

Highlights

- Parafoveal words are semantically accessed and integrated during reading.
- The meaning of words is activated and shared across languages in bilingual readers.
- Novel cross-linguistic semantic preview benefit effects in alphabetic languages.
- The co-registration technique may assist in the study of parafoveal processing.

Cross-linguistic semantic preview benefit in Basque-Spanish bilingual readers: Evidence from Fixation- Related Potentials

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Abstract:

During reading, we can process and integrate information from words allocated in the parafoveal region. However, whether we extract and process the meaning of parafoveal words is still under debate. Here, we obtained Fixation-Related Potentials in a Basque-Spanish bilingual sample during a Spanish reading task. By using the boundary paradigm, we presented different parafoveal previews that could be either Basque non-cognate translations or unrelated Basque words. We prove for the first time cross-linguistic semantic preview benefit effects in alphabetic languages, providing novel evidence of modulations in the N400 component. Our findings suggest that the meaning of parafoveal words is processed and integrated during reading and that such meaning is activated and shared across languages in bilingual readers.

Keywords: Parafovea – FRPs – N400 –Semantics – Cross-linguistic - Bilingualism - Reading

Introduction

Reading is a cognitive activity that we carry out in our everyday lives. However, far from being a simple activity, it involves several perceptive and cognitive processes. It is widely accepted that we process many words at a high speed during reading, including words located at the foveal region and in the parafovea, which is located between 2° and 5° away from the fixation point. Parafoveal processing may modulate reading in two different ways. First, parafoveal words may affect the processing of the currently fixated word (n), i.e. a parafoveal-on-foveal effect. Additionally, the processing of incoming words (n+1) can also be facilitated. Since such words would have been previously processed partially at a parafoveal level, these words would be easier to process by the time they are fixated. Such processing facilitation is known as the preview benefit effect.

For the most part, reading research has focused on disentangling the mechanisms undergoing foveal word processing. However, it is not yet agreed what kind of information we are able to extract from the parafoveal region and how we process parafoveal words. There is an agreement from eye movement research that parafoveal words are accessed and processed at an orthographic and phonological level, with mixed results regarding semantic processing (for a review, see Schotter, Angele, and Rayner, 2012). Eye movement investigations of parafoveal processing has classically used the boundary paradigm (Rayner, 1975). This paradigm consists of setting an invisible boundary between the end of a given word (n) and the preview of the next word (n+1). When eyes cross the boundary during reading, a target word replaces the previewed one, thereby fixating a different word than the one previously previewed. Consequently, the preview word is only perceived at the parafoveal level. The manipulation of the semantic relationship between the word presented in the parafovea and the word fixated would shed light into whether we are able to extract the meaning of parafoveal words during reading. While there is some evidence from eye movements and the boundary paradigm supporting semantic preview effects (Hohenstein, Laubrock, and Kliegl, 2010; Schotter, 2013; Schotter, Lee, Reiderman, and Rayner, 2015), several authors failed to find similar outcomes (Altarriba, Kambe, Pollatsek, and Rayner, 2001; Hyönä and Häikiö, 2005; Rayner, Balota, and Pollatsek, 1986; Rayner, Schotter, and Drieghe, 2014).

Having said that, strong evidence of semantic parafoveal processing has been provided by electrophysiological studies during the last decade. For instance, studies recording Event-Related Potentials (ERP) found robust evidence of semantic parafoveal processing (Barber, Ben-Zvi, Bentin, and Kutas, 2011; Barber, Doñamayor, Kutas, and Münte, 2010; Barber, van der Meij, and Kutas, 2013; Li, Niefind, Wang, Sommer, and Dimigen, 2015; López-Pérez, Dampuré, Hernández-Cabrera, and Barber, 2016). Nonetheless, a lack of semantic effects has also been reported (Dimigen, Kliegl, and Sommer, 2012; Simola, Holmqvist, and Lindgren, 2009). Interestingly, additional evidence comes from studies that co-registered Electroencephalography (EEG) and Eye Movements (EM) to study semantic parafoveal processing (Dimigen, Sommer, Hohnfeld, Jacobs, and Kliegl, 2011; Dimigen et al., 2012; Kretzschmar, Bornkessel-Schlesewsky, and Schlewsky, 2009; Kretzschmar, Schlewsky, and Staub, 2015). In a co-registration study with the conjoined use of EEG and the boundary technique, López-Pérez et al. (2016) manipulated the semantic relatedness of word pairs presented in the fovea and in the parafovea. When participants looked at the target word (n+1), they had to indicate if it was related to the pretarget word (n) previously fixated. The parafoveally-processed word (n+1) could be either identical or unrelated to the previously fixated word. By obtaining Fixation Related Potentials (FRPs), they found semantic parafoveal-on-foveal and preview

