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Attentional distribution and semantic parafoveal processing in natural reading: Co-registration of EEG and eye movements

Tesis doctoral internacional

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Summary

The current thesis aims to increase the current knowledge about how we can access to the meaning of parafoveal words and the role of individual differences in visual attentional distribution of readers over semantic parafoveal processing. The thesis starts by providing a theoretical background of reading and parafoveal perception, focusing on semantic parafoveal processing. The initial theoretical chapters also cover the role of individual differences of readers in reading, focusing mainly on attentional distribution and the perceptual span. An informative section of the co-registration technique of EEG and EM is also provided, to better understand the avantages and limitations of the chosen technique of this thesis. The three aims and hyptheses of the current work are also showed and discussed. As the reader will see, our studies aimed to obtain neurological markers of semantic parafoveal processing in artifitial and, more importantly, ecologically valid scenarios of natural reading. The next step was to explore how these neurological markers are modulated by individual differences in the ability of readers to distribute their attentional resources across the visual field, highlighting the importance of considering such variable when studying semantic parafoveal processing. We show here the three studies with all detailed information, including theoretical introduction, methodology, results and discussion of each sepparated study. We then conclude by interpreting the results obtained in the three studies and highlighting the maing conclusions extracted from the thesis. As it is showed in the final sections, the thesis fulfilled the presented aims. The results obtained here allowed to obtain electrophysiological markers of semantic parafoveal processing in both artifitial and natural reading scenarios, which adds evidence that the meaning of parafoveal words can be accessed and used to modulate reading behaviour. Importantly, the results obtained showed that individual differences in attentional distribution of readers modulate such mentioned semantic parafoveal processing, highlighting the importance of understanding the visual spatial distribution of readers during natural reader in future research involving parafoveal processing.

Index

Part 1. Theoretical background

Chapter 1. Reading and parafoveal perception

1.1 Visual Word Recognition

Language is the ultimate human developed trait. A skill that, despite its complexity, requires little to no effort from infants to learn and develop by themselves. On the other hand, acquiring the basic skills to communicate through written language is a completely different story. In fact, brain systems for different functions had to evolve and reorganize through the evolutionary steps to allow the learning of reading. As commonly known, reading is a relatively recent human activity that appeared around 5 millennia ago and it is not universally present in all human lives. After all, reading is a cultural skill that must be obtained through learning and practice during multiple years. For instance, children that are 5 years old already master the basic linguistic and visual processes that are mandatory to read, by mere exposure and practice (see Carr, 2005).

However, once reading is acquired, it allow us to communicate with each other around the globe, no matter the distance nor the time. The fields of psychology and neuroscience have aimed to decipher the mechanisms behind reading, which has proven to be an extremely complex mental process that implies a whole set of motor, perceptive and cognitive skills. One of the most important (but basic) aspects during reading is the visual word recognition (VWR) process, which refers to our ability to identify a printed letter string and convert it into a word with its own meaning. The majority of the current models consider the VWR process a hierarchical operation that involves multiple layers of orthographic representations. Thus, representations of visual features led to convert letters map into representations that code letter position, as well as abstract letter identity. More interestingly, these activation of orthographic features led to the activation of sub-lexical units representations, which later activates multiple candidates of a unique word representation (see Rastle, 2016). As the readers can already foresee, the VWR process is far from being a simple activity, which starts with the perception of visual features and ends with the recognition and integration of the meaning of the word. Such process occurs multiple times during reading, since we have to decode and process multiple words per sentence, which is why VWR models are a basic first step in understanding all the cognitive computations during reading.

For the sake of clarity, we could not refer to the VWR process without considering how it relies in basic anatomical properties of the brain and eyes. In fact, it is common knowledge that visual information is projected to both cerebral hemispheres, owing to a connection of the receptors located in the center of the fovea to both hemispheres. Interestingly, information precedent from the fovea is split and information from each visual hemi-field is sent to its contralateral hemisphere counterpart. In the reading scenario, this means that right letters of a word would be projected to the left hemisphere, while left letters of a word would be projected to the right hemisphere (see Brysbaert, 1994; see also Leff, 2004). However, how do these projections affect the lexical and semantic access of a word? Some layered models, such as the SERIOL model (see Whitney, 2001, 2004) indicates that after cones have been activated in the retina, visual and sub-orthographic features are already being projected to the contralateral hemisphere, following the split-fovea hypothesis. Then, letters are accessed, and interestingly, letter information located in both right and left hemisphere would be processed in the left hemisphere (i.e. information from the right hemisphere would be sent to the left hemisphere for letter and orthographic processing). The fact that orthographic information would be located in the left region would be explained by the presence of the visual word form are in the left hemisphere, which is located in the left fusiform cortex and it is in charge of initially analyse of orthographic information (see McCandliss, Cohen, & Dehaene, 2003; see also Cohen et al, 2000). After recognition of letters, the processing follows a serial approach, where bigrams are recognized, and then followed by the processing of the representation of the word. This layered model may explain what it may be happening for a word located in the fovea. Having said that, when we fixate a word in the text, our visual field extends away from the foveal region, perceiving more words than just the fixated word.

1.2 Visual parafoveal perception

During reading, we execute multiple fixations across multiple words in the text. The fixated word is located in the foveal region, but our visual field if far larger than that. The foveal region extends to the central 2 degrees of the visual field. One degree away to the right or left to the center of fixation, we lose visual acuity and we enter in what is known as the parafoveal region, which extends up to 5 degrees of visual angle from the center of fixation. More than 5 degrees away from fixation, we enter in the peripheral visual region, with has a much more severely decreased visual acuity. Therefore, the visual field during reading can be distributed across the foveal, parafoveal and peripheral visual regions (see Figure 1). Even though foveal region is essential and allows the access to detailed information, information allocated in the parafovea, even with poorer resolution, becomes absolutely vital in visual search scenarios since it is the responsible to trigger saccades and eye movements to specific and salient locations. Similarly, during reading tasks, parafoveal information is used to indicate where the eyes should jump to, but physical properties of parafoveal stimuli are not the only information used to reach these ocular decisions. In fact, in a sentence or a text, parafoveal words are also processed at different representational levels and identified to some extent, so such information is vital to determine eye movements (see Rayner, 1998, 2009).

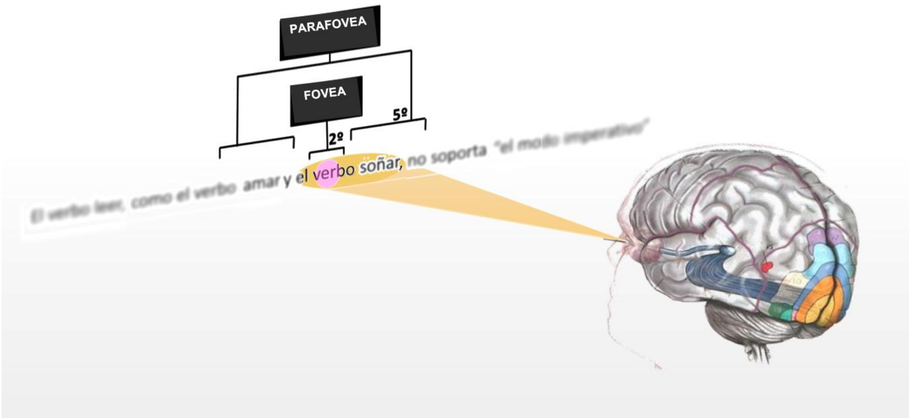

Figure 1. Extracted from Rayner et al. Psychological Science in the Public Interest 2016;17:4-34. *While the cone peak is located in the centre of the foveal region, making words allocated in this region to have the maximum visual acuity, we have an impaired vision of words in the parafoveal and peripheral regions. Note asymmetry of the clarity in the visual field. In Wester languages, the words located in the right parafoveal field are more visible than the words in the left parafoveal field, following Western reading direction.*

From eye movements research, it has been stablished some standard and typical fixation and saccade measurements. For instance, fixations usually last about 200-250 ms while saccades between fixations usually last about 20-50 ms during reading (see Rayner, 1978, 1998, Rayner, Castlelhano, & Yang, 2009). All these measures, as previously indicated, are affected by parafoveal information. Saccades usually progress seven to nine letter spaces (i.e.

usually more than a word) which lead readers to skip words. 30% of words are skipped during reading, which means that only 70% of words are fixated (see Schotter, Angele & Rayner, 2012). This clearly implies that some words are already pre-processed parafoveally, which, in some circumstances, makes readers to decide to skip such a word. Consequently, this means that readers are able to process two or three words in a single fixation. Properties of both foveal and parafoveal words are the ones to decide how long we fixate words and how big our saccades may be. For instance, how long we fixate a word can be affected by variables such as word frequency, word predictability, word length or neighborhood size (see Hyönä, 2011). On the other hand, the decision of skipping or not a word, is affected by the length of the parafoveal word (i.e. longer words are more difficult to skip, see Brysbaert, Drieghe, & Vitu, 2005; Brysbaert & Vitu, 1998; Rayner & McConkie, 1976). Interestingly, the predictability of a parafoveal word also influences our decision to fixate such a word or not (Rayner, Slattery, Drieghe, & Liversedge, 2011), meaning that different levels of processing of the parafoveal word also influences reading behaviour. In the literature, two main effects have been reported when talking about the influence of parafoveal information over reading. First, the parafoveal word may affect the processing of the currently fixated word (i.e. the foveal word may be fixated less time if the parafoveal word is related to the foveal word), which is known as a parafoveal-on-fovea effect. Second, if the parafoveal word is partially pre-processed, it will allow a easier processing of such word when fixated (i.e. the now fixated word would be fixated less time, because it was already previewed and partially preprocessed parafoveally before), which is known as a preview benefit effect. Of course, the next question is: what does evidence of these two parafoveal effects tell us about at what levels of representation we accessed to parafoveal words?

1.3 Orthographic and phonological parafoveal processing

The majority of the research evidence of the different levels of processing of parafoveal words comes from eye movements' literature. One of the most important paradigms, and most notably used, has been the gaze-contingent boundary paradigm (Rayner, 1975b). In the boundary paradigm, an invisible boundary is located before a previewed word. When the reader's gaze crosses the invisible boundary, the previewed word is replaced by a target word as the reader fixates it. Therefore, the previewed word could only have been perceived from the parafovea during the fixation of the previous word (which allow research to explore parafoveal-on-fovea effects), and any difference in reading time of the target word when it is fixated must be due to that parafoveal processing (i.e., a parafoveal preview effect). Mostly, evidence from eye movements have mainly found interactions with preview effects, while parafoveal-on-foveal effects have been less clear (see Hyönä & Bertram, 2004).

Most preview effects evidence agrees that parafoveal words are accessed at an orthographic level (e.g. Balota, Pollatsek, & Rayner, 1985; Briihl & Inhoff, 1995; Drieghe, Rayner, & Pollatsek, 2005; Inhoff, 1987, 1989a, 1989b, 1990; Inhoff & Tousman, 1990; Lima & Inhoff, 1985; Rayner, 1975b; White, Johnson, Liversedge, & Rayner, 2008, see Schotter et al., 2012). For instance, the identification of letters (and not the order of the letters, see Perea & Lupker, 2003; Johnson, Perea, & Rayner, 2007) of previews yield a processing advantage for that word when fixated, which may both enhance orthographic processing and also probably may initiate earlier the lexical access process. Additionally, similarly to foveal processing, the lexical frequency of parafoveal words has a role to play in the extraction of orthographic features. An example of such experiments is the one of Williams, Perea, Pollatsek, & Rayner (2006). With the boundary paradigm, they used an identical preview word (sleet), a word orthographically related preview word (sweet) and a non-word orthographically related preview word (speet) and the preview and target could be high or low frequency in two experiments. When the previews were low frequency and targets were high frequency, orthographic-related words had a similar advantage than orthographic-related non-words. On the other hand, when the preview was high frequency and targets low frequency, orthographic-related words yielded a processing advantage superior to orthographically-related non-words, reaching a similar advantage than identical previews. Schotter et al., (2012) suggested that the frequency of a preview may affect the extraction of letter information of that word without considering its integration with the target, which supports the idea that the extraction of orthographic features plays a role in early stages of the recognition of the word, while the integration between previews and targets are more important in later stages. However, preview effects are usually more related to activating different levels of the word at later stages and integration processes with the target word, at the lexical and phonological level.

