that was found to be significant. Interactions with topographic factors were followed up with pairwise comparisons in electrode clusters used in prior literature to examine the N2 and P3 effects of interest (Luck & Hillyard, 1994). In all cases, N2 and P3 effects were largest in our dataset in the same electrode clusters predicted based on prior literature.

3. RESULTS

Average response latency was 792ms ($SD = 100ms$). Participants correctly responded to 81.3% of the target words before the next stimulus appeared ($SD = 9.6%$) and made 0.8% false alarms for nontarget words ($SD = 1.7%$). Participants made significantly more false alarm errors for target-like pseudowords (11.1%, $SD = 11.6%$) than nontarget-like pseudowords (0.3%, $SD = 0.9%$; $t(31) = 5.40, p < .001$). Grand average ERP waveforms and target-like minus nontarget-like difference waveforms are plotted in Figures 1 and 2, respectively.

3.1 N2 (200–275ms)

Both target words and target-like pseudowords elicited an increased posterior negativity 150–300ms post-stimulus onset compared to nontarget-like stimuli. Mean amplitudes in the 200–275ms window (Luck, 1994) revealed significant main effects of Orthographic Bias (Lateral: $F(1,31) = 4.31, p = 0.046$; Midline: $F(1,31) = 1.19, ns$), with more negative amplitudes for target-like stimuli than for nontarget-like stimuli. A marginal interaction was found between Anteriority and Hemisphere in the lateral analysis ($F(2,62) = 3.46, p = .065$), with more negative amplitudes in the left hemisphere on posterior electrodes. The interaction of Orthographic Bias and Anteriority also trended toward significance ($F(2,62) = 2.90, p = .083$), with more negative amplitudes for target-like stimuli over the posterior electrode sites but no significant differences across target-like and nontarget-like conditions at anterior or central sites ($t_s < 1.6$). Critically, no main effect of Lexicality ($F < 1$) or interactions between Lexicality and the other factors (all $F_s < 2.4$) were found in this time window.

In the posterior electrode cluster (P3/4, T5/6, O1/2) where effects were found to be largest, in accordance with prior literature on the visual pop-out N2 (Luck & Hillyard, 1998), we

found a main effect of Orthographic Bias ($F(1,31) = 8.14, p = .008$) but no effects of Lexicality ($F_s < 1$). Mean amplitudes were more negative for target-like stimuli ($0.83 \mu\text{V}$) compared to nontarget-like stimuli ($1.23 \mu\text{V}$). Planned comparisons revealed that both target words and target-like pseudowords elicited a significant negativity in this window compared to nontarget words and nontarget-like pseudowords (Figure 3; Words: $t(31) = 2.42, p = .02$; Pseudowords: $t(31) = 2.09, p = .04$). This suggests that orthographic language membership cues produced an early visual pop-out effect, differentiating potential targets from nontargets prior to differentiating between words and pseudowords.

3.2 P3 (400–700ms)

Target words elicited a typical oddball positivity (P3) over much of the scalp starting around 300ms and extending until the end of the epoch. Target-like pseudowords also elicited a P3, which was smaller in amplitude and more focally located on centroparietal electrodes. Main effects of Lexicality (Lateral: $F(1,31) = 106.79, p < .001$; Midline: $F(1,31) = 106.83, p < .001$) and Orthographic Bias (Lateral: $F(1,31) = 23.60, p < .001$; Midline: $F(1,31) = 44.93, p < .001$) were found on mean amplitude in the 400–700ms time window. There was a clear interaction between these two factors in this window (Lateral: $F(1,31) = 42.46, p < .001$; Midline: $F(1,31) = 45.81, p < .001$), signifying a larger Orthographic Bias effect for words than pseudowords. In the midline analysis, Anteriority interacted with both Lexicality ($F(4,124) = 6.40, p = .004$) and Orthographic Bias ($F(4,124) = 17.57, p < .001$). In the lateral analysis, a four-way interaction was found among Orthographic Bias, Lexicality, Anteriority and Hemisphere ($F(2,62) = 4.79, p = .02$).

To follow-up on this four way interaction, we examined the centroparietal cluster (CPI/2, P3/4, Pz, POz) where the P3 was maximal for both words and pseudowords as expected from prior literature (Luck & Hillyard, 1994). In this cluster, mean amplitudes revealed significant main effects of Orthographic Bias ($F(1,31) = 65.20, p < .001$) and Lexicality ($F(1,31) = 103.85, p < .001$) as well as their interaction ($F(1,31) = 41.02, p < .001$). Planned comparisons revealed that Orthographic Bias significantly modulated the P3 in both words (Target: $6.01 \mu\text{V}$; Nontarget: $1.57 \mu\text{V}$; $t(31) = 8.77, p < .001$) and pseudowords (Target: $1.88 \mu\text{V}$; Nontarget: $0.98 \mu\text{V}$; $t(31) = 2.67, p = .01$).