benefit effects reflected in modulations of the N400 component that has been linked with semantic processing (see Kutas and Federmeier, 2011). Despite such findings of semantic preview effects, having conditions where the preview and target are identical could potentially reflect shared orthographic and phonological representations rather than semantic relatedness per se. Additionally, the orthographic dissimilarity between unrelated previews and target words could have imposed preview costs in that target words preceded by a different previewed word would be more difficult to read. This may have potentially led to an overestimation of semantic preview benefits (see Hutzler, Schuster, Marx, and Hawelka, 2019).

A possible approach to overcome such limitations is to use translated words from a second language, since translations hold one of the strongest semantic relationships between two words (Altarriba, 1992). Multiple studies have shown that bilinguals co-activate both of their languages during reading (e.g., Bobb, Von Holzen, Mayor, Mani, and Carreiras, 2020; Dimitropoulou, Duñabeitia, and Carreiras, 2011; Macizo, Bajo, and Martín, 2010; Martín, Macizo, and Bajo, 2010; Perea, Duñabeitia and Carreiras, 2008). Interactive activation models, such as the BIA (Dijkstra and Van Heuven, 1998; Grainger and Dijkstra, 1992; Van Heuven, Dijkstra, and Grainger, 1998) and BIA+ (Dijkstra and Van Heuven, 2002) models, endorse a non-selective access to a lexicon that is integrated across languages. According to this account, co-activation of semantic representations across languages during reading would be expected even for non-cognate translations (e.g., Duñabeitia, Perea, and Carreiras, 2009; Duyck and Warlop, 2009). Non-cognate translations, contrary to cognates, do not have any similar orthography or phonology, therefore sharing only the common semantic representation. These words would prove particularly useful in the study of semantic preview benefit effects, since non-cognate translations and unrelated words from a second language would impose non-semantic preview costs to an equal degree

In fact, some studies have used non-cognate translations to explore whether we can access semantic parafoveal information across-languages. Some of them found evidence of cross-linguistic semantic preview effects in Korean-Chinese bilinguals by monitoring eye movements during sentence reading and using the boundary paradigm to manipulate parafoveal previews (Wang, Yeon, Zhou, Shu, and Yan, 2016). However, such evidence is inconsistent in alphabetic languages. For instance, Altarriba et al. (2001) tested the same question in Spanish-English bilinguals. They monitored their eye movements during sentence reading in one experiment and they registered the naming latency of a target word in a second experiment. In both experiments, they used the boundary paradigm to manipulate the parafoveal preview word, which was an identical word, cognate translation, non-cognate translation or unrelated word. Even though they found evidence of orthographic parafoveal processing across languages, they did not find pure semantic effects. Snell, Declerck and Grainger (2018) also failed to find parafoveal-on-foveal effects during sentence reading in a French-English bilingual sample. However, in a follow up experiment, participants had to categorize an English word in the fovea that was flanked by French words that were either non-cognate translations or unrelated words. In this task, they found that participants were faster when the English word was flanked by French translations, reflecting semantic parafoveal processing. The mixed evidence regarding cross-linguistic semantic parafoveal processing effects could be owed to the use of different paradigms, manipulations and, more importantly, the use of less sensitive techniques to explore semantic parafoveal processing. In this study we obtained FRPs during the boundary paradigm to explore whether readers are able to process cross-linguistic semantic

information in the parafovea. Considering that non-cognate translations only share the same meaning but not orthographic or phonological features, using these words will allow us to isolate semantic parafoveal processing from other levels of representation. Additionally, EEG measures may uncover new insights on this question, which has not been resolved in the eye movement literature.