In fact, the activation of orthographic information leads to the activation of phonological codes before accessing to its lexical representation and its meaning. Again, evidence showing a phonological preview benefit effect is not scarce (e.g. Ashby & Rayner, 2004; Ashby, Treiman, Kessler, & Rayner, 2006; Chace, Rayner, &Well, 2005; Liu, Inhoff, Ye, & Wu, 2002; Miellet & Sparrow, 2004; Pollatsek, Lesch, Morris, & Rayner, 1992; Rayner, Sereno, Lesch, & Pollatsek, 1995; Sparrow & Miellet, 2002; Tsai, Lee, Tzeng, Hung, & Yen, 2004, see Schotter et al, 2012). Usually, these studies have found a processing advantage from homophones and pseudo-homophone preview words of the target word, that lead to faster reading of target words after a phonological preview facilitation, being these effects even more enhanced when the initial syllabic structure was similar between previews and target (Henderson, Dixon, Petersen, Twilley, & Ferreira, 1995). As mentioned, these parafoveal processing at the phonological level, in combination with the activation of the orthographic level, led to the access of the lexical representation of the parafoveal word. However, the real objective of activating the word lexically is ultimately to access the meaning of the word, i.e. its semantic representation. Even though it is well known that this happens during normal visual word recognition of foveal words, what happens in such a high processing level in the parafoveal region? That is another story and shall be told in the next chapter of this thesis.

Chapter 2. Semantic parafoveal processing

2.1. The meaning of words and eye movements

Whether we can access or not to the meaning of parafoveal words has been, at the very least, a controversial question. Initially, evidence of the activation of semantic information was scarce, provided by behavioral and eye movement data (Hohenstein, Laubrock, & Kliegl, 2010; Yan, Richter, Shu, & Kliegl, 2009), leading to the conclusion that semantic information was not accessed parafoveally (Altarriba, Kambe, Pollatsek, & Rayner, 2001; Hyönä & Häikiö, 2005; Rayner, Balota, & Pollatsek, 1986; White et al., 2008; see Schotter et al., 2012). Some evidence could be found with different languages and manipulations. For instance, some evidence of semantic preview effects comes from German (Hohenstein et al., 2010), Chinese (Pollatsek, Tan, & Rayner, 2000; Yan et al., 2009; Yang, Wang, Xu, & Rayner, 2009) readers and English (Rayner & Schotter, 2014; Schotter, 2013; Schotter, Lee, Reiderman, & Rayner, 2015, see also Andrews & Veldre, 2019; Schotter, 2018). In one study reporting such semantic preview effects, Schotter & Jia (2016) decided to use the boundary paradigm to manipulate the plausibility of the preview word with the sentence context, having identical previews (e.g., "Kevin's brother ate all their *fresh/fresh* bread in the apartment), unrelated previews but plausible to the sentence context (e.g., "Kevin's brother ate all their *baked/fresh* bread in the apartment") and unrelated previews that were also implausible to the sentence context (e.g., "Kevin's brother ate all their *place/fresh* bread in the apartment"). They also decided to use synonyms and antonyms (e.g., "Jane will travel *north/south* on her trip to Los Angeles next week" and "Harry bought a broken *watch/clock* to repair for fun" respectively). All previews that were plausible to the sentence context facilitated the processing of the target word, compared to implausible previews, i.e. a sentence with an implausible preview as "Kevin's brother ate all their *place/fresh* bread in the apartment" would be more difficult to process than the other sentence preview conditions previously mentioned. The authors argued that those findings could mean that the meaning of parafoveal words may be integrated with the sentence context. However, it was not clear why semantic preview effects could not be found when the manipulation involved trans-saccadic integration processes between the preview and target words (as it did happen with orthographic and phonological preview effects).

It has been widely argued that the little evidence of semantic parafoveal processing may be owed to orthographic effects nullifying semantic ones, since words semantically related may be also orthographically different. Another strong possibility was that behavioural eye movements measures are so sensible to orthographic features that they are not a suitable measure to grasp and more high-level process like is the access and integration of the meaning of the parafoveal word. After all, early EM measures are very sensitive to the computations that determine eye movement control and, considering the characteristics and speed of natural reading, eye movement control uses only the minimum amount of information necessary to maximize the efficiency of saccades. However, word recognition is not finished after our gaze leaves a given word, it is a multimodal and cumulative process that extends along time, determined by many contextual and lexical factors (Barber & Kutas, 2007), which continues until meaning is fully processed, continuously updating its mental representation. Following this reasoning, past evidence has used a different measure to tackle the question of whether we can access to the meaning of words or not. We refer to electrophysiological-EEG studies.

2.2. EEG evidence of semantic parafoveal processing

Electrophysiological research has proven particularly useful in delineating semantic parafoveal effects. Such studies have recorded the EEG signal of readers and mostly collected Event-Related Potentials (ERPs). ERPs have an extremely high temporal resolution (Luck, 2014) which have allowed the study the many cognitive processes in reading (Kutas, Van Petten & Kluender, 2006). Initially, owing to methodological limitations related to the sensibility of the technique to eye movements artefacts, past research obtained ERPs in reading by using the Rapid Serial Visual Presentation paradigm (RSVP). In the original version of the RSVP paradigm, sentences were presented word by word in the centre of the screen at a fixed rate, which allowed participants to read sentences without executing any EM, allowing researchers to extract a clean ERP signal. With the purpose of studying parafoveal processing, Barber, Doñamayor, Kutas & Munte (2010) created a modification of the paradigm by adding flankers (i.e. flanker-RSVP paradigm). Similarly, to the original paradigm, words were presented in the center of the screen, but the previous word and next word of the sentence were located to the left or right parafoveal field respectively. With such a paradigm, researchers could manipulate the upcoming parafoveal preview in the right of fixation, similar to a boundary paradigm without eye movements. Barber et al., (2010) used the flanker-RSVP paradigm to manipulate the upcoming parafoveal flanker word presented in the right visual field, which could be congruous or incongruous with the sentence context. Parafoveal words that were incongruent to the sentence context produced larger amplitudes in the N400 component (classically linked with semantic processing, see Kutas & Federmeier, 2011) time-locked to the presentation of the parafoveal word, meaning that the meaning of parafoveal words was beginning to be accessed before they were replaced by a new target word in the foveal region (see also Li, Niefind, Wang, Sommer, & Dimigen, 2015). In another study, Barber, Ben-Zvi, Bentin & Kutas (2011) used a different manipulation with the flanker-RSVP paradigm with Hebrew readers, where flankers in either the right or the left could be pseudo-words, identical words or unrelated words to the foveal word. The ERP they collected showed a greater positivity in the P2 component for identical words, compared to unrelated ones. More interestingly, they found these effects when the manipulation was performed in the left flanker, but not in the right flanker. Therefore, this paradigm proved also useful in supporting the idea that parafoveal processing depends on reading direction. In fact, to confirm such statement, they performed the same experiment with English readers, finding that, in this case, the effects were found when the right flanker was manipulated, confirming the asymmetry of the visual field and that parafoveal processing depends on properties of the language. Furthermore, in another experiment with the flanker-RSVP-ERP paradigm Barber, van der Meij, & Kutas (2013) manipulated the contextual predictability of parafoveal words, which could be congruent or incongruent with the sentence context. In both low and high-constratint sentences, they found more negative amplitudes in the N400 component when incongruent parafoveal words were presented while reading the previous word.

Interestingly, modulations of the N400 component were greater under high contextual constraint, meaning that predictability of words modulated the amount of parafoveal processing. They also showed that parafoveal effects related to the N400 component in low constraint sentences were observed only at a slow stimulus presentation rate (SOA = 450 ms) but not when words were presented faster (SOA = 250 ms) (see Figure 2) with a speed similar to natural reading. Therefore, the N400 modulations related to semantics can interact with other sources of the task related to cognitive load and, importantly, cognitive load may determine the amount of semantic parafoveal processing at any time (see also Payne, Stites, & Federmeier, 2016). Therefore, it was argued that the attentional distribution in these experiments could be probably different from the situations of natural reading, meaning that their ecological validity had to be tested in order to extend EEG-related semantic parafoval findings to reading situations where EM were present.

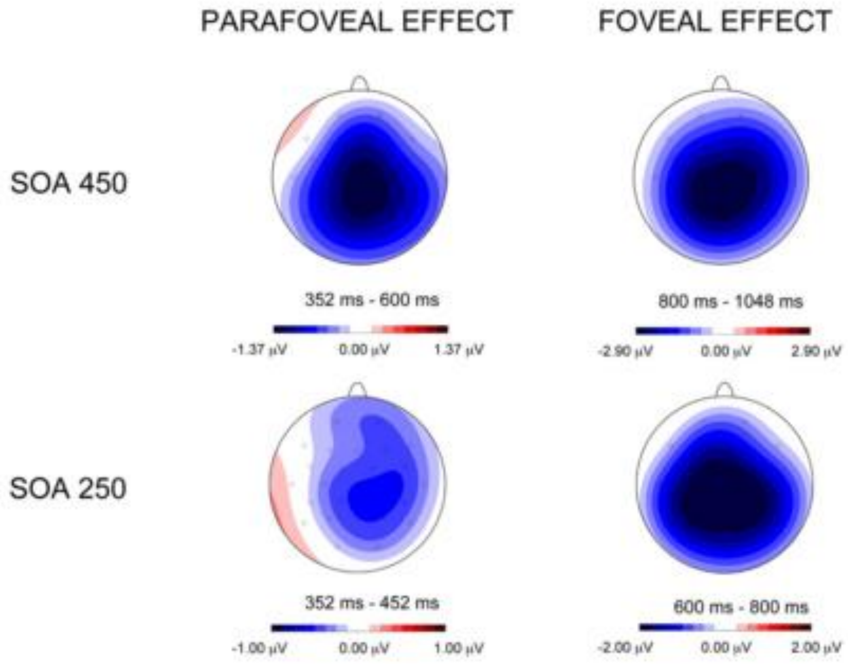

Figure 2. Extracted from Barbet et al. (2013). *Topographical maps of the N400 semantic parafoveal effects (incongruent minus congruent) in the flanker-RSVP-EEG task. Slow presentation rate, measured at a Stimulus-Onset-Asynchrony (SOA) of 450 ms kept semantic parafoveal processing, but such effects disappeared at a SOA value of 250 ms, displaying the importance of cognitive load over semantic parafoveal processing.*

Some recent studies have already used the co-registration of EM and EEG to extract Fixation-Related Potentials (FRPs) time-locked to the fixation onset of words to explore semantic parafoveal processing (see Dimigen, Sommer, Hohlfeld, Jacobs, & Kliegl, 2011; Dimigen Kliegl, & Sommer, 2012; Kretzschmar, Bornkessel-Schlesewsky, & Schlesewsky, 2009; Kretzschmar, Schlesewsky, & Staub, 2015). In one older study, Kretzschmar et al., (2009) reported FRPs evidence parafoveal semantic processing in a natural reading task. They used highly constraining sentence constructions where they compared comparing predicted sentence endings with related and unrelated unpredicted endings in antonym constructions (e.g., “the opposite of black is white/yellow/nice”). They found larger modulations of the N400 component in semantically incongruent endings when compared to congruent predictable words, when FRPs were time-locked to the last fixation before the target fixation, suggesting that some semantic processing of the critical words could take place in the parafovea. Having said that, the strong predictability manipulation used in the mentioned study does not make totally clear in which circumstances this kind of effect can be produced. More importantly, since they did not use the boundary paradigm to change the parafoveal preview, the effects of both the parafoveal word when previewed and the same word when fixated in the fovea were confounded. In order to overcome such limitations, López-Pérez, Dampuré, Hernández-Cabrera, & Barber (2016) used the boundary technique in a co-registration set-up and manipulated the semantic relatedness of word pairs presented in the fovea and in the parafovea. When participants looked at the target word, they had to indicate if it was related to the pretarget word previously fixated. The parafoveally-previewed word could be either identical or unrelated to the previously fixated word. For example, for a pretarget word “sand”, there could be four possible conditions: a- Related preview and related target (beach/beach), b- Related preview and unrelated target (beach/letter), c- Unrelated preview and related target (letter/beach) and d- Unrelated preview and unrelated target (letter/letter). By obtaining Fixation Related Potentials (FRPs), they found semantic parafoveal-on-foveal and preview benefit effects (see Figure 3) reflected in modulations of the N400 component. However, their study is also not free from limitations. Since they had conditions where preview and target were identical, it is possible that shared orthographic and phonological representations led to an overestimation of semantic preview effects (see Hutzler, Schuster, Marx, & Hawelka, 2019). Therefore, even though semantic parafoveal processing seem to be supported by the electrophysiological evidence presented here, there is still work to do in order to create clean and more ecologically valid designs. In fact, as previously mentioned, semantic parafoveal processing seem to be affected by multiple variables, not only derived from properties of the task, but also derived from individual differences of the readers.