3.3 Comparing the time course of Orthographic Bias and Lexicality effects

To confirm that participants showed differential ERP responses to words and pseudowords, we analyzed waveforms in the typical N400 window from 300–500ms (Kutas & Federmeier, 2011). In this window, we found a main effect of Lexicality (Lateral: $F(1,31) = 26.12, p < .001$; Midline: $F(1,31) = 29.07, p < .001$) that did not interact with any topographic factors. This effect is shown in Figure 4, with more negative amplitudes for pseudowords than for words starting at approximately 300ms. To directly compare the time course of the effects of Orthographic Bias and Lexicality, we performed two different onset latency analyses, zooming in on a posterior electrode cluster where both effects were present (P3/4, T5/6, O1/2, Pz, POz).¹ To isolate the effect of Lexicality, we report differences

¹A similar pattern emerged in whole-head analyses including topographic factors.

between target words and target-like pseudowords, which were matched on frequency of occurrence.²

3.3.1 Fractional area latency of difference waves—For the first time course analysis, we used fractional area latency measures (Hansen & Hillyard, 1980; Luck, 2005) to compare the onset latency of each effect. To isolate the effect of Orthographic Bias from lexical factors, we subtracted the waveform of the target-like stimuli point-by-point from that of the nontarget-like stimuli, averaging across words and pseudowords. To isolate the effects of Lexicality, we subtracted the pseudoword waveform from the word waveform for the target-like stimuli. We then calculated the latency at which each difference waveform reached 20% of the total negative area between 100 and 600ms post-stimulus onset. According to this measure, the Orthographic Bias effect emerged at 207ms and the Lexicality effect emerged at 346ms post-stimulus onset, a difference of 130ms ($t(31) = 7.13, p < .001$).

3.3.2 Latency analysis in successive time windows—To confirm the primacy of Orthographic Bias, we also conducted t-tests for each effect on the raw waveforms in successive 100ms increments staggered by 50ms (Table 3). In the first three windows (0–100ms, 50–150ms, and 100–200ms), neither effect reached significance (all $t_s < 1.72$). In the 150–250ms window, the effect of Orthographic Bias emerged as significant ($t(31) = 2.29, p = .029$) and remained significant in the 200–300ms window ($t(31) = 2.79, p = .009$). The effect continued to trend toward significance in the 250–350ms window as well ($t(31) = 1.99, p = .056$). Conversely, the effect of Lexicality did not reach significance until the 300–400ms window ($t(31) = 2.70, p = .011$). This pattern matches that of the fractional area latency results above, providing converging evidence that the Orthographic Bias effect emerged significantly earlier than the Lexicality effect by approximately 100–150ms.

4. DISCUSSION

In this experiment we investigated the time course of activation of orthographic language membership information using ERPs. If this information is available early during processing prior to lexical access, it could enable early language membership identification (e.g., Hoversten et al., 2015) and language change detection (Casaponsa et al., 2015) as well as modulation of cross-language activation (Hoversten et al., 2015; Casaponsa et al., 2014, Casaponsa & Duñabeitia, 2016). On the other hand, if this information is not available until later stages of word recognition, it could not influence lexical processing in real time and might instead affect task/decision processes after lexical access (van Kesteren et al., 2012). Using the oddball paradigm uniquely enabled us to establish *when* orthographic bias information was available relative to lexical information while counterbalancing stimuli across conditions of interest to rule out any influence of low-level stimulus confounds.

The data clearly demonstrated that bilinguals used orthographic cues to identify language membership of both words and pseudowords. Participants made more false alarm errors for target-like pseudowords than nontarget-like pseudowords, suggesting that they treated these

²The same pattern of results held when examining the two nontarget-like conditions as well as the overall main effect of Lexicality. In all cases, the Lexicality effect emerged at least 50ms later than the Orthographic Bias effect.

stimuli as potentially belonging to target and nontarget language categories respectively. Additionally, both words and pseudowords elicited larger N2 and P3 effects when the orthographic bias resembled the target category as compared to the nontarget category. The sensitivity of N2 and P3 components to orthographic typicality of the stimuli corroborates prior evidence demonstrating that orthographic cues affect the activation of language membership information, even in the absence of lexical information (Lemhöfer & Radach, 2009; van Kesteren et. al., 2012; Oganian et. al., 2016). These results support the concept of a sublexical source of language membership information added by van Kesteren and colleagues (2012) in the extended BIA+ model. However, the results refute the activation time course of such information proposed by the BIA+ model.

Instead, results of the current study uniquely suggest that orthographic language membership information is available *early* during word recognition processes. The neural effects of Orthographic Bias (target-like vs. nontarget-like) appeared in an early time window (200–275ms) before the ERP effect of Lexicality (word vs. pseudoword), which appeared in a later time window (300–500ms). Together, the latency analyses we performed both suggest that orthographic language membership information was available within 150–200ms after presentation of a visual stimulus, while differentiation between words and pseudowords occurred within 300–400ms.