To this end, we recruited a sample of Basque-Spanish bilinguals who were proficient in both languages. Participants were instructed to read Spanish word pairs and indicate if such words were semantically related or unrelated. On each trial, participants looked at a fixation cross in the left area of a screen before word pairs were presented in the center and the right of the display. Participants moved their eyes to fixate the pretarget word at the center of the screen (n) and then moved their eyes to the word on the right ($n+1$). When their eyes crossed an invisible boundary located after the pretarget word (n), the preview of the subsequent word ($n+1$) was replaced by the target word. The preview was always in Basque, and it could be either a direct non-cognate translation of the Spanish target word or an unrelated word. Additionally, Basque previews could be related or unrelated to the pretarget word, which allowed us to explore cross-language semantic parafoveal-on-foveal effects.

If cross-language semantic information in the parafovea affects processing early, then we would expect to find N400 effects in FRPs time-locked to the pretarget word (n) as found by Lopez-Perez et al. (2016) in monolinguals. If cross-language semantic information in the parafovea affects target processing, we would expect to find modulations on the N400 component in FRPs time-locked to the fixation on the target ($n+1$) word. If we find semantic parafoveal-on-foveal and/or preview benefit effects in a cross-linguistic context, we would provide evidence that bilinguals are able to extract and integrate the meaning of parafoveal words across alphabetic languages.

2.Methods

2.1.Participants

32 Basque-Spanish bilinguals (21 females, 11 males; age: $M= 27.34$, $SD=4.1$) participated in the study. They were recruited from a pool of proficient bilingual participants from the Basque Center on Cognition, Brain and Language (BCBL) database. They all lived in the Basque Country, a region where Basque and Spanish are co-official languages (Age of Spanish acquisition: $M=1.3$, $SD=2.3$; Age of Basque acquisition: $M= 0.5$, $SD=1.2$). They completed the BEST picture naming task, with a mean score in Spanish of 64.5 , $SD=0.9$; and a mean score in Basque of 62.5 , $SD=2.3$ (de Bruin, Carreiras and Duñabeitia, 2017). The participants were right-handed, had no history of neurological disorders and were rewarded economically for their participation.

2.2.Materials

360 semantically related or unrelated word pairs were extracted from the Rules of Free Association in Spanish of the University of Salamanca (www.usal.es/gimc/nalc). One of these pairs served as the pretarget (n) word and the other as the target (n+1) word. The Spanish target could be, therefore, related or unrelated to the Spanish pretarget word. Using the boundary paradigm, the target word could be preceded by a non-cognate Basque translation preview or by an unrelated Basque preview.

In order to ensure that Basque preview words did not have orthographic overlap with the Spanish target words, each preview-target pair had a Levenshtein distance value inferior to 0.45 ($M=0.12$, $SD=0.12$). Since Basque words could have different lengths than Spanish words, length difference between preview and target words was also calculated. Length and lexical frequency of pretarget, preview and target words in each condition can be seen in Table 1, as well as Levenshtein distance and length difference between preview and target words. There were no differences between conditions in linguistic properties (all $p's > 0.05$). Lexical frequency was defined by a logarithm in base 10 of number of corpus events + 1 ($\text{Log}_{10} \text{freq}$). Properties of Spanish words were obtained through the EsPal database (Duchon, Perea, Sebastián-Gallés, Martí, and Carreiras, 2013) while properties of Basque words were obtained via E-Hitz software (Perea et al., 2006). All items were randomized and no participant saw any pair more than once.