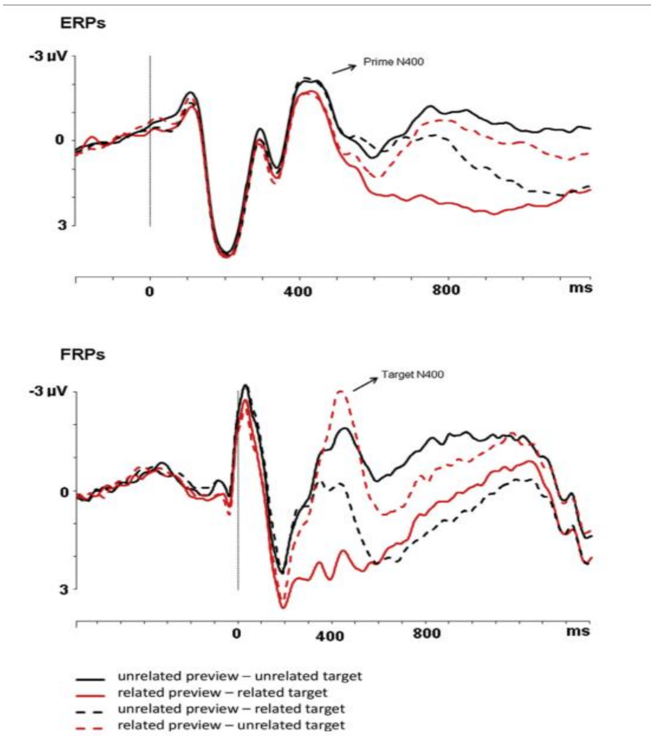

Figure 3. Extracted from López-Pérez et al. (2016). *Grand average of the ERPs (n) and FRPs (n+1). Semantic parafoveal effects of related and unrelated previews can be observed in both cases in the N400 component, reflected semantic parafoveal-on-fovea (n, up) and semantic preview benefit (n+1, down) effects.*

Chapter 3. Individual differences in reading: attentional distribution and the perceptual span

3.1. Individual differences in reading

We have talked about visual word recognition and decoding during reading for words that are located in the foveal and parafoveal region. Even though, as exposed, there is a gigantic amount of research studying the processes related to word recognition and reading, the variance among readers related to such processes are a (even) more difficult question to tackle. Partially, the reason involves a great variety of experimental designs, individual differences measures and subjects populations. However, from a long time ago, it was concluded that a large proportion of the variance in word recognition would be accounted for differences in phonological processes of the readers, without a great influence of individual differences in visual processes (see Stanovich, 1982a). In line with this Jared, Levy, & Rayner (1999) also found differences in word recognition processing between highly skilled readers and low skilled readers based on differences in phonological activation, finding also that poor readers executed longer fixations owing to this difficulty in the identification of words.

Of course, more processes are involved during sentence and text reading than isolated word recognition. A classic review from Stanovich (1982b) suggested that less-skilled readers with a low phonological coding ability of words cause them to fail in using contextual information to facilitate word recognition and, therefore, slowing the reading process. Ashby, Rayner, & Clifton (2005) found that while better readers had no problems in using contextual information for word identification, poorer readers only were able to do it when they read words that were low-frequency (i.e. easier to recognize and process) supporting the idea that they are not always able to use contextual information for word recognition. Veldre & Andrews (2014) suggested that their findings support the idea of an interactive model of reading skill, assuming that better readers has a rapid, autonomous lexical retrieval of words, keeping more attentional resources available (see also Perfetti, 1992; Stanovich, 2000).

In line with such statement, it has been argued that the processes in word recognition may involved different cognition in natural sentence reading, owing to the fact that attentional resources can be differently distributed considering different tasks and individual differences of readers (see Kornrumpf, Niefind, Sommer, & Dimigen, 2016; Niefind & Dimigen, 2016). In this sense, understanding how and why readers distribute their attention during reading is vital to understand how we can process and recognize words and how we integrate them to the context to reach a fluent reading level and, more importantly, the mechanisms behind the individual differences of readers in visual word recognition and parafoveal processing.

3.2. The perceptual span and attentional distribution

As implicitly suggested, the attended spatial area from which useful information can be extracted is limited in readers (Huey, 1908; Woodworth, 1938). To understand how readers vary in their ability to distribute their attentional resources across the visual field during reading, multiple research have studied the size of their perceptual span (McConkie & Rayner, 1975). The perceptual span refers to the extension of the attended region at a given fixation in which visual information can be accessed and processed. The perceptual span is assymetrical, extending only to 3-4 characters to the left of fixation while reaching about 15 characters to the right of fixation in skilled readers (see Rayner et al., 2009, Rayner, Schotter, & Drieghe, 2014), showing an assymetrical distribution of attentional resources during reading. The perceptual span has been explored with the gaze-contingent moving window paradigm (McConkie & Rayner, 1975; Rayner, 1975b). In the mentioned paradigm, participants read sentences where letters are replaced by "X" masks in the entire sentence but a predefined window that extends to the left and right area away from the fixated point. With each fixation, the window moves to the new fixated area, so readers are always exposed to the same amount of visible letters. Research using the moving window paradigm usually relies on multiple experimental conditions where the amount of information available to the right of fixation can vary. The different conditions, in combination with a full free-viewing condition, make it possible to estimate the approximate size of the perceptual span, i.e. the extent of the visual field that can be attended and accessed at a given fixation in the sentence. Its size depends on properties of the text, among which we can refer to syntactic ambiguity (Apel, Henderson, & Ferreira, 2012), the difficulty of the text (Rayner, 1986) and, more classically established, the lexical frequency and syntactic complexity of the fixated word, i.e. the foveal load (Henderson & Ferreira, 1990). According to the foveal load hypothesis, when a fixated word is more difficult to process or less accessible, less attentional resources are available to distribute and to process upcoming words, which may hinder parafoveal processing by reducing the size of the called perceptual span of readers. Interestingly, it also depends on the language-reading direction. For instance, while the advantage derived from the perceptual span seem to be greater in the right of fixation in language that are read from left to right (e.g. Western writing systems, see Rayner, Well, &

Pollatsek, 1980), such advantage is greater in the left of fixation in languages that are read from right to left (e.g. Hebrew, see Pollatsek, Bolozky, Well, & Rayner, 1981; Deutsch, Frost, Pelleg, Pollatsek & Rayner, 2003, see also Barber et al., 2011). All this evidence also implies that the asymmetrical allocation of attentional resources in both visual hemi-fields is influenced by reading direction or, more specifically, by their reading habits.

In line with such an idea, the size of the perceptual span may vary across readers owing to a variety of individual differences. As an example, Belanger, Slattery, Mayberry & Rayner (2012) wanted to test if auditory deprivation would affect low-level visual processing. Comparing deaf signers' readers and hearing readers, they found that the first group had a larger perceptual span, demonstrating that this population of readers had an enhanced attention allocation to the parafoveal region. However, the effect of individual differences are not only found in special populations but it also includes variance in the reading habits and linguistic ability of common readers, as previously suggested. For example, Choi, Lowder, Ferreira & Henderson (2015) used the moving-window paradigm to explore what individual differences of readers could be related to the size of the perceptual span of readers. To do so, they collected a large battery of individual differences measures that could be grouped into two factors: oculomotor processing speed and language ability. Interestingly, they demonstrated that language ability was the individual difference measure that modulated the size of the perceptual span (see Figure 4). Additionally, a study of Veldre & Andrews (2014) also collected individual differences measures of language ability and explore the size of the perceptual span with the moving window paradigm. They found that readers with low scores in spelling ability and reading had shorter perceptual spans when compared to readers with higher reading and spelling scores. In line with this, Rayner, Slattery, & Bélanger. (2010) also found that faster readers had larger perceptual spans relative to lower readers, suggesting that individual differences in reading rate are also related to the size of the perceptual span. Similarly, Rayner et al., (1986) found that beginning readers devote the majority of their processing to the foveal words whereas more proficient skilled readers have larger (and more asymmetric) perceptual span, devoting more attention to the right hemifield. In an interesting longitudinal study with German children, Sperlich, Schad & Laubrock (2015) found that children with better grades had a greater perceptual span and that their perceptual span increased as a consequence of differences in their basic linguistic skills. More interestingly, they found that slower reading children will show later deficits in reading rate and in their perceptual span after one year. On the other hand, children with better reading skills and grades would have an even greater perceptual span after that time. Such an increase is considered in developmental research as the Matthew effect (Stanovich, Nathan, & Vala-Rossi 1986). The effect, termed after the biblical verse Matthew 13:12 “Whoever has will be given more, and they will have abundance. Whoever does not have, even what they have will be taken from them.” states that an initial reading skill correlates positively with growth rates, at least in early and crucial stages of reading adquisition (Sperlich et al., 2015). This effect also creates a concern on the size of the perceptual span of crucially young readers and its role in their future reading adquisition. All of these findings can be summarize as follows: there is enough evidence to state that attentional distribution of readers may be related to their linguistic and reading ability. However, which individual differences are the ones to directly affect the depth of parafoveal processing?

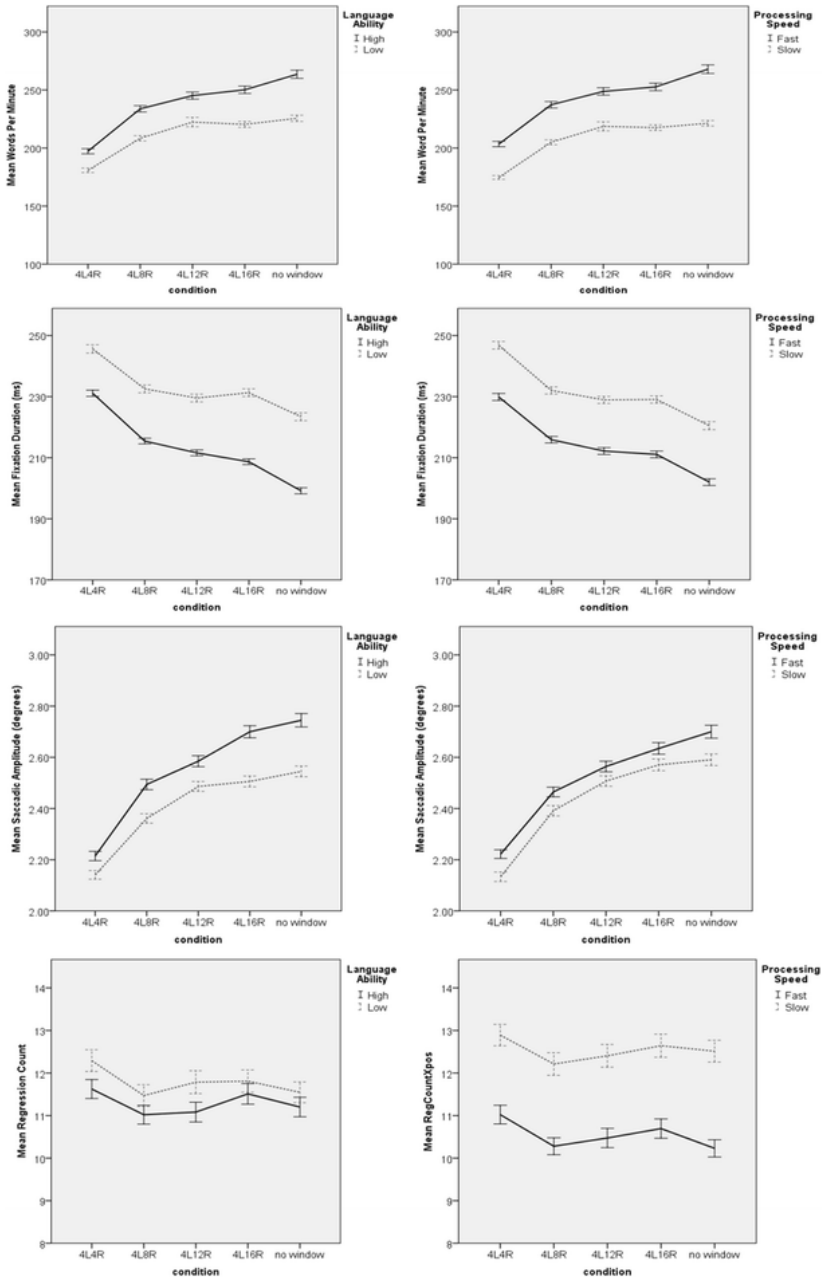

Figure 4. Extracted from Choi et al. (2015). *Summary of the effects of individual differences measures in language ability (left) and processing speed (right) effects over eye movements behavioral measures associated with the manipulated visible window size.*

3.3. The role of individual differences over parafoveal perception

As indicated, individual differences may directly affect the depth of parafoveal processing. Among this individual differences measures we can find the reading strategy (Wotschack & Kliegl, 2013) or age (Payne & Stine-Morrow, 2012; Rayner et al., 2010), as well as linguistic ability. As an example, in a study of Veldre & Andrews (2016) participants had to read sentences and the gaze-contingent boundary paradigm (McConkie & Rayner, 1975; Rayner, 1975b) was used to manipulate how much semantic and orthographic information were available in the parafoveal region. The previews presented could be an identical word (psycho/psycho), a semantically related word (insane/psycho), an orthographically related non-word (psyrla/psycho) or a totally unrelated word (circus/psycho). They also collected reading and spelling ability measures of readers and found that higher reading ability increased semantic preview effects, while higher spelling ability was related to greater preview costs when previews and targets were orthographically dissimilar. Thus, individual differences between skilled readers in linguistic ability could modulate directly the depth of parafoveal processing at the semantic level.