The Orthographic Bias main effect, which was observed on posterior electrodes between 150–300ms, is most consistent with the visual pop-out N2b component found in similar visual target detection tasks (Luck, 2005). While small in amplitude, this N2 pop-out effect is in line with previous results (Folstein & van Petten, 2008). This potential is thought to be generated in extrastriate cortex, particularly in inferior temporal areas of the ventral stream (Fuster & Jervey, 1981; Potts & Tucker, 2001). In the current study, the target-defining feature was orthographic bias as measured by bigram frequency. Prior studies have suggested that the area of the left ventral occipitotemporal cortex known as the visual word form area (VWFA) as well as an area in the right posterior occipital cortex are sensitive to the bigram frequency of pseudowords in a native language (Binder et. al., 2006; Oganian et. al., 2015). These brain areas may thus have contributed to the orthographic bias effects observed on the posterior N2 in the current experiment.

We also observed differential ERP responses to words and pseudowords beginning in the 300–500 time window. Some of this Lexicality effect was likely driven by an increase in the amplitude of the N400 component for pseudoword stimuli. Previous ERP studies investigating pseudoword processing have linked this increase in N400 amplitude to increased lexical processing difficulty compared to real words (Holcomb, 1993). This Lexicality effect was also likely influenced by a larger P3b component to target words compared to target-like pseudowords. Prior studies have suggested that the P3b is sensitive to target status as well as the difficulty of stimulus categorization (Johnson, 1986). Critically, both the pseudoword N400 and the target word P3b should only emerge in the ERP signal after the brain has begun to differentiate word and pseudoword stimuli. The clear latency difference between the Lexicality effect and the earlier Orthographic Bias effect thus suggests that there is a pre-lexical processing stage in which the bilingual brain decodes

orthographic language membership cues such as bigram frequency before a single lexical candidate has been uniquely identified.

The current data demonstrates that language nodes can be activated early during orthographic decoding and that this process unfolds similarly for all word-like stimuli, even items that are not represented in the lexicon. The early availability of orthographic bias compared to lexicality information provides a mechanism by which language membership information can be available early enough to modulate ongoing word recognition processes. This finding may thus be more consistent with the role of the language nodes in the BIA model, a predecessor to BIA+ (Dijkstra & van Heuven, 1998). In this model, language nodes could directly inhibit lexical representations belonging to the other language. BIA+ removed these feedback connections under the assumption that language membership information arrives late during processing and does not have time to affect word identification. Instead, the BIA+ and its extension propose that influences of language membership information arise at the level of the task decision system. This assumption has been called into question by recent evidence that language membership information can adjust the depth of processing as a function of top-down task demands (Hoversten et al., 2015) and that orthographic markedness can constrain cross-language activation (Casaponsa & Duñabeitia, 2014, 2016; Casaponsa et al., 2015). Results from the current study support the latter account due to the early influence of orthographic cues on the lexico-semantic processing stream. Therefore, an extension of the BIA model with a sublexical source of language membership information may better characterize the architecture of the bilingual word recognition system.

While current evidence suggests that language-unique bigrams can reduce or even eliminate cross-language activation, it is also possible that continuous differences in orthographic regularities restrict cross-language activation in a graded fashion. This graded restriction may contribute to partially selective access, whereby the nontarget language is less active than the target language (Elston-Güttler, Gunter, & Kotz, 2005; Hoversten & Traxler, 2016). Beyond the visual domain, fine-grained phonetic cues may also influence the degree of cross-language activation during speech comprehension (Ju & Luce, 2004). Furthermore, orthographic bias may be one of several sources of linguistic and extra-linguistic language membership information that can accumulate during natural language processing. In this way, orthographic cues may contribute to the “zooming-in” process (Elston-Güttler et al., 2005) through the activation and inhibition of target and nontarget languages. Orthographic language membership cues may also aid in the recognition of unexpected code switches, which have been shown to incur processing costs (Altarriba, Kroll, Sholl, & Rayner, 1996). An important goal for future research will be identifying the relative importance of sublexical, lexical, and extra-linguistic language membership cues and how they interact during bilingual language comprehension.

Supplementary Material

Refer to Web version on PubMed Central for supplementary material.