<Table 1>

2.3. Task

The task was similar to the one used by Lopez-Perez et al. (2016) with slight modifications (see Fig. 1). Participants read the word pairs at 60 cm of distance from the computer screen, with a resolution of 1024x768 pixels and a 120 Hz refresh rate. In each trial, a fixation cross appeared in the left part of the screen. After fixating it for 800 ms, the cross was replaced by a character mask (e.g. #####) while simultaneously the Spanish pretarget word was presented at the center of the screen and the Basque preview word on the right. The distance between each word was 2 visual degrees. Participants moved their eyes to fixate the pretarget word (n) and then executed a saccade to the subsequent word (n+1), during which the Basque preview word was replaced by the Spanish target word. After 400 ms, the target word was replaced with a question mark, and participants had to indicate if the target word was semantically related to the pretarget word by pressing a button. The question mark appeared at a fixed time in all conditions, in order to avoid possible misinterpretation of the results. Pretargets and previews were presented in lowercase letters, and targets were presented in uppercase letters. After the experiment, participants were asked if they had noticed any word change and to report any previewed word. The task was programmed with Experiment Builder software (SR Research Ltd., Canada) and words were presented in Courier New format, font size 17. Distances between words in pixels was estimated with the visual angle calculator of SR Research (<https://www.sr-research.com/visual-angle-calculator/>) The duration of the task was no more than 45 minutes, and the whole session, including cap set-up, lasted less than 90 minutes.

<Figure 1>

2.4 EEG and eye movement co-registration

EEG were recorded continuously from 27 Ag/AgCl electrodes mounted in an elastic cap. Four additional electrodes were placed above and below the right eye and at the outer canthus of each eye to monitor eye movements and blinks. All electrodes were referenced to the left mastoid and later re-referenced to the mean of the activity recorded from the two mastoids. The signal was amplified with a bandwidth of 0.01-100 Hz and a sampling rate of 500 Hz. Impedances were kept under 5 k Ω .

Eye movements were recorded with the EyeLink 1000 eye-tracking system (SR Research Ltd., Ontario, Canada). The system had a sampling rate of 1000 Hz and a spatial resolution of 0.01. Calibration was performed on a standard nine-point grid. Eye movements were synchronized with the EEG signal by sending TTL pulses from the eye tracker to the EEG recorder for fixations detected in the regions of interest.

2.5. Processing

After collecting the EEG data, the signal was filtered with a band-pass 0.1-30 Hz filter and re-referenced to both mastoids. After that, an Independent Component Analysis was performed considering the data from the ocular electrodes in order to detect which components were linked with eye movements. The EEG data were segmented in two epochs of interest: -200 to 1000 ms time-locked to the fixation of the pretarget and target words. A baseline correction for both FRPs was performed using the 200 ms previous to fixation onset on the pretarget word. This choice was made to avoid any possible bias in the FRPs time-locked to the target word, since the processing of the target word may be modulated by the parafoveal information extracted during the fixation of the pretarget word. Artefacts were flagged automatically, visually inspected and removed manually to avoid any possible artefact not detected by the automatic artefact rejection process.

Eye movements were processed and visually inspected through EyeLink DataViewer. We extracted first-pass fixations related to the interest area of the pretarget word. However, since the target was replaced by a question mark after 400 ms, we did not consider first-pass fixations in this region. We excluded any fixation immediately before or after blinks and any fixation less than 50 ms or greater than 800 ms.

2.6. Analysis

To assess the parafoveal-on-foveal effect on FRPs time-locked to the pretarget word (n), we considered the relatedness of the Basque preview word in a one factor ANOVA (Preview-pretarget *relatedness*: Related vs Unrelated). Target relatedness to the pretarget word was not considered in this analysis because target words were not presented during the fixation of the pretarget word (n). To analyse preview effects upon fixation of the target word, a 2x2 ANOVA (*Target relatedness*: Related vs Unrelated X *Preview translation*: Translation vs Unrelated) was conducted (see Table 2 for

a summary of the design). To select the time window for the FRPs analyses, a point-by-point *t*-test analysis using the Guthrie-Buchwald approach was performed from 0 to 700 ms. We then performed the ANOVA analyses on a 200 ms time window starting from the first of 12 consecutive points with a significant *t*-test (Guthrie and Buchwald, 1991). We expected to find effects around the N400 temporal window for FRPs time-locked to both the pretarget and target words.