No study has directly assessed individual differences in attentional distribution over the depth of parafoveal processing, however, it is more than clear that attentional processes are crucial to access to the representation of parafoveal words. In this line, studies that manipulate the foveal load (see Henderson & Ferreira, 1990) imply that the perceptual span may be enhanced or reduced by different processing difficulties of the foveal load, leading to having more or less attentional resources available to process the parafoveal word. As an example, Payne et al. (2016) studied the influence of foveal load over parafoveal processing by manipulating the semantic expectancy and congruity of the currently fixated word in a flanker-RSVP-ERP experiment, by using orthographically illegal invalid previews. A greater foveal load hindered the processing of parafoveal words, since less attentional resources were available to distribute onto the parafoveal region (see also the mentioned study of Barber et al., 2013 with a similar paradigm and conclusions). More recently, in a study of Antúnez, López-Pérez, Dampuré & Barber (*under review*), readers had to fixated central words that could vary in their lexical frequency in a Go-noGo task and could be flanked by identical semantically related or entirely unrelated words. They found semantic parafoveal-on-foveal effects reflected in modulations in the N400 component when the foveal load was low, while the meaning of parafoveal words could not be accessed when the foveal word was more difficult to process, supporting again the idea that when not enough attentional resources are available parafoveal words cannot be accessed and processed. Attentional allocation also plays a role in parafoveal processing in visual search scenarios. For example, Dampuré, Benraiss & Vibert (2019) manipulated the foveal load in a visual search task by modifying the relevance of the foveal stimuli for the task. They found that, only when there was enough availability of cognitive resources, defined by low foveal and task-related loads, participants were able to access orthographic and semantic properties of parafoveal words.

In addition to these studies manipulating properties of the task, some studies that took different individual differences measures have highlighted the importance of differences in attentional distribution of readers over the depth of parafoveal processing. In one of these studies, Payne & Stine-Morrow (2012) recruited younger and older readers. They used the boundary-paradigm to present valid and invalid previews while readers could read words located in different positions of the sentence (sentence-internal, clause-final, sentence final). They found that older readers had no preview benefit (as younger readers showed a preview benefit) in later eye movements' measures in the sentence-final word position. The authors suggested that the greater workload for older readers in semantic-integration processes demanded a lot of attentional resources that led to a reduced parafoveal processing. In another study, while studying the effects of age over parafoveal processing, Payne & Federmeier (2017) used the flanker-RSVP-ERP paradigm to present sentences and to manipulate the upcoming parafoveal word. They showed that while young adults were able to use parafoveal pre-processing to facilitate subsequent processing of foveal words, older adults had difficulties in their ability to integrate parafoveal and foveal information at the semantic level. Since older adults have a tendency to display a smaller perceptual span size (see Rayner et al., 2009), it was possible that a poorer distribution of attentional resources in older readers led to a deficit in parafoveal processing. Even though this was suggested by the authors, they did not collect any measures of individual differences in the attentional distribution of readers, which would may have been of great assistance to disentangle the real role of attention on parafoveal processing. In fact, the influence of multiple individual differences of the subjects over parafoveal processing may be confounded with attentional mechanisms, such as reading strategy (Wotschack & Kliegl, 2013) or degenerated visual acuity related to age (Rayner et al., 2010). After all, as all the evidence presented here suggests, attention is a crucial factor for parafoveal processing to take place.

Part 2. Co-registration of EEG and EM: Considerations of a methodology

The current thesis relies heavily in a relatively new methodology and technique, i.e. the co-registration of EEG and EM in order to obtain FRPs and EM fixation measures simultaneously. The technique has been chosen owing to its ability to grasp the complex cognitive mechanisms behind visual word recognition and, more specifically, parafoveal processing. This section of the thesis aims to inform the reader about this methodology of choice, discussing about its benefits and disadvantages, as well as considerations to take into account.

As previously illustrated, most of the evidence of parafoveal processing comes from two different data-streams and experimental designs. First, evidence from eye movements has used the boundary paradigm to manipulate the parafoveal preview in sentences and the vast majority of orthographic and phonological parafoveal processing evidence comes from such studies. However, eye movements' behavioural measures may not always grasp more subtle and high-level processes that are independent from saccade processing (e.g. semantic parafoveal processing). On the other hand, electrophysiological measures (ERPs) has been collected in artifitial reading paradigms with the absence of EM to provide evidence of semantic parafoveal processing. Artificial tasks that allow the adequate experimental control of multiple variables are necessary and recommended for isolating questions and consolidating hypotheses. However, the ecological validity of such ERP paradigm has been questioned, since attentional resources may be differently distributed in natural sentence reading, which may affect the word recognition process.

Considering the limitations of both techniques and paradigms alone one approach is the integration of both techniques. Eye movements and EEG together can give us a better interpretation of the time-course of word recognition in more ecologically valid scenarios, such as natural reading (Kliegl, Dambacher, Dimigen, Jacobs, & Sommer, 2012). The main idea of combining both data-streams and paradigms is to obtain both Fixation-Related Potentials and eye movements in natural sentence reading for fixations in a pretarget (n) and target (n+1) word, and using the boundary paradigm between both words to modulate the parafoveal previewed word while fixating the pretarget word. For achieving the goal of establishing a co-registration set-up, a Faraday room is recomended to present the stimuli and to record the EEG signal, since the EEG amplifier may be altered by the electromagnetic field generated by electric dispositives outside the room. Inside the room, in addition, it needs to be allocated the monitor, control, keyboard and, more importantly, the camera of the eye tracker, which uses a infra-red light to detect in all moment fixation and saccades information. In another room, three computers for the registering of Eye Movements, EEG signal and stimuli presentation are necessary. Thanks to the Eye-EEG toolbox of Matlab (Dimigen et al., 2011), saccades and fixations can be either imported from the eye tracking data into the EEG recording or detected in the EEG signal with an adaptive velocity-based algorithm. This allows a high synchronization of both data-streams with millisecond precision and the easy obtantion of FRPs (see Figure 1 from www.hu-berlin.de to better understand their co-registration set-up guidelines).

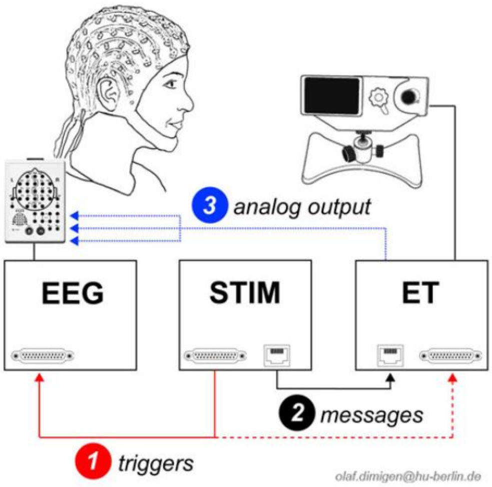

Figure 1. **Extracted from www.hu-berlin.de**. *Following the guidelines of Dimigen et al., (2011) for a co-registration set-up. (1) Common trigger pulses can be sent from the stimulation computer (STIM) to the Eye Tracking computer (ET) and the EEG computer at the same time via a parallel port. (2) Text messages can be linked to specific events for the ET data while triggers are still sent to EEG data simultaneously. Both text messages and triggers can be synchronized a posteriori in the EEG signal. (3) A copy of the ET is fed directly into the EEG headbox as an analogue signal, which requires rescaling voltages.*

As mentioned, obtaining FRP has a considerable number of advantages compared to the recording of EEG and EM alone. In a review, Degno & Livversedge (2020) indicated that the patterns of the FRP signal in free-viewing reading might vary from more classical ERP paradigms, having different time-courses, leading to earlier onsets of the effects. For example, Kornrumpf et al. (2016) used a flanker-RSVP task and a free reading of word-lists task with the boundary paradigm and recorded ERPs and FRPs respectively. They found that, while a preview effect started around 200 ms during the flanker-RSVP task, this preview effect started around 150 ms during reading lists of words. This early onsets may reflect a more accurate estimate of parafoveal processing during natural reading. Of course, this also means that FRPs may provide an ecological validity associated with recording electrophysiological brain activity in natural sentence reading, where oculomotor behavior, eye movements and natural attentional distribution are present. Additionally, FRPs provide information that is complementary to the information provided by EM in natural sentence reading. While EM are a direct estimation of reading behavior and this measures are used to infer the cognitive processing behind word recognition and parafoveal processing, they lack the ability to detect some cognitive activity that may not modulate behavior in the same way, which can be grasped by electrophysiological measures. Therefore, exploring the consistencies and differences between FRPs and EM data-streams is crucial to understand which processes are linked to oculomotor behavior and which processes are unrelated to them.

However, there are some methodological considerations to take into account, FRP research come at the cost of a great contamination of the EEG signal owing to overlapping activity from multiple fixations. Additionally, FRP and EM data streams has different filtering and processing criteria, which combined may lead to a greater loss of trials and statistical power in complex reading situations. However, since the co-registration set-up is an emergent field, current research is working on improving the quality of the signal and better statistical approaches to use FRPs (e.g. see Dimigen & Ehinger, 2020 for a non-linear deconvolution approach). Hence, future research may be updated with the latest improvements to guarantee the best use of FRPs in reading research and, in the view of this thesis, semantic parafoveal processing.

Part 3. Aims and hypothesis

This section tries to summarize all the questions that are more relevant in this thesis for the study of parafoveal perception during reading. This section will be directly related to the aims of the projects related to the thesis, derived from the current state of the theoretical literature. As indicated in the chapters 1 and 2 of the theoretical background section, multiple evidence suggests that the meaning of parafoveal words can be accessed. However, the neural mechanisms behind a deep and continues updating processing of the mental representation of a previewed word are not yet solidly stablished. Such circumstances are owed to limitations inherent to experimental designs and methodological approaches. Therefore, the firsts and crucial steps to take are to obtain neurological markers of semantic parafoveal processing where semantic effect may not be confounded with other variables. More importantly, the next steps are to replicate the presence of such neurological markers in ecologically-valid scenarios of natural reading, where visual word recognition processing and attentional distribution may act differently than in previous controlled-reading ERP paradigms (see Chapter 2). In fact, as discussed in Chapter 3, very little is known about how attentional distribution processes in natural reading interact with semantic parafoveal processing, despite the fact that attention is a crucial factor for visual word recognition. The chapter also highlighted the importance of the individual differences in the characteristics of readers for parafoveal processing to take place. Consequently, the neural markers of semantic parafoveal processing in natural sentence reading must be understood while considering individual differences of readers in their ability to distribute attentional resources across the visual space.