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References

- Altarriba J, Kroll JF, Sholl A, Rayner K. The influence of lexical and conceptual constraints on reading mixed-language sentences: Evidence from eye fixations and naming times. *Memory & Cognition*. 1996; 24:477–492. [PubMed: 8757496]
- Binder JR, Medler DA, Westbury CF, Liebenthal E, Buchanan L. Tuning of the human left fusiform gyrus to sublexical orthographic structure. *Neuroimage*. 2006; 33:739–748. [PubMed: 16956773]
- Brysbaert M, Warriner AB, Kuperman V. Concreteness ratings for 40 thousand generally known English word lemmas. *Behavior Research Methods*. 2014; 46:904–911. [PubMed: 24142837]
- Casaponsa A, Carreiras M, Duñabeitia JA. Discriminating languages in bilingual contexts: the impact of orthographic markedness. *Frontiers in Psychology*. 2014; 424
- Casaponsa A, Carreiras M, Duñabeitia JA. How do bilinguals identify the language of the words they read? *Brain Research*. 2015; 1624:153–166. [PubMed: 26236021]
- Casaponsa A, Duñabeitia JA. Lexical organization of language-ambiguous and language-specific words in bilinguals. *The Quarterly Journal of Experimental Psychology*. 2016; 69:589–604. [PubMed: 26123205]
- Casillas JV, Simonet M. Production and perception of the English/æ/–/ɑ/contrast in switched-dominance speakers. *Second Language Research*. 2016; 32:171–195.
- Dijkstra, T., van Heuven, WJB. The BIA model and bilingual word recognition. In: Grainger, J., Jacobs, AM., editors. *Localist connectionist approaches to human cognition*. Mahwah, NJ: Erlbaum; 1998. p. 189-225.
- Dijkstra T, Van Heuven WJ. The architecture of the bilingual word recognition system: From identification to decision. *Bilingualism: Language and Cognition*. 2002; 5:175–197.
- Donchin E, Coles MG. Is the P300 component a manifestation of context updating. *Behavioral and brain sciences*. 1988; 11(3):357–427.
- Elston-Güttler KE, Gunter TC, Kotz SA. Zooming into L2: Global language context and adjustment affect processing of interlingual homographs in sentences. *Cognitive Brain Research*. 2005; 25:57–70. [PubMed: 15905078]
- Fuster JM, Jervey JP. Inferotemporal neurons distinguish and retain behaviorally relevant features of visual stimuli. *Science*. 1981; 212:952–955. [PubMed: 7233192]
- Goldhahn D, Eckart T, Quasthoff U. Building Large Monolingual Dictionaries at the Leipzig Corpora Collection: From 100 to 200 Languages. *LREC*. 2012:759–765.
- Gonzales K, Lotto AJ. A bafri, un pafri Bilinguals' pseudoword identifications support language-specific phonetic systems. *Psychological Science*. 2013
- Hansen JC, Hillyard SA. Endogeneous brain potentials associated with selective auditory attention. *Electroencephalography and clinical neurophysiology*. 1980; 49:277–290. [PubMed: 6158404]
- Holcomb PJ. Semantic priming and stimulus degradation: Implications for the role of the N400 in language processing. *Psychophysiology*. 1993; 30:47–61. [PubMed: 8416062]
- Hoversten LJ, Brothers T, Swaab TY, Traxler MJ. Language membership identification precedes semantic access: Suppression during bilingual word recognition. *Journal of Cognitive Neuroscience*. 2015; 27:2108–2116. [PubMed: 26102228]
- Hoversten LJ, Traxler MJ. A time course analysis of interlingual homograph processing: Evidence from eye movements. *Bilingualism: Language and Cognition*. 2016; 19:347–360.
- Izura C, Cuetos F, Brysbaert M. Lextale-Esp: A test to rapidly and efficiently assess the Spanish vocabulary size. *Psicológica*. 2014; 35:49–66.
- Johnson R Jr. A triarchic model of P300 amplitude. *Psychophysiology*. 1986; 23:367–384. [PubMed: 3774922]