<Table 2>

In order to estimate the topographic distribution of effects, electrodes were assigned to different clusters, creating three additional factors (see Barber et al., 2013). As in the study of Barber et al. (2013), the topographic factors were Anteriority (frontal, frontocentral, central, centroparietal, parietal), Laterality (medial, lateral) and Hemisphere (left, right), for the analysis. All analyses were performed with R software ([http:// www.rproject.org](http://www.rproject.org)), by using the ULLRToolbox ([https:// sites.google.com/site/ullrtoolbox/home](https://sites.google.com/site/ullrtoolbox/home)). On violation of sphericity, *p* values were corrected with Greenhouse Geisser.

3.Results

3.1.Pretarget (n) word and parafoveal-on-foveal effects

Looking at behavioural responses to semantic relatedness judgments, participants answered 93% of trials correctly. A 2x2 ANOVA showed that error rates were similarly distributed across conditions (*Target relatedness*, $F(1,31)=1.82$, $p>0.05$; *Preview translation*, $F(1,31)=1.85$, $p>0.05$; *Target relatedness:Preview translation*, $F(1,31)=0.9$, $p>0.05$). As previously indicated, response times were not considered for analysis, since participants could not answer until the question mark appeared 400 ms after target fixation. In post-experiment debriefing, most participants detected a physical word change, but only 21% of them were able to report the identity of any previewed words. First-pass fixation durations on the mask located in the left of the screen did not show differences between conditions ($p>0.05$, $M=228.5$ ms, $SD=24.9$). Looking at the first-pass fixation durations on the pretarget word, the ANOVA showed no significant effects of the Basque preview relatedness $F(1,31)=0.6$, $p>0.05$.

In the FRPs time-locked to the fixation onset on the pretarget word (Figure 2), the point-by-point *t*-test analysis performed from 0 to 700 ms showed an insufficient amount of consecutive significant points, revealing no significant main effects or interaction. Therefore, no ANOVA was performed in any time-window to estimate the effects of Basque preview and target relatedness, since a much more anticonservative analysis, the consecutive paired *t*-test comparison, already failed to provide evidence to reject the Null hypothesis.

3.2.Target (n+1) word and preview effects

We performed a point-by-point t-test analysis for all conditions using the Guthrie-Buchwald approach (Guthrie and Buchwald, 1991). The analysis showed that effects started around 350 ms. Since we decided to choose a 200 ms long temporal window starting from the beginning of the effects, the time window chosen to perform the ANOVA was 350-550 ms, which allowed us to explore if our manipulation modulated the N400 component.

The FRPs to the fixation onset on the target (n+1) word and the modulation of the N400 component by the experimental conditions can be seen in Fig. 2. The ANOVA showed a main effect of the *preview translation* factor $F(1,31)=5.52$, $p<0.05$, $\eta^2 = 0.15$ and a main effect of *target relatedness*, $F(1,31)=32.68$, $p<0.001$, $\eta^2 = 0.51$ on the 350-550 temporal window with no effect of the interaction, $F(1,31)=0.24$, $p>0.05$.

<Figure 2>

Looking at the topographic factors, there was an interaction between *target relatedness* and *anteriority* $F(1,31)=4.36$, $p=0.01$, $\eta^2 = 0.42$ and between *target relatedness* and *laterality* $F(1,31)=24.32$, $p<0.001$, $\eta^2 = 0.43$. Additionally, there was an interaction between the *preview translation* factor and *laterality* $F(1,31)=5.66$, $p<0.05$, $\eta^2 = 0.15$. Post-hoc comparisons showed that *target relatedness* effects were present at all levels of the *anteriority* and *laterality* factors. On the other hand, the effects of *preview translation* were mainly present on medial electrodes, $t(31)=2.52$, $p=0.03$, which agrees with the topographical distribution of semantic effects during word recognition (Rugg, 1985). Topographic maps of the two main factors are displayed in Fig. 3 to better understand the distribution of the effects.