The section proposes a series of experiments which purpose is to increase our knowledge about how we can access to the meaning of parafoveal words and the role of individual differences in attentional distribution of readers over semantic parafoveal processing. The first part of the thesis aimed to find different electrophysiological markers related to semantic parafoveal processing in reading situations where eye movements were present. Our first objective was to test if the meaning of parafoveal words could be found while reading pairs of words in a more artifitially controlled reading situation, since most of semantic parafoveal processing evidence comes from artificial reading situations. Our second objective, aims to extend such electrophysiological markers of semantic parafoveal processing to natural sentence reading, where attentional distribution is distributed across the sentence. The second part of the thesis and third objective aimed to study how such electrophysiological markers in natural reading can be modulated by individual differences in attentional distribution of readers. More schematically, the aims of the thesis are as follows:

Section 1. Electrophysiological correlates in semantic parafoveal processing

Aim 1. Co-registration of EEG-EM and semantic parafoveal processing markers in word pairs reading

In the first study, we obtained FRPs during a Spanish reading task of word pairs with a Basque-Spanish bilingual sample. They had to read both words and to indicate if they were semantically related or not. We wanted to obtain electrophysiological markers of semantic parafoveal processing. To do so, we used the boundary paradigm to manipulate the preview of one of the words. On each trial, words were presented in the center (n) and on the right (n+1) of display, and participants had to read both of them. When their gaze crossed an invisible boundary located between both words, the previewed right word was replaced by a new target word. While it was a Spanish reading task, preview word was always in Basque language, which could be a non-cognate translation of the Spanish target word or a totally unrelated word. Additionally, Basque previews could be also related or unrelated to the pretarget word. The use of non-cognate translations will allow us to explore strong semantic relationships between preview and both target and pretarget words, without confounding any effect of orthography or phonology. Therefore, we could extract pure semantic parafoveal markers in an artifitial reading task.

Aim 2. Co-registration of EEG-EM and semantic parafoveal processing markers in natural sentence reading

In the second study, we obtained FRPs and EM during a English reading of natural sentences. They had to read to sentences and to answer some comprehension questions after reading them. Our aim was to obtain electrophysiological markers of semantic parafoveal processing in such ecologically valid situation. In order to reach such aim, we used again the boundary paradigm to manipulate the relationship of a previewed word with the sentence context. Therefore, the preview word could be identical to the target, unrelated to the target but plausible to the sentence context, and unrelated to both the target and the sentence context.

Therefore, we could obtain electrophysiological markers of semantic parafoveal processing in a natural reading situation.

Section 2. Role of attentional distribution over semantic parafoveal processing

Aim 3. The role of individual differences in the perceptual span of readers over semantic parafoveal processing in natural sentence reading

In the final study of the thesis, we obtained individual differences measures in the attentional distribution of readers (i.e. their perceptual span) and use it to predict the semantic processing of parafoveal words in the natural reading task previously performed. To do so, we again recruited the participants from the second study and they had to perform a natural reading task where they had to answer comprehension questions after reading the sentences. We used the moving-window paradigm to manipulate the number of visible letters in the sentence. By using conditions, with different numbers of visible letters and exploring how much their reading rate may vary, we run an individual predictive model to get an estimation of the size of their perceptual span. We also collected individual differences measures in the spelling ability of readers through a spelling task as a control measure, since it may be related to both the perceptual span and directly to the depth of parafoveal processing. Later, we run a predictive model with the FRP data of the second study, where both spelling ability and the perceptual span of readers may predict the depth of semantic parafoveal processing. Hence, we could explore the role of attentional distribution of readers into semantic parafoveal processing in an ecologically valid natural reading scenario.

Below, the fourth section of the thesis will display in detail the three studies run in order to fulfill the described aims. Each study has an initial abstract summarizing the experiment, followed by an introduction, method, results and discussion section. After describing all the studies, the fifth and sixth section of the thesis will provide a general discussion and main conclusions of the experimental evidence obtained here, using the theoretical background provided to the reader to discuss and answer the described research questions and comment implications and future directions of the current thesis.

Part 4. Experimental studies

4.1. Study 1. Co-registration of EEG-EM and semantic parafoveal processing markers in word pairs reading

Publication:

Antúnez, M., Mancini, S., Hernández-Cabrera, J., Hoversten, L., Barber, H., & Carreiras, M. (2021). Cross-linguistic semantic preview benefit in basquespanish bilingual readers: Evidence from fixation-related potentials. *Brain and Language*, *214*, 104905.

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

4.1.1. 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. During reading, we process many words at a time, including words located at the foveal region and in the parafovea, which is located between 2º and 5º 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 mainly 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 et al., 2012). Parafoveal evidence coming from eye movements 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 that the one previously previewed. Consequently, the preview word is only perceived at the parafoveal level. 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 benefit effects (Hohenstein et al., 2010; Schotter, 2013; Schotter et al., 2015), several authors failed to find similar outcomes (Altarriba et al, 2001; Hyönä & Häikiö, 2005; Rayner et al., 1986; Rayner et al., 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 et al., 2011; Barber et al., 2010; Barber et al., 2013; Li et al., 2015; López-Pérez et al., 2016). Nonetheless, a lack of semantic effects has also been reported (Dimigen et al., 2012; Simola, Holmqvist, & Lindgren, 2009). Interestingly, additional evidence comes from studies that co-registered Electroencephalography (EEG) and Eye Movements (EM) to study semantic parafoveal processing (Dimigen et al, 2011; Dimigen et al., 2012; Kretzschmar et al., 2009; Kretzschmar et al., 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-previewed 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, a component that has been linked with semantic processing (see Kutas and Federmeier, 2011). Despite such semantic preview benefit findings, having conditions where the preview and target are identical could make the semantic preview benefit effects less evident, since these words also share orthographic and phonological representations.

A possible approach to overcome such limitations is to use translated words from a second language, since translations hold one of the strongest semantic relations 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, & Carreiras, 2020; Dimitropoulou, Duñabeitia, & Carreiras, 2011; Macizo, Bajo, & Martín, 2010; Martín, Macizo, & Bajo, 2010; Perea, Duñabeitia & Carreiras, 2008). Interactive activation models, such as the BIA+ model, endorse a non-selective access to a lexicon that is integrated across languages, (Dijkstra & Van Heuven, 2002). According to this account, co-activation of semantic representations across languages during reading would be expected even in non-cognate translations (e.g., Duñabeitia, Perea, & Carreiras, 2009; Duyck & Warlop, 2009). Non-cognate translations, contrary to cognates, do not have any similar orthography or phonology, therefore sharing only the common semantic representation.

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 benefit 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, & 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 could have been identical words, cognate translations, non-cognate translations or unrelated words. Even though they found evidence of orthographic parafoveal processing across languages, they did not find pure semantic effects. Snell, Declerck & Grainger (2018) also failed to find parafoveal-on-fovea 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.

4.1.2. Materials and methods

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 belonged to the Basque Country, a region where Basque and Spanish are co-official languages (Age of Spanish adquisition: M=1.3, SD=2.3; Age of Basque adquisition: 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 & Duñabeitia, 2017). The participants were right-handed, had no history of neurological disorders and were rewarded economically for their participation.

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, lexical frequency of pretarget, preview and target words per 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 ($p>0.05$). Lexical frequency was defined by a logarithm in base 10 of number of corpus events + 1 (Log10 freq). Properties of Spanish words were obtained through the EsPal database (Duchon, Perea, Sebastián-Gallés, Martí, & 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. *Lexical frequency, length and Levenshtein distance of the pretarget preview and target words for all the experimental conditions. Length differences and Levenshtein distances between previews and targets are also included.*

Condition		*Log10 freq*			*Length*				*Levenshtein Distance*
		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

Task

The task was similar to the one used by Lopez-Perez et al. (2016) with slight modifications (see Figure 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. 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 of no more than 45 minutes, whereas the whole session, including cap set-up, lasted less than 90 minutes.

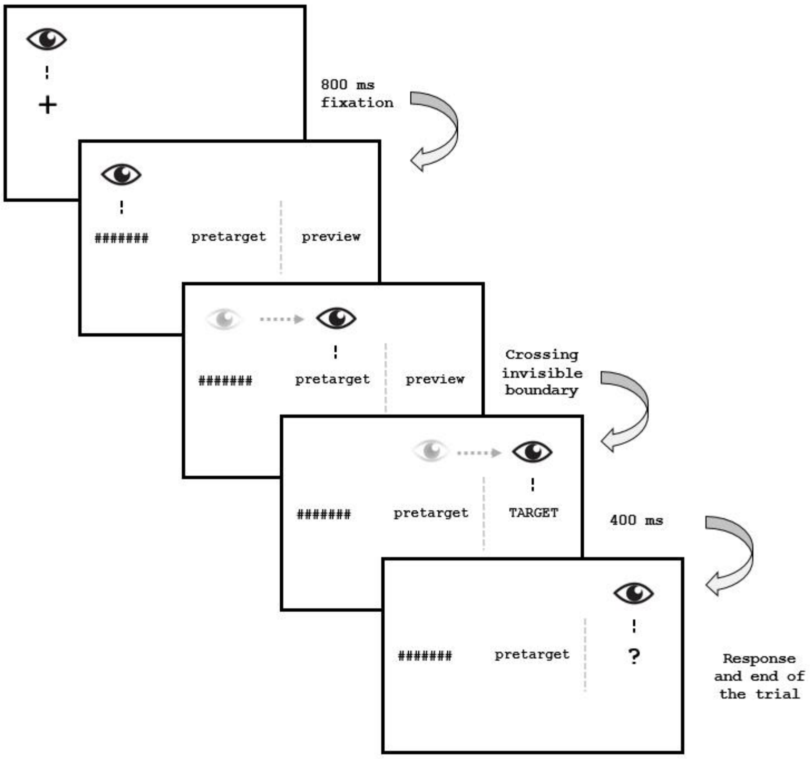

Figure 1. *Presentation procedure. Participants had to fixate the cross in the left of the screen for 800 ms before the word pairs appeared. Participants could then make a saccade to the word in the center of the screen and then to the word on the right of the screen. When the eyes crossed the invisible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

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 kΩ.

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.

Processing

After collecting the EEG data, the signal was filtered with a band-pass 0.1-30 Hz 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.

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 relatedness*: Related vs Unrelated). Target relatedness was not considered in this analysis because target words were not presented during the fixation of the pretarget word (n). To analyse the preview benefit effect 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 & Buchwald, 1991). We expected to find effects around the N400 temporal window for both FRPs time-locked to the target and pretarget words.

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)	*Target Relatedness*	*Preview Translation*
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

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), by using the

ULLRToolbox (https:// sites.google.com/site/ullrtoolbox/home). On violation of sphericity, *p* values were corrected with Greenhouse Geisser.

4.1.3. Results

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, $F(1,31)=1.82$, $p>0.05$; Preview, $F(1,31)=1.85$, $p>0.05$; Target:Preview, $F(1,31)=0.9$, $p>0.05$). 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.

Target (n+1) word and preview benefit effects

Because the target word was displayed for a fixed amount of time and participants had to wait until the question mark in order to respond, fixation durations on the target word were not analyzed. For the electrophysiological measures, we visually explored the data and performed the point-by-point t-test analysis for all conditions. Based on this analysis, 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 $F(1,31)=5.52$, $p<0.05$, $\eta p2 = 0.15$ and a main effect of *target relatedness*, $F(1,31)=32.68$, $p<0.001$, $\eta p2 = 0.51$ on the 350-550 temporal window with no effect of the interaction, $F(1,31)=0.24, p>0.05$.

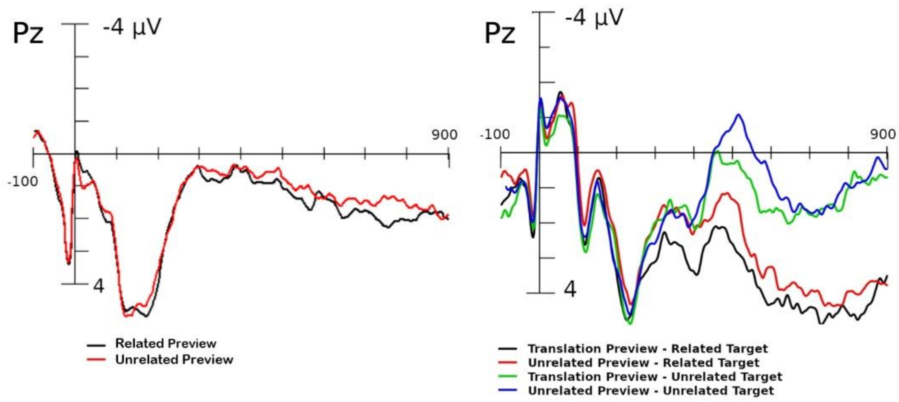

Figure 2. *Grand average FRPs at the Pz electrode for the fixation onset on the pretarget word (left) and on the target word (right). For FRPs to the pretarget word, only the Basque preview relatedness was considered: (a) Related preview, (b) Unrelated preview. For FRPs to the target word, the preview translation and target relatedness factors were considered: (a) Translation preview – related target, (b) Unrelated preview – related target, (c) Translation preview – unrelated target, (d) Unrelated preview – unrelated target.*

Looking at the topographic factors, there was an interaction between *target relatedness* and *anteriority* $F(1,31)=4.36$, $p=0.01$, $\eta p2 = 0.42$ and between *target relatedness* and *laterality* $F(1,31)=24.32$, $p<0.001$, $\eta p2 = 0.43$. Additionally, there was an interaction between the *preview translation* factor and *laterality* $F(1,31)=5.66$, $p<0.05$, $\eta p2 = 0.15$. Post-hoc comparisons showed that *target relatedness* effects were present in all levels of the *anteriority* and *laterality* factors. On the other hand, the effects of *preview translation* were mainly present on medial electrodes, $t(31)=2.52$, $p=0.03$. Topographic maps of the four conditions are displayed in Fig. 3 to better understand the distribution of the effects.