- Ju M, Luce PA. Falling on sensitive ears: Constraints on bilingual lexical activation. *Psychological Science*. 2004; 15:314–318. [PubMed: 15102140]
- Kaplan, E., Goodglass, H., Weintraub, S. *Boston Naming Test*. Philadelphia: Lee & Febiger; 1983.
- Keuleers E, Brysbaert M. Wuggy: A multilingual pseudoword generator. *Behavior Research Methods*. 2010; 42:627–633. [PubMed: 20805584]
- Kohnert KJ, Hernandez AE, Bates E. Bilingual performance on the Boston Naming Test: preliminary norms in Spanish and English. *Brain and language*. 1998; 65(3):422–440. [PubMed: 9843612]
- Kroll JF, Bobb SC, Wodniecka Z. Language selectivity is the exception, not the rule: Arguments against a fixed locus of language selection in bilingual speech. *Bilingualism: Language and Cognition*. 2006; 9:119–135.
- Kutas M, Federmeier KD. Thirty years and counting: finding meaning in the N400 component of the event-related brain potential (ERP). *Annual Review of Psychology*. 2011; 62:621–647.
- Lemhöfer K, Broersma M. Introducing LexTALE: A quick and valid lexical test for advanced learners of English. *Behavior Research Methods*. 2012; 44:325–343. [PubMed: 21898159]
- Lemhöfer K, Dijkstra T. Recognizing cognates and interlingual homographs: Effects of code similarity in language-specific and generalized lexical decision. *Memory & Cognition*. 2004; 32(4):533–550. [PubMed: 15478748]
- Lemhöfer K, Radach R. Task context effects in bilingual nonword processing. *Experimental Psychology*. 2009; 56:41–47. [PubMed: 19261577]
- Li P, Zhang F, Tsai E, Puls B. Language history questionnaire (LHQ 2.0): A new dynamic web-based research tool. *Bilingualism: Language and Cognition*. 2014; 17:673–680.
- Luck, SJ. *An introduction to the event-related potential technique*. MIT press; 2005.
- Luck SJ. Is it legitimate to compare conditions with different numbers of trials? *UC-Davis Center for Mind & Brain*. 2010:1–4.
- Luck SJ, Hillyard SA. Spatial filtering during visual search: evidence from human electrophysiology. *Journal of Experimental Psychology: Human Perception and Performance*. 1994; 20:1000. [PubMed: 7964526]
- Makeig S, Bell AJ, Jung TP, Sejnowski TJ. Independent component analysis of electroencephalographic data. *Advances in Neural Information Processing Systems*. 1996:145–151.
- Martin CD, Molnar M, Carreiras M. The proactive bilingual brain: Using interlocutor identity to generate predictions for language processing. *Scientific Reports*. 2016; 6
- Morey RD. Confidence intervals from normalized data: A correction to Cousineau (2005). *Tutorial in Quantitative Methods for Psychology*. 2008; 4:61–64.
- Oganian Y, Conrad M, Aryani A, Heekeren HR, Spalek K. Interplay of bigram frequency and orthographic neighborhood statistics in language membership decision. *Bilingualism: Language and Cognition*. 2016; 19:578–596.
- Oganian Y, Conrad M, Aryani A, Spalek K, Heekeren HR. Activation patterns throughout the word processing network of L1-dominant bilinguals reflect language similarity and language decisions. *Journal of Cognitive Neuroscience*. 2015; 27:2197–2214. [PubMed: 26226076]
- Oldfield RC. The assessment and analysis of handedness: the Edinburgh inventory. *Neuropsychologia*. 1971; 9:97–113. [PubMed: 5146491]
- Potts GF, Tucker DM. Frontal evaluation and posterior representation in target detection. *Cognitive Brain Research*. 2001; 11:147–156. [PubMed: 11240117]
- Titone D, Libben M, Mercier J, Whitford V, Pivneva I. Bilingual lexical access during L1 sentence reading: The effects of L2 knowledge, semantic constraint, and L1–L2 intermixing. *Journal of Experimental Psychology: Learning, Memory, and Cognition*. 2011; 37:1412.
- Vaid J, Frenck-Mestre C. Do orthographic cues aid language recognition? A laterality study with French–English bilinguals. *Brain and Language*. 2002; 82:47–53. [PubMed: 12174814]
- van Kesteren R, Dijkstra T, de Smedt K. Markedness effects in Norwegian–English bilinguals: task-dependent use of language-specific letters and bigrams. *The Quarterly Journal of Experimental Psychology*. 2012; 65:2129–2154. [PubMed: 22554207]

HIGHLIGHTS

- Orthographic cues are used to identify language membership of words and pseudowords.
- Orthographic language membership cues are available prior to lexical information.
- The early availability of orthographic cues may enable partially selective access.