<Figure 3>

4. Discussion

In this study, we aimed to test if semantic parafoveal information can be accessed and processed cross-linguistically during reading. By obtaining FRPs using the boundary paradigm, we explored semantic parafoveal-on-foveal and preview benefit effects related to Basque previews while reading Spanish words. We expected to find modulations in the N400 component, reflecting semantic parafoveal-on-foveal effects during the fixation of the pretarget word. Additionally, we also expected a modulation in this component during the fixation of the target word, reflecting semantic preview benefit effects unrelated to any potential non-semantic preview costs. Target relatedness to the pretarget word was also manipulated and included in the analyses in order to ensure that the task was working properly (i.e., to indicate whether target and pretarget words were related or not) and would produce the typical N400 modulations found with strong semantic relatedness manipulations like this.

In line with one of our hypotheses, we found evidence of semantic preview benefit effects, reflected in modulations in the N400 component in the FRPs time-locked to the target (n+1) word. More specifically, readers showed a greater negativity in this temporal window when the Basque previewed word was unrelated to the Spanish target word currently fixated compared to when the previewed word was a Basque non-cognate translation. This result replicates and extends previous findings of López-Pérez et al. (2016), who reported semantic preview benefit effects using a similar paradigm where the previous word could be either identical or semantically unrelated to the target word. As indicated in the introduction, the use of an identical word to test a preview benefit effect has strong limitations, since identical words share the same orthographic and phonological representations in addition to a common meaning. Additionally, the orthographic dissimilarity for unrelated words could have imposed preview costs, leading to an overestimation of preview benefit effects in the prior study (see Hutzler et al., 2019). In fact, Dimigen et al. (2012), who found preview effects when the parafoveal word was identical, failed to find such facilitation when the previewed word was semantically related to the target. Our manipulation, however, shows a facilitation of non-cognate Basque translations of Spanish target words when compared to Basque unrelated words, which reflects a direct effect of the meaning of the previewed word on target word facilitation without any potential effects of other form similarities like orthography or phonology. This contrast with the findings of Dimigen et al. (2012) can be explained by the fact that their semantically related pairs were either synonyms, antonyms, associatively related or conceptually related words. The use of non-cognate translations that share the same meaning might facilitate semantic effects since the two words represent the same meaning, not just an associated meaning.

Contrary to our expectations, the N400 component was not modulated by the parafoveal word for the FRPs time-locked to the pretarget (n) word. Thus, we did not find any evidence of semantic parafoveal-on-foveal effects. This differs from previous N400 findings reflecting parafoveal-on-foveal effects in co-registration studies (Kretzschmar et al., 2009; López-Pérez et al., 2016), while it matches similar FRP research that did not find such effects (Dimigen et al., 2012). One possible explanation for this contradictory evidence is the use of different experimental paradigms. For instance, in our experiment, as in Dimigen et al. (2012), we use a task closer to natural reading scenarios, since the reader needs to execute a saccade before fixating the pretarget (n) word. However, in the experiment of López-Pérez et al. (2016), participants were already looking at the center of the screen when the pretarget word was presented in this exact location, involving different mechanisms related to eye movements. In fact, Snell, Meeter and Grainger (2017) suggested that parafoveal-on-foveal effects could be limited to shared sub-lexical information via the spatial integration of orthographic features during sentence reading. On the other hand, they also proposed that higher-order parafoveal-on-foveal effects could be present only in single-word reading paradigms since a mechanism for mapping syntactic categories onto word positions would not be required in these tasks. Even though Kretzschmar et al. (2009) found semantic effects during natural reading situations, they did not use any boundary to change the previewed word, which may have altered the observed processing in the FRP signal. More importantly, it is possible that our between-language manipulation is less sensitive to semantic effects than within-language ones, which would also account for these discrepancies. It could be the case that in this experimental situation, the level of activation of the language that is not in use is not enough to trigger this type of effect. Additional evidence coming from designs involving switching within and between languages in both directions would shed light on this question. These findings also contribute to questions about the activation of both languages during bilingual processing. Considering that a large body of evidence already supports the co-activation of languages during reading, the interest