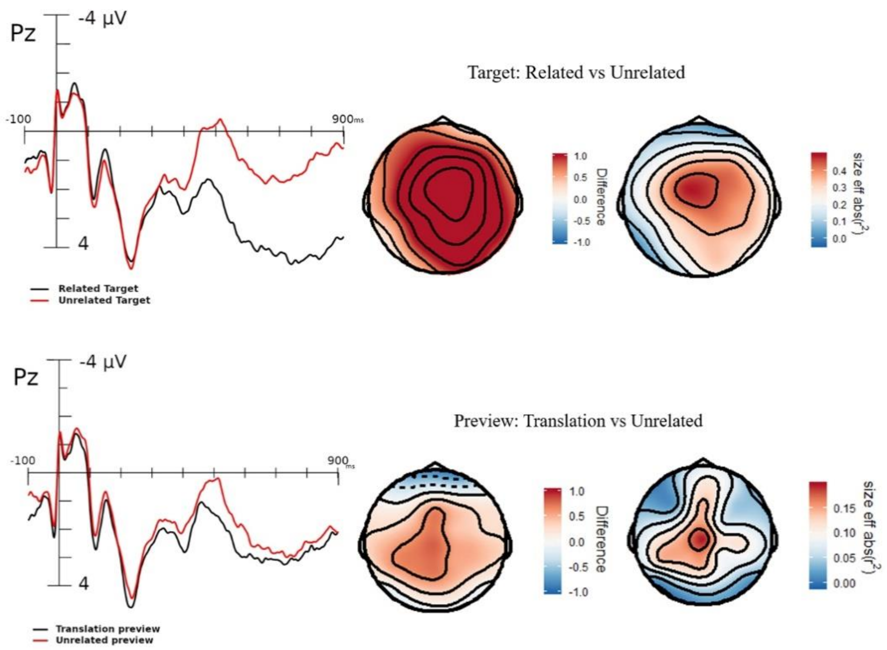

Figure 3. *FRPs of the two main effects from fixation onset of the target word: (a) Related and unrelated targets, (b) Translation and unrelated previews. The topographic maps on the right display the mean differences and effect sizes in the N400 temporal window (350-550 ms).*

4.1.4. 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 processing of parafoveally-previewed words.

In line with our hypothesis, 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 around 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. 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. In fact, Dimigen et al. (2012), who found preview benefit effects when the parafoveal word was identical, failed to find such facilitation when the previewed word was semantically related to the target one. Our manipulation, however, shows a facilitation of non-cognate Basque translations of Spanish target words when compared to Basque unrelated words, which reflects that only the meaning of the previewed word was involved in such facilitation, and not other form similarities (e. g., orthography, 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. Even though Kretzschmar et al. (2009) also used 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 these type of effects. Additional evidence coming from designs involving switching within languages and between languages in both directions would shed light into 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 favor a bilingual mental lexicon integrated across languages, such as the BIA+ model (Dijkstra & Van Heuven, 2002). 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 testing 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 benefit 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, & 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, participant’s goal alone would not explain the success in finding cross-linguistic semantic parafoveal effects, since several within-language research 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 benefits (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 benefit effects would not necessarily be replicated 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.

Acknowledgments

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4.2. Study 2. Co-registration of EEG-EM and semantic parafoveal processing markers in natural sentence reading

Under review:

Antúnez, M., Milligan, S., Hernández-Cabrera, J., Barber, H. A., & Schotter, L. Semantic parafoveal processing in natural reading: Insight from Fixation-Related Potentials and eye movements. *Psychophisiology.*

Abstract:

Prior research suggests that we may access the meaning of parafoveal words during reading. We explored how semantic-plausibility parafoveal processing takes place in natural reading through the co-registration of eye movements (EM) and fixation-related potentials (FRPs), using the boundary paradigm. We replicated previous evidence of semantic parafoveal processing from highly controlled reading situations, extending their findings to more ecologically valid reading scenarios. Additionally, and exploring the time-course of plausibility preview effects, we found distinct but complementary evidence from EM and FRPs measures. FRPs measures, as opposed to EM evidence, revealed that plausibility preview effects may be long-lasting. We highlight the importance of a co-registration set-up in ecologically valid scenarios to disentangle the mechanisms related to semantic-plausibility parafoveal processing.

Keywords: Parafovea – FRPs – N400 –Semantics - Co-registration – Natural Reading

4.2.1. Introduction

One remarkable characteristic of reading is the large amount of information that we can extract from a text in an extremely brief period of time. However, there are limitations to how fast we can scan strings of words. During the presentation of linguistic and orthographic stimuli, an accurate description of the constraints of the visual system is necessary to fully understand the nature of subsequent cognitive operations. For instance, readers can process words located not only in the foveal visual field, but also in the parafoveal region –located between 1 and 5 degrees away from the fixation point. However, information in the parafoveal region is of poorer quality, due to decreased visual acuity and visual attention (Schotter et al., 2012). Therefore, the orthographic input will depend on the perception of letters at different spatial locations in combination with a series of sequential eye movements and attentional shifts. This leads us to some relevant questions: How many letters can we perceive in the parafoveal visual field? How deep do we process them? Is that information used only to guide our gaze or it is contributing to improve comprehension as well? At the core of all those issues is the debate on whether word meanings can be activated and integrated from parafoveal perception. In this study we have focused on parafoveal semantic processing during natural sentence reading combining two methodological approaches: The eye-tracking and the EEG-ERP research.

Semantic parafoveal processing: evidence from eye tracking research

Eye movement research has investigated parafoveal processing using the *gaze-contingent boundary paradigm* (Rayner, 1975), which allows making inferences about how information obtained from parafoveal perception modulates subsequent reading behavior. In the boundary paradigm, an invisible boundary is located before a previewed word. When the reader's gaze crosses the invisible boundary, the previewed word is replaced by a target word as the reader fixates it. Therefore, the previewed word could only have been perceived from the parafovea during the fixation of the previous word, and any difference in reading time of the target word when it is fixated must be due to that parafoveal processing (i.e., a parafoveal preview effect). The general conclusion from this paradigm is that readers regularly use orthographic and phonological features from parafoveal words, since fixated words need less time to be read after orthographically and phonologically related previews. On the other hand, evidence about the activation of semantic information was initially scarce (Hohenstein et al., 2010; Yan, Richter, Shu, & Kliegl, 2009), leading to the conclusion that semantic information was not accessed parafoveally (Altarriba et al., 2001; Hyönä & Häikiö, 2005; Rayner et al., 1986; White, Bertram, & Hyönä, 2008; see Schotter et al., 2012).

Subsequent experiments have found that semantic information can be obtained from the parafovea (Rayner & Schotter, 2014; Schotter, 2013; Schotter et al., 2015), but they concluded that semantic preview effects are determined not by the relationship between the preview and target word, but rather by the semantic relationship between the parafoveal preview and the sentence context (i.e. plausibility preview effects; see Andrews & Veldre, 2019; Schotter, 2018). For example, Schotter & Jia (2016) used the boundary paradigm with identical, plausible and implausible unrelated previews (e.g., "Kevin's brother ate all their fresh/baked/place bread in the apartment"), in addition to synonyms and antonyms (e.g., "Harry bought a broken watch/clock to repair for fun" and "Jane will travel north/south on her trip to Los Angeles next week" respectively); these words were read in low-constraint sentences, in order to ensure that predictability did not affect the processing of plausibility. They found that all plausible previews led to shorter durations compared to the implausible preview in first-pass reading measures on the target word, with no effects in later reading measures. Discrepancies between earlier and later eye movement reading measures could suggest that plausibility preview effects are short-lived; while implausible conditions had longer first-pass reading durations, total fixation durations were similar between plausible and implausible preview conditions (Schotter & Jia, 2016; Veldre & Andrews, 2016, 2017, 2018b). Andrews & Veldre (2019) suggested that a plausible preview may lead to later costs related to subsequent trans-saccadic integration processes between the preview and target words, which would lead to higher rates of regressions to the target word. This could explain the equivalence between plausible and implausible conditions in total fixation durations, since integrative processes of the preview with both the target word and the sentence context may influence this later processing measure. Since evidence suggest that plausibility preview effects are independent of trans-saccadic integration processes (Veldre & Andrews, 2016; Schotter & Leinenger, 2016; see Schotter, 2018), it is still possible that integrative processes of preview with the sentence context are still present in later processing after fixating the target word, but undetected by total fixation duration measures.

Semantic parafoveal processing: evidence from ERPs and FRPs

While studying the time-course of processing may be limited in eye tracking research, EEG has proved particularly useful in this regard. Word recognition is a multimodal and cumulative process that extends along time, determined by many lexical and contextual factors (Barber & Kutas, 2007). Early EM measures are very sensitive to the computations that determine eye movement control. However, considering the characteristics and speed of natural reading, eye movement control uses only the minimum amount of information necessary to maximize the efficiency of saccades. Word processing is not finished after our gaze leaves a given word. It continues until meanings are fully processed and involves the continuous updating of mental representations. Language-related Event Related Potential (ERP) components like the N400 peak much later (around 400 ms) than the average fixation duration (250 ms), and therefore are crucial physiological markers that may help us to understand the discrepancies between early and late EM measures. For instance, some cognitive processes may not be detected by early EM measures if they take place after saccades, but they may still modulate late ERP components and to have an impact on much later EM behavioural measures. Therefore, EEG and EM measures can be mutually complementary when describing the time course of parafoveal semantic processing during reading. Fixation-Related Potentials (FRPs) may be experimentally obtained through a co-registration set-up, allowing us to obtain ERPs time-locked to fixation onsets (similarly to EM fixation events) during natural sentence reading (Dimigen et al., 2011). By obtaining FRPs, semantic processing in the time-course of plausibility preview effects may be detected through the N400 amplitude modulation, which is an index of the ease of semantic access determined by sentence-level context information (Kutas & Federmeier, 2011).

Kretzschmar and colleagues (Kretzschmar et al., 2009) reported FRP effects compatible with parafoveal semantic processing in a natural reading task. They found modulations of the N400 component associated with semantically incongruent compared to congruent predictable words in highly constraining sentence constructions (e.g., “the opposite of black is white/yellow/nice”). These effects were found when Event-Related Potentials (ERPs) were time-locked to the last fixation before the target fixation, providing evidence that at least some semantic processing of the critical words took place parafoveally. However, considering the strong predictability manipulation used in that study, it is still an open question under which circumstances this kind of effect can be produced. In fact, a later study failed to replicate this parafoveal N400 effect in sentences with predictable targets but without extreme predictability (e.g., "The extremely skinny model looked like she suffered from *anorexia* and a lack of sleep") when compared with unpredictable targets (see Kretzschmar et al., 2015). Consequently, it is important to note that, especially in high-constraint sentences, semantic effects can be the result of predictions of the upcoming word's orthography, where the availability of orthographic features has a downstream influence over semantics (see Lazlo & Federmeier, 2009).

The time course of parafoveal semantic processing during reading has been also addressed with artificial reading tasks that allow for tight experimental control; the presentation of words in the sentence is controlled via Rapid Serial Visual Presentation with bilateral flankers (Flanker-RSVP) while the reader fixates the word at the center of the screen, which is flanked to the right by the next word of the sentence and to the left by the previous word of the sentence (Barber et al., 2010; Barber et al., 2011; Barber et al., 2013; Li et al., 2015). For example, Barber et al. (2010) used this paradigm to manipulate the parafoveal word presented in the right flanker, which could be congruous or incongruous with the sentence context. Incongruent words in the parafovea produced larger amplitudes in the N400 component time-locked to the presentation of the parafoveal word, showing that semantic processing of parafoveal words began before they were replaced by a new target word in the foveal region. In a later study, Barber et al. (2013) manipulated the contextual predictability of the critical words that were either congruent or incongruent within the sentential context. They again found larger N400 amplitudes for incongruent words when presented parafoveally while reading the previous word, both in high and low-constraint sentences. Interestingly, N400 modulations were greater under high contextual constraint, indicating that predictability can modulate the amount of parafoveal processing. In order to totally rule-out the possibility that predictions were primarily orthographic rather than semantic, Stites, Payne, & Federmeier (2017) used the same flanker-RSVP paradigm presenting a graded manipulation of the predictability of the target words, combinating predictability and plausibility manipulations (high cloze probability, low cloze probability, unexpected but plausible, and anomalous words), which resulted in graded parafoveal N400 effects, with differences between unexpected plausible and anomalous words (i.e. a plausibility effect).