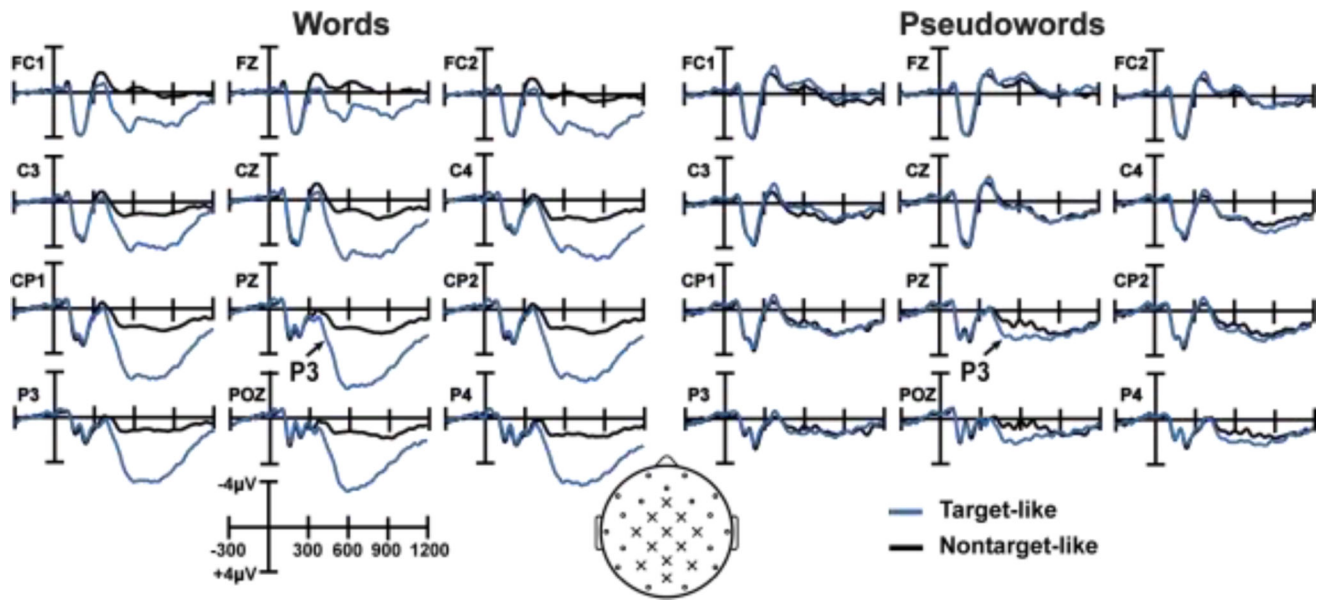


Figure 1. Grand average ERP waveforms for target-like (blue) and nontarget-like (black) words and pseudowords.

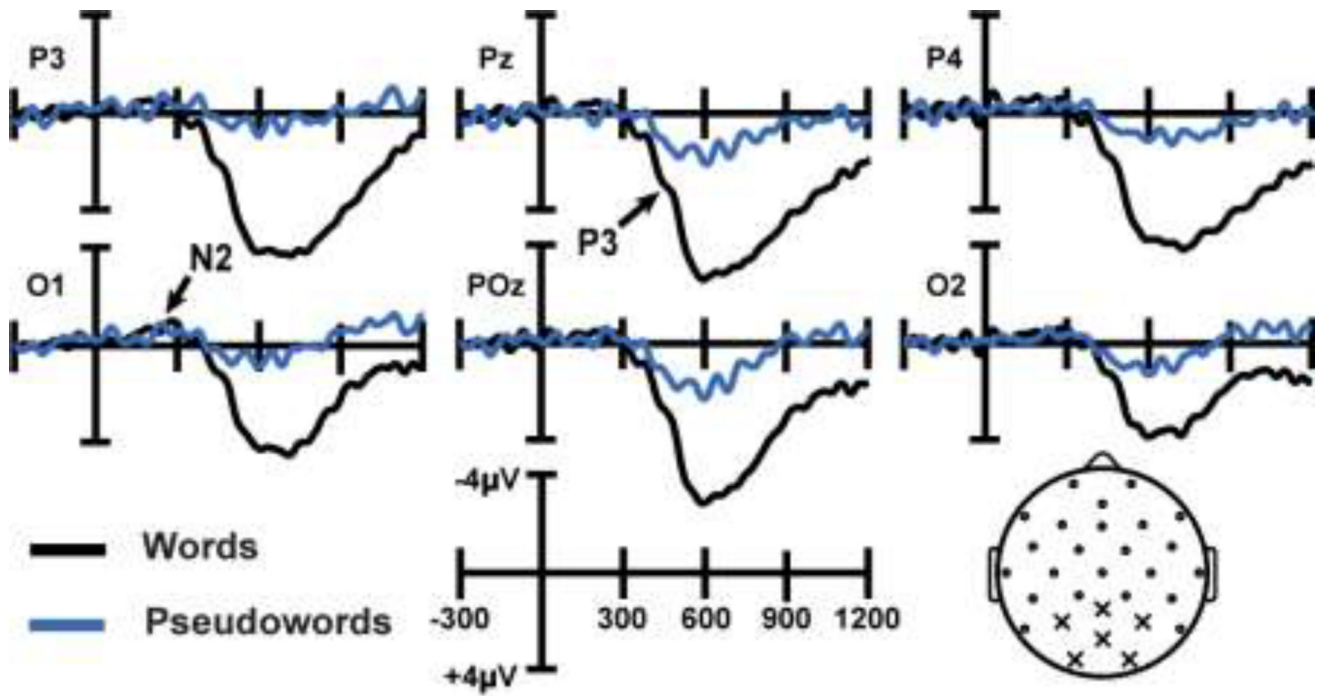


Figure 2.
ERP difference waves representing the orthographic bias effect in words (black) and pseudowords (blue).