is at which level and in which specific circumstances this takes place. Our findings suggest that the semantic representations of words are linked cross-linguistically during reading, which supports models that favour a bilingual mental lexicon integrated across languages, such as the BIA (Dijkstra and Van Heuven, 1998; Grainger and Dijkstra, 1992; Van Heuven et al., 1998) and BIA+(Dijkstra and Van Heuven, 2002) models. Our bilingual sample was proficient in both languages, so they had symmetrical semantic representations greatly connected between languages, allowing the activation of Basque translations in a task where only Spanish was needed (Bobb et al., 2020). In fact, Perea et al. (2008) showed similar masked priming effects for associative related pairs of words between and within languages in a similar sample of balanced Basque Spanish bilinguals. It remains to be seen whether cross-linguistic semantic activation requires high proficiency in both languages.

More interestingly, we found evidence for the first time of cross-linguistic semantic preview effects in alphabetic languages in the electrophysiological record. Even though there is similar evidence coming from logographic languages, such as Korean-Chinese bilinguals (Wang et al., 2016), such findings were not replicated previously in alphabetic languages. It has been argued that the smaller size of characters in logographic languages, and therefore their proximity to the fovea, may lead to a faster semantic activation compared to what happens in alphabetic languages (Schotter et al., 2012; Yang, Wang, Xu, and Rayner. 2009). On the other hand, the contradictory results in alphabetic languages may be owed to the measure of choice. Here, we decided to obtain Fixation-Related Potentials, since electrophysiological measures may tap into effects that do not emerge in the eye movement record. Another point to consider is that our task asked participants specifically about the relatedness of the read words, therefore maximizing semantic integration effects. However, participants' goal alone may not fully explain the success in finding cross-linguistic semantic parafoveal effects, since several within-language studies have succeeded in finding semantic parafoveal effects in a wide variety of task paradigms by looking at modulations in the N400 component (e.g. Barber et al., 2010; Barber et al., 2013; Kretzschmar et al., 2009).

Finally, in the few studies of parafoveal processing of cross-language semantic information, a pattern does appear to emerge. The studies that have recorded eye movements during natural sentence comprehension have *not* found evidence of cross-language semantic preview effects (Altarriba et al., 2001; Snell et al., 2018 Experiment 1). On the other hand, the studies that have used a task with word pair or triplet reading *have* found evidence of these effects (the current study; Snell et al., 2018). Considering this, it is possible that preview effects would act differently during full sentence comprehension. Future bilingual research may rely on the co-registration technique and the boundary paradigm to explore in which circumstances we can access the meaning of parafoveal words cross-linguistically, including extending these studies to sentence comprehension.

In summary, we found evidence for the first time of semantic preview benefit effects across alphabetic languages in the electrophysiological record by combining fixation-related potentials with the boundary change paradigm. These results suggest that the meaning of parafoveal words is accessed and integrated during reading and that the meaning is activated and shared across languages in bilingual readers.

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TABLE CAPTIONS

Table 1: Lexical frequency, length and Levenshtein distance of the pretarget, preview and target words for all of the experimental conditions. Length differences and Levenshtein distances between previews and targets are also included.

Table 2: Experimental design to explore preview benefit effects. The target was either semantically related or unrelated to the pretarget word. The Basque preview word was either a translation of the target word or a completely unrelated word.

FIGURE CAPTIONS

Figure 1: Presentation procedure. Participants had to fixate the cross in the left of the screen for 800 ms before the word pairs appeared. Participants could then make a saccade to the word in the center of the screen and then to the word on the right of the screen. When the eyes crossed the invisible boundary, the preview word was replaced by the target word. After 400 ms, a question mark appeared indicating that participants could respond.

Figure 2: Grand average FRPs at the Fz, Cz and Pz electrodes for the fixation onset on the pretarget word (left) and on the target word (right). For FRPs time-locked to the pretarget word, only the Basque preview relatedness to the pretarget word was considered: (a) Preview-pretarget: related, (b) Preview-pretarget: unrelated. For FRPs time-locked to the target word, the preview translation and target relatedness factors were considered (see also Table 2): (a) Translation preview – related target, (b) Translation preview – unrelated target, (c) Unrelated preview – related target, (d) Unrelated preview – unrelated target.