In spite of this evidence, it has not been established yet if the previously described ERP parafoveal semantic effects can be replicated under conditions of natural reading. In relation to this question, Barber et al. (2013; experiment 2) showed that parafoveal N400 effects in low constraint sentences were observed only at a slow stimulus presentation rate (SOA = 450 ms) but not when words were presented to a faster speed, similar to that of natural reading (SOA =

250 ms). Therefore, it seems that semantic N400 modulations related to predictability can interact with other sources of cognitive load to determine the amount of semantic parafoveal processing at any time (see also Payne et al., 2016). FRPs seems to be a natural step forward to tackle the ecological validity of parafoveal ERP findings in complex natural reading situations.

For instance, FRPs have already been useful in testing the ecological validity of parafoveal ERP and EM effects unrelated to semantic processing. Experimental conditions where previews and targets are different show greater processing costs when compared to conditions where previews and targets are identical, a preview effect related to display change frequently reported in EM research (see Schotter et al., 2012). These effects may be triggered by a perceptual mismatch that affects low level visuo-attentional processes and by the identical preview facilitation of the subsequent target processing. These display change effects have also been reported in Flanker-RSVP-ERP paradigms during controlled reading (see Li et al., 2015), where valid previews elicited smaller N1 and N400 components than invalid preview when the target word was presented. More interestingly, in a situation more similar to natural reading, Dimigen, Kliegl, & Sommer (2012) obtained FRPs while participants read word lists freely from left to right, and they used the boundary paradigm to manipulate parafoveal information. They presented an identical, semantically related or semantically unrelated word as a preview. They found that identical previews, compared to the other conditions where a display change was present, lead to facilitatory effects reflected in shorter fixation durations and a more positive amplitude that emerged from around 170 ms to 280 ms in the PO9 and PO10 electrodes. As they indicated, their findings in fixation durations and FRP amplitudes may support the idea that the display change effect is related to a pre-activation of orthographic codes before meaning activation. Additionally, they also reported a modulation of the N400 component such that the identical condition was less negative than the conditions with invalid previews. Dimigen et al. (2012) proposed that the N400 attenuation derived from a valid preview could be equivalent to the repetition priming effect described in other visual word recognition studies (see Holcomb & Grainger, 2006; 2007), which would suggest that similar mechanisms of trans-saccadic integration of low-level features in flanker paradigms could be involved in natural sentence reading.

The extraction of FRPs through a co-registration set-up provides some important advantages. For instance, both FRP and EM data together may discern between different types of processing that cause either distinct or comparable disruption to both data streams (for a review, see Degno & Liversedge, 2020). Additionally FRPs have already been successfully combined with the boundary paradigm in word pair or word lists reading experiments (Antúnez et al., 2021; Dimigen et al., 2012; López-Pérez, Dampuré, Hernández-Cabrera, & Barber, 2016) and this combination allows a better interpretation of the ERP components that are highly overlapped in a situation of natural reading. Therefore, the ecological validity advantage of obtaining both FRPs and EM with the boundary paradigm over traditional ERP and EM approaches alone may provide a deeper understanding of how parafoveal processing may be affected by additional cognitive processes inherent to natural sentence reading, especially those related to reading speed and eye-movement control.

The Present Study

In this experiment, we analyzed the relationship between EM and FRP measures of semantic parafoveal processing in natural reading scenarios, posing two questions: 1) do ERP semantic parafoveal effects that have been obtained under controlled situations (e.g. Flanker-RSVP) replicate in a natural reading task? 2) do these FRP-based plausibility preview effects provide clarity on the discrepancies in earlier and later EM measures? We recruited a sample of native English speakers and obtained FRPs through the co-registration of EM and EEG during a natural sentence-reading task. As in EM research, we used the boundary paradigm to manipulate the relationship of the previewed word with the sentence context. Participants read sentences such as “Harry bought a broken watch to repair for fun.” We manipulated the previewed word so that it was either identical to the target (e.g. Harry bought a broken watch...), an unrelated but plausible preview (e.g. Harry bought a broken chair...) or an unrelated and implausible preview (e.g. Harry bought a broken peace...; see Figure 1). The identical condition represents a situation where preview and target words share all features, allowing us to explore trans-saccadic integration effects when compared to the other two conditions. The comparison of plausible and implausible previews allowed us to explore integration processes of semantic preview information with the sentence context independent of any relationship between the preview and target because the previews in these conditions were both orthographically, phonologically, and semantically unrelated to the target word. The plausibility manipulation within low constraint sentences will allow us to confirm genuine parafoveal semantic processing in natural reading, ruling out alternative explanations such as orthographic prediction. Additionally, the comparison of the identical preview with the plausible and implausible previews would be useful to explore preview effects related to a mere pre-activation of orthographic codes before meaning activation. FRPs were time-locked to the pretarget and target words, in order to explore whether parafoveal information can be processed during the fixation of the pretarget word and if such semantic information may modulate the processing of the target word when fixated.

We expect to replicate previous FRPs findings of preview effects related to a display change (Dimigen et al., 2012) in a more ecological reading situation in early and later components of the FRP time-locked to the target word (e.g. N1 and N400). More importantly, considering previous electrophysiological evidence from controlled-reading paradigms where EMs were absent (Barber et al., 2013; Stites et al., 2017), we expect parafoveal word plausibility to modulate the N400 component time-locked to the fixation of the pretarget word (i.e., a greater negativity associated with the implausible preview). Such a finding would suggest that the N400 component involves semantic processing that is independent from early EM measures. In addition to this, we expect plausibility preview effects in early reading measures on the target word and FRP components time-locked to fixation on the target word (i.e. around the 200 ms temporal window), consistent with previous EM evidence with similar experimental paradigms (Schotter & Jia, 2016; Veldre & Andrews, 2016, 2017, 2018b). Interestingly, and despite previous EM evidence showing that later reading measures are equivalent across plausible and implausible conditions, EEG measures (i.e. FRPs and the N400 component) may reveal types of processing undetected by fixation durations. Moreover, if plausibility effects are long-lasting, we would expect inconsistencies between EM and FRP measures, finding modulations in the N400 component for the FRPs time-locked to the target word, with total fixation durations not showing plausibility effects. This would be our main guess related to the later time-course of plausibility effects, since subtler experimental manipulations (i.e. semantics) would cause less disruption to behavioral or EM measures, leading to less consistency between both data streams (Degno & Liversedge, 2020). On the other hand, if plausibility effects are short-lived and absent in later processing, we would not find modulations in the N400 component. Such consistency between both data streams would suggest that EM and FRPs measures share common cognitive mechanisms related to semantic-plausibility parafoveal processing.

4.2.2. Materials and methods

Subjects

Fifty-nine Psychology students at University of South Florida (Florida, United States) volunteered to participate in the experiment in exchange for course credits. After excluding participants due to failure to follow instructions or stay awake (N = 5), problematic recording (N = 6), and excessive data loss (i.e., subjects with fewer than 20 trials in any condition were excluded; N = 11), thirty-seven participants (21 females and 16 males, age: M = 20.7, SD = 4.19) were included in the analyses. They all were monolingual native English speakers, had normal or corrected vision, were right-handed and had no history of neurological disorders.

Materials and design

One hundred twenty-six sentences were taken from Schotter & Jia (2016) for the study. In each sentence, a preview of a specific target word could be either identical, an orthographically, phonologically, and semantically unrelated word that was plausible in the context of the sentence or an orthographically, phonologically, and semantically unrelated word that was implausible in the sentence context. All preview words shared the same length with the target word, were similar in lexical frequency, and had low orthographic similarity to the target word (for non-identical preview; see Table 1). Cloze probability norming was conducted with 30 volunteers who were not in the main experiment. This revealed that none of the preview words were predictable in the sentences (Table 1).

In the original study, plausibility norms were collected for the entire sentence containing each of the preview/target words. For this study, we conducted an additional plausibility norming task, which included the sentence fragment only up to the preview word to confirm the plausibility manipulation at the point where the preview word was encountered (i.e., the point where the FRPs were time locked). For the norming study, 30 participants indicated if sentences were well or poorly written using a 1-7 Likert scale. Sentence conditions were counterbalanced and randomly presented. From the norming procedure, the average plausibility rating was 4.6, 4.6, and 2.9, in the identical (target), plausible, and implausible conditions, respectively.

Table 1. *Descriptive statistics of the target and preview words used in the experiment.*

Condition	Log10 freq M	Log10 freq SD	Orthographic similarity with target word M	Orthographic similarity with target word SD	Cloze probability (%) M	Cloze probability (%) SD
Plausible preview word	1.5	0.7	0.13	0.15	1.58	3.32
Implausible preview word	1.4	0.8	0.14	0.17	0	0
Identical preview word (Target word)	1.4	0.8	---	---	2.93	2.89

Task and procedure

Subjects were seated 60 cm away from a 20” HP p1230 CRT monitor, with a refresh rate of 150 Hz and a screen resolution of 1024 x 768 pixels. After arriving, participants read and signed the informed consent. They were instructed to read sentences and to answer occasional yes-no comprehension questions. They answered the question by pressing the left or right button of a response controller, in order to answer affirmatively or negatively. After the EEG cap was set up and the eye tracker was calibrated, participants performed five practice trials before the real task, in order for them to get used to the experimental procedure.

During the task, a fixation point was presented in the center of the screen at the beginning of each trial in order to ensure that calibration of the eye tracker remained accurate. Then the experimenter started the trial, and a fixation box was presented on the left side of the screen, at the location of the beginning of the sentence. Once a fixation was detected in this box, the sentence was presented and stayed on the screen until the subject indicated that he had finished reading it by pressing a button on the response controller. They were also instructed to look at a target sticker located on the right side of the screen when they were done reading a sentence, to keep them from making additional eye movements that could have contaminated EM measures. When the reader’s gaze crossed an invisible boundary located between the pretarget (n) and the previewed word (n + 1), a target word replaced the preview word, following the boundary paradigm (Rayner, 1975; see Figure 1). A “yes-no” question was presented after 30 of the sentences (23.8 %). Accuracy on comprehension questions was high in all subjects (M = 91.83 %, SD = 4.49%). Participants reported little to no display or word changes after the experiment (below 5 trials) and no one reported recognizing a previewed word when there was a display change.

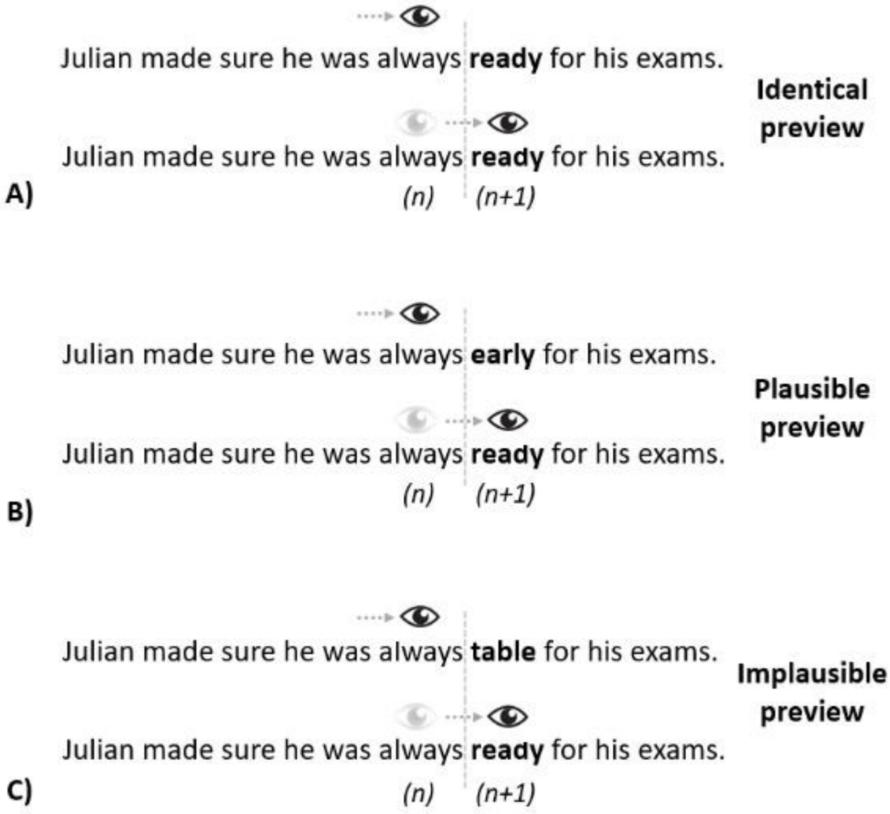

Figure 1. *Illustration of the boundary paradigm. When readers crossed with their gaze an invisible boundary located between a pretarget (n) and a previewed word (n + 1), a target word replaced the preview word. The target word was always plausible to the sentence context. The previewed word could be identical to the target word (a), a different word but plausible to the sentence context (b) and a different word implausible to the sentence context (c).*

Stimuli from this experiment were intermixed with 144 sentences and 40 comprehension questions from another experiment (see Milligan, Antunez, Barber, & Schotter, under review). Following this experimental procedure, another reading task was performed and measures of spelling ability were collected. Those data were not analyzed for the purpose of this study and are not reported here. The entire experimental session took 90 minutes.