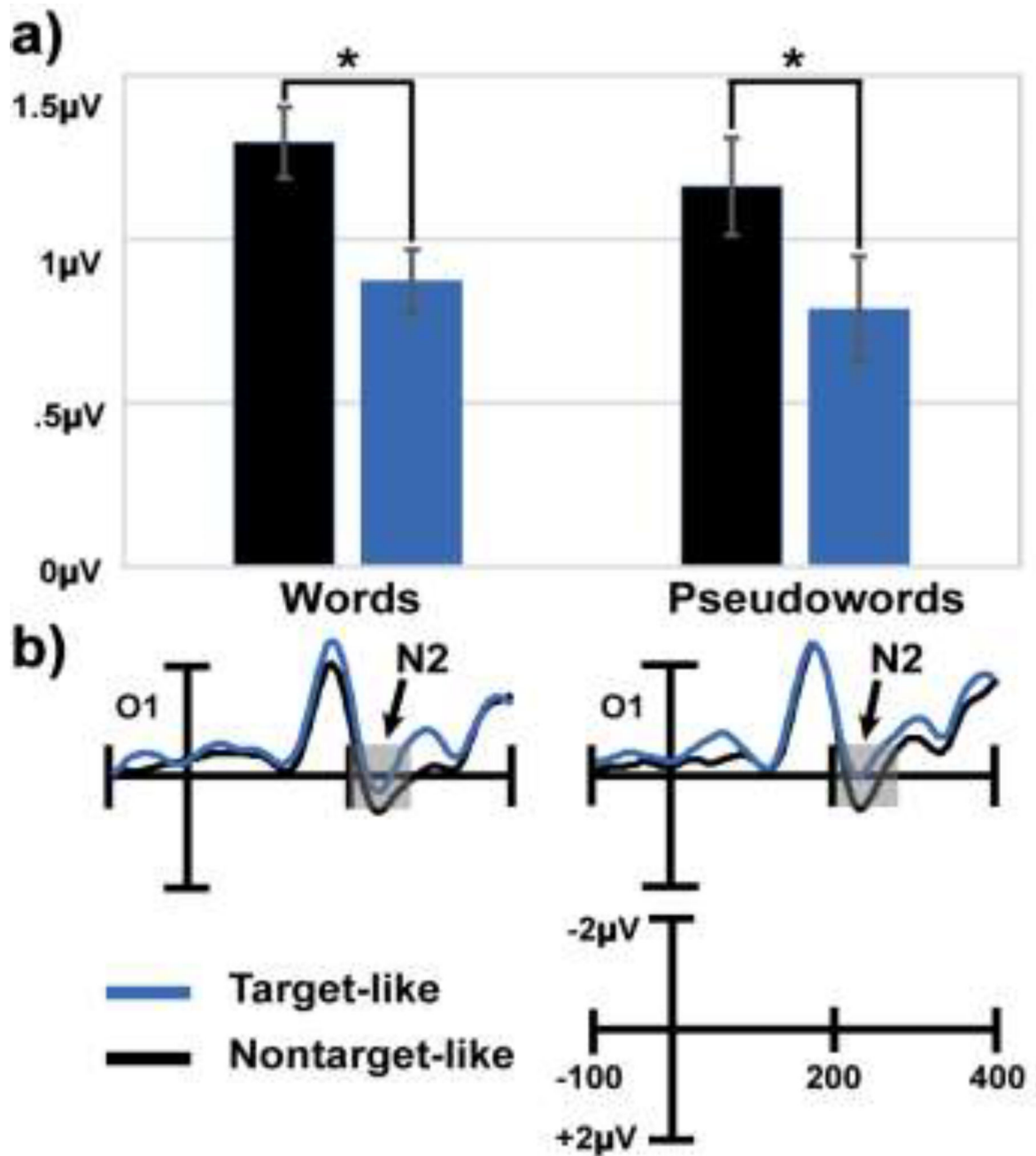


Figure 3. A) Mean amplitudes in the 200–275ms time window on posterior electrodes (P3/4, T5/6, O1/2) for target-like (blue) and nontarget-like (black) stimuli. B) ERP grand average waveforms representing orthographic bias effects for words and pseudowords on electrode O1. 200–275ms time window is highlighted in gray. Error bars represent within-subject standard error of the mean (Morey, 2008).