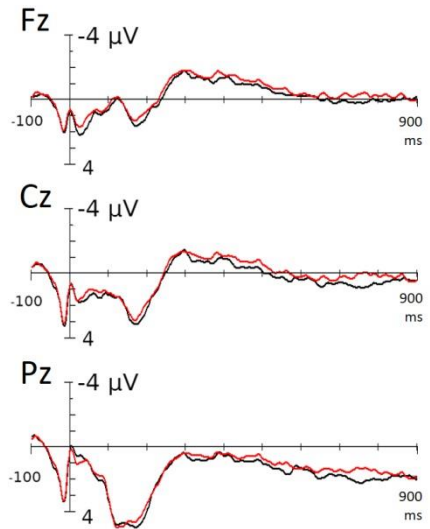
Figure 3: FRPs of the two main effects from fixation onset of the target word: (a) Related and unrelated targets, (b) Translation and unrelated previews. The topographic maps on the right display the mean differences and effect sizes in the N400 temporal window (350-550 ms).

Table 1: Lexical frequency, length and Levenshtein distance of the pretarget, preview and target words for all of the experimental conditions. Length differences and Levenshtein distances between previews and targets are also included.

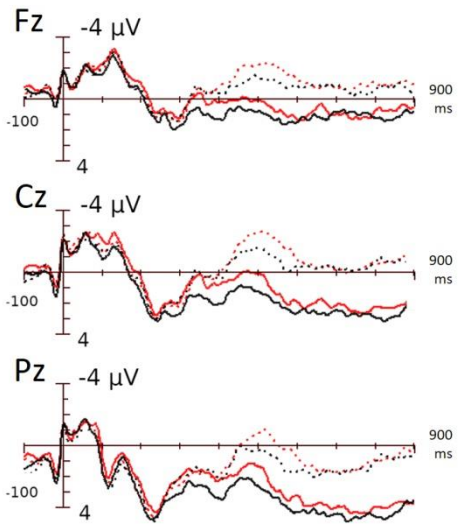
Condition		<i>Log10 freq</i>			<i>Length</i>				<i>Levenshtein Distance</i>
		Pretarget	Preview	Target	Pretarget	Preview	Target	Preview-Target	Preview-Target
Translation Preview – Related Target	M	1.31	1.53	1.5	5.6	5.85	5.63	1.37	1.30
	SD	0.76	0.67	0.63	1.21	1.76	1.39	1.14	1.16
Translation Preview – Unrelated Target	M	1.23	1.62	1.52	5.48	5.7	5.32	1.42	1.04
	SD	0.74	0.69	0.51	0.99	1.81	1.15	1.30	1.03
Unrelated Preview – Related Target	M	1.28	1.57	1.53	5.57	5.75	5.35	1.48	1.08
	SD	0.78	0.65	0.63	1.16	1.81	1.09	1.21	1.24
Unrelated Preview – Unrelated Target	M	1.24	1.49	1.42	5.74	5.98	5.33	1.52	1.17
	SD	0.78	0.65	0.57	1.08	1.92	1.10	1.35	1.21

Table 2: Experimental design to explore preview benefit effects. The target was either semantically related or unrelated to the pretarget word. The Basque preview word was either a translation of the target word or a completely unrelated word.

Pretarget Word (Spanish)	Preview Word (Basque)	Target Word (Spanish)	<i>Target Relatedness</i>	<i>Preview Translation</i>
Silla (chair)	Mahaia (table)	MESA (table)	Related	Translation
Silla (chair)	Katua (cat)	GATO (cat)	Unrelated	Translation
Silla (chair)	Katua (cat)	MESA (table)	Related	Unrelated
Silla (chair)	Mahaia (table)	GATO (cat)	Unrelated	Unrelated



— Preview-Pretarget: Related
 — Preview-Pretarget: Unrelated



— Translation Preview - Related Target
 Translation Preview - Unrelated Target
 — Unrelated Preview - Related Target
 Unrelated Preview - Unrelated Target