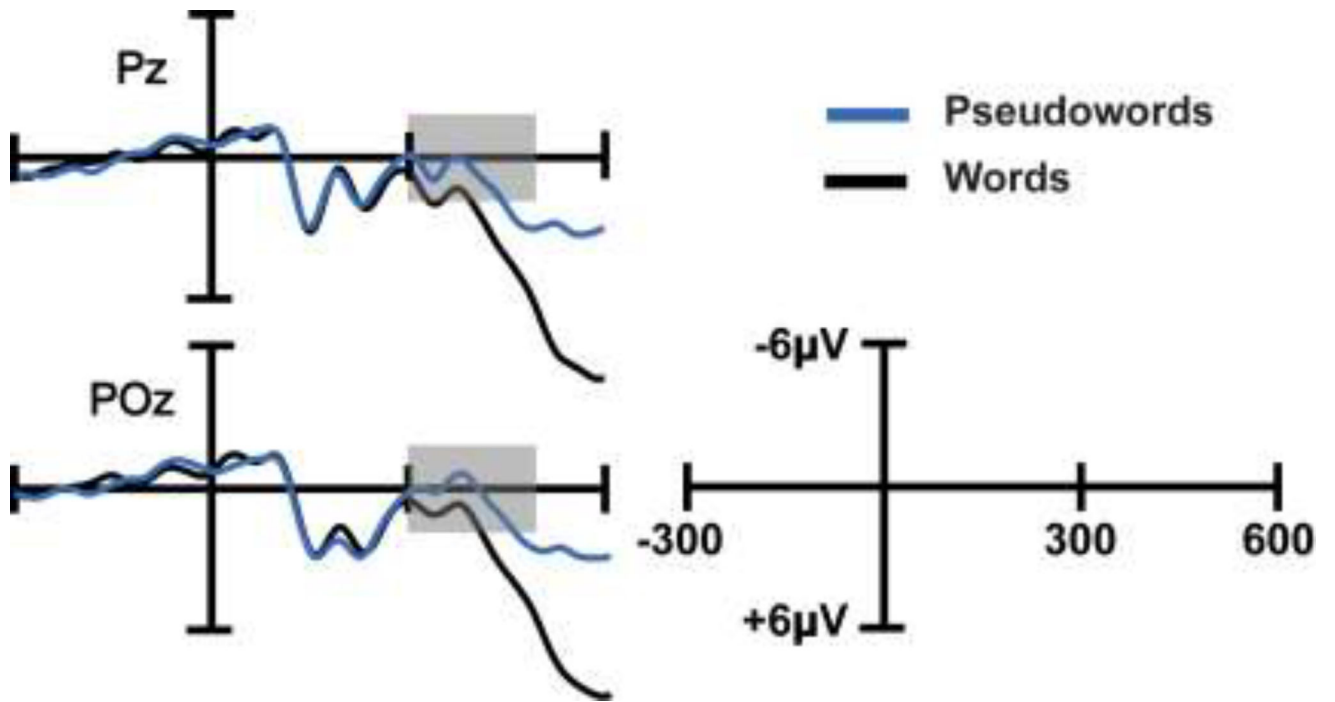


Figure 4. ERP grand average waveforms representing lexicality effect for target words (black) and target-like pseudowords (blue) on electrodes Pz and POz. The 300–500ms time window is highlighted in gray.

Table 1

Language proficiency scores and standard deviations.

	Spanish		English	
	M (SD)	Range	M (SD)	Range
Age of acquisition	Native	-	4.9 (2.8)	0–11
Mode of acquisition	Home	-	School	-
Use (%)	38.5 (14.5)	10–60	61.5 (14.5)	40–90
Reading (1–7)	5.6 (1.0)	4–7	6.4 (.7)	4–7
Writing (1–7)	5.1 (1.1)	4–7	6.3 (.9)	4–7
Speaking (1–7)	5.9 (.9)	4–7	6.5 (.7)	5–7
Listening (1–7)	6.6 (.7)	5–7	6.7 (.5)	5–7
Boston Naming Test (1–60)	28.8 (7.8)	17–44	43.7 (6.0)	29–52
LexTALE-Esp/LexTALE (% correct _{av})	63.5 (10.6)	45–88	85.7 (8.3)	65–99
Extended Lexical Decision (d')	1.00 (.54)	.09–2.34	2.62 (.79)	1.56–4.91

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Table 2

Stimulus Characteristics

	Words		Pseudowords	
	English (SD)	Spanish (SD)	English (SD)	Spanish (SD)
Length	6.64 (.97)	6.64 (.97)	6.70 (.93)	6.70 (.93)
Syllables	2.31 (.48)	2.35 (.51)	2.32 (.55)	2.36 (.53)
Coltheart's N	2.64 (2.5)	2.72 (2.5)	0 (0)	0 (0)
Orthographic Bias	0.21 (.16)	0.21 (.16)	0.47 (.15)	0.47 (.15)
Concreteness	3.30 (1.0)	3.27 (1.0)		
Frequency	0.92 (.42)	0.92 (.42)		

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Table 3

Time Course of Orthographic Bias and Lexicality Effects

Latency window (ms)	Orthographic Bias		Lexicality	
	<i>t</i> (31)	<i>p</i>	<i>t</i> (31)	<i>p</i>
0–100	1.72	ns	<1	ns
50–150	1.41	ns	<1	ns
100–200	1.57	ns	<1	ns
150–250	2.29	0.029	<1	ns
200–300	2.79	0.009	<1	ns
250–350	1.99	0.056	1.57	ns
300–400	<1	ns	2.70	0.011

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