EEG and eye movements co-registration

EEG was recorded from 27 Ag/AgCl electrodes, following the 10/20 system (EasyCap, www.easycap.de). Four additional electrodes were placed in the external canthus of each eye and in the infra and supraorbital regions of the right eye. Electrodes were referenced online to the left mastoid and re-referenced offline to the algebraic mean of the right and left mastoids.The signal was amplified with a bandwidth of 0.01-100 Hz and a sampling rate of 500 Hz with the BrainVision system (www.brainproducts.com). Impedances were kept under 5 kΩ (electro-oculogram < 10 kΩ).

EMs were recorded with a SR Research Ltd. Eyelink 1000 eye tracker in remote setup so that a target sticker was used to measure and control for head movements (Sampling rate = 500 Hz). Measures from the right eye were recorded, even though viewing was binocular. Calibration was performed on a standard five-point grid and eye position errors were less than 0.3º at each calibration point. Such calibration was performed not only at the beginning of the experiment but also during the task if calibration error was greater than 0.3º. Saccades crossing the invisible boundary activated the display change, which was completed almost immediately (M = 5.38 ms, SD = 0.39 ms).

Processing

EMs were processed and inspected through SR Research DataViewer. On the first stage of pre-processing, fixation that were preceded or followed by blinks were discarded. Additionally, trials where a display change was triggered prior to the eye movement to the target word were removed from later analysis (5.8 % of total data). Fixations on the pretarget and target interest areas were considered and exported for the analyses of interest. Only trials where readers fixated both the pretarget and target words during first-pass reading were kept and fixation durations shorter than 50 ms and greater than 800 ms were excluded from analysis (retaining 82.14% of the total data trials).

The EEG data was pre-processed using the EEGLAB toolbox (Delorme & Makeig, 2004) for Matlab. The signal was filtered with a band-pass of 0.1-30 Hz and re-referenced offline to the average of the right and left mastoids. EMs were synchronized offline with the EEG signal with the EYE-EEG toolbox (Dimigen et al., 2011). Based on the trigger alignment, the mean synchronization error was below 1 ms. Independent components related to EMs were detected by using optimized ICA training data with overweighted spike potentials for better ocular artifact correction (Dimigen, 2020). Following Dimigen's (2020) guidelines, ICA was trained on band-pass filtered training data (at a passband edge of 2.5 Hz) and ocular components were removed with eye tracker-guided component identification (Plöchl, Ossandón & König, 2012), with a variance ratio threshold of 1.1. EEG data was segmented into two epochs of interest: -200 to 800 ms time-locked to the first fixation on the pretarget (n) and target (n+1) words. Non-ocular artifacts were detected with a moving window peak to peak threshold of 100 µV and later visually inspected and rejected manually, in order to control for possible artifacts not detected automatically. After processing both EM and EEG data streams, only participants with at least 20 trials per condition were kept in the analyses to maximize statistical power.

Analysis

For the EM data, we analyzed first fixation durations (duration of the first fixation made on a specific word during first-pass reading), single fixation durations (duration of the fixation made on a specific word, when there is only one fixation in first-pass reading), gaze durations (the sum of all fixations made on a specific word during first-pass reading before leaving it) and go-past time (the sum of all fixations on a specific word and subsequent fixations on words to the left of that word before fixating any word to the right of it) to assess early word processing. These measures were considered for both the pretarget (n) and target (n+1) words, in order to study previous parafoveal processing and preview effects, respectively. Additionally, later word processing of the target word was assessed by analysing total reading time (sum of all fixations on a word, including re-readings). Additionally, as in Schotter and Jia (2016), we analyzed fixation probability measures to better understand the effects of the preview word on the probability of fixating the target word during first-pass reading, the probability of making a regression out of the target word and re-reading words located to the left of it, and the probability of making a regression into the target word from later words in the sentence. All the chosen measures are standard reading measures for the study of the time-course of word processing (Rayner, 1998).

For the electrophysiological measures, FRPs time-locked to the pretarget (n) and target (n+1) words were also considered to study both previous semantic parafoveal processing while fixating the pretarget word and semantic preview effects when fixating the target word.

Theoretically we expected to analyse time windows related to the N400 component, which should hold significant effects, based on our hypothesis. A mass univariate analysis was performed to select the specific time windows. More precisely, a point-by-point t-test analysis using the Guthrie-Buchwald approach (Guthrie & Buchwald, 1991) was performed for the whole epoch. The beginning and end of a time window would be defined by the beginning and end of, at least, 12 consecutive points with a significant t-test (Guthrie & Buchwald, 1991).

Electrodes were grouped into three clustered factors in the final mixed model analyses, in order to estimate the topographic distribution of effects. We followed the same topographic design as Barber et al (2013), with the anteriority, laterality and hemisphere factors. The anteriority factor had 5 levels: frontal (Fz, F7, F3, F4, F8), frontocentral (FC5, FC1, FC2, FC6), central (Cz, T7, C3, C4, T8), centroparietal (CP5, CP1, CP2, CP6), parietal (Pz, P7, P3, P4, P8). The laterality factor had 2 levels: medial (F3, F4, FC1, FC2, C3, C4, P3, P4, CP1, CP2), lateral (F7, F8, FC5, FC6, CP5, CP6, P7, P8, T7, T8). Finally, the hemisphere factor had 2 levels: left (F7, F3, FC5, FC1, T7, C3, CP5, CP1, P7, P3) and right (F8, F4, FC2, FC6, T8, C4, CP2, CP6, P8, P4).

In order to more accurately observe the display change effect in the FRP signal, an additional analysis was performed in parieto-occipital electrodes (P7, O1, O2, P8). We based our analysis on the FRP study of Dimigen et al. (2012), where he found a display change preview effect from 170 to 252 ms in PO9 and PO10 electrodes in free reading of lists of words. The temporal window of choice was guided by the point-by-point t-test analysis, although we expected the effect to be present at a similar time-window as in the mentioned study.

All analyses were performed with R software (http:// www.rproject.org), by using the ULLRToolbox (https:// sites.google.com/site/ullrtoolbox/home). All EM measures and mean voltage from the selected time windows were analysed using linear mixed effects models with the lme4 and lmerTest R packages (Bates, Maechler, & Bolker, 2011; Bates, Mächler, Bolker, & Walker, 2015; Kunzetsova, Brockhoff, & Christensen, 2017). If a preferable maximal random effects model (Barr, Levy, Scheepers, & Tily, 2013) did not converge, we reduced the random effects structure to include random intercepts for subjects and items and a random slope for the preview condition for subjects, followed by random intercept for items and a random slope for subjects model. If none of these models converged, we reduced the structure to an only intercept for subjects and items random effects model. We used Satterthwaite's method to calculate the pooled degrees of freedom of the variances (Khuri, Mathew, & Sinha, 1998;

Satterthwaite, 1941). In case of the non-normality of the residuals of the estimated models, a scaled power (box-cox) transformation was performed with the estimated lambda of the model (Box & Cox 1964; Fox & Weisberg 2018). For fixation probability measures, the mixed model was conducted using a logistic link function.

For the eye movements analysis, orthogonal Helmert contrast comparisons were included in the mixed model, which were decided a priori based on the hypothesis described in the introduction. We compared the identical preview condition to the combination of plausible and implausible preview conditions, in order to look for display change effects. Additionally, we compared plausible and implausible conditions to each other, in order to look for pure preview plausibility effects. For the FRP analysis, we included the three clustered topographic factors (5 x 2 x 2) to explore the interaction of the main manipulation with scalp topography. We used the *anova* output of lmer and emeans (Lenth, Singmann, Love, Buerkner, & Herve, 2018) packages to look at the contrasts at relevant topographical levels. Contrasts were performed with the emeans package and p values were adjusted with Hochberg's method (Hochberg, 1988). We report significant F and p values for the anova output for the topographical factors and b, t and p values of the fixed effects table.

4.2.3. Results

Eye movements

For the EM analysis, we ran mixed models with random intercepts for items and subjects because the maximal model did not converge (Barr et al. 2013). Early reading time measures for fixation on the target words revealed that, compared to the implausible and plausible conditions, the identical condition led to shorter first fixation durations, single fixation durations, gaze durations, and go-past times (all $ps < 0.001$). Additionally, compared to the plausible condition, the implausible condition led to longer first fixation durations ($p < 0.05$), single fixation durations ($p < 0.01$), gaze durations ($p < 0.01$) and go-past times ($p < 0.001$). For fixations on the pretarget word, there were no differences in reading times between the different preview conditions.

Contrasts of total reading time spent on the target word revealed that the total time spent on the target word was shorter in the identical condition, compared to the conditions where a display change took place ($p < 0.001$). Contrary to earlier reading measures, time spent on the target word was longer for the plausible condition than for the implausible condition, but the difference was not significant (p = 0.38; see Figure 2).

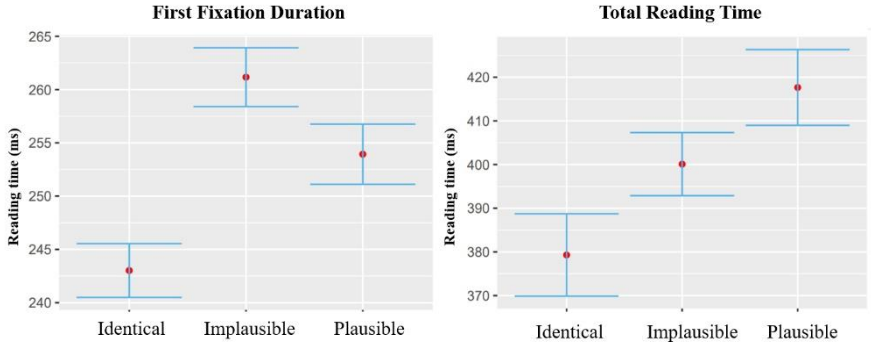

Figure 2. *Early (left) and late (right) reading measures on the target word for the identical, plausible and implausible conditions.*

Participants had similar target fixation probability across conditions (both ps > 0.05). However, participants regressed out of the target word more often in the implausible compared to the plausible preview condition (p < 0.01). Additionally, they regressed back to the target word more often in the plausible condition than in the implausible condition (p < 0.001), and less often when there was no display change compared to the other two conditions (p < 0.01; see Table 2 and 3).

Table 2. *Reading measures on the target word. Mean and standard errors.*

Measures	Preview condition		
	Identical	Plausible	Implausible
First Fixation Duration	243.01 (2.73)	253.93 (2.68)	261.16 (2.73)
Single Fixation Duration	243.67 (3.3)	252.92 (3.51)	263.35 (3.69)
Gaze Duration	262.5 (3.35)	277.87 (3.48)	288.4 (3.76)
Go-Past Time	321.76 (6.79)	330.02 (7.22)	354.58 (6.25)
Total Time	379.29 (8.47)	417.64 (8.72)	400.09 (8.12)
Fixation Probability	0.88 (0.01)	0.90 (0.01)	0.90 (0.01)
Regressions out of the target	0.12 (0.01)	0.11 (0.01)	0.14 (0.01)
Regressions into the target	0.24 (0.01)	0.31 (0.01)	0.25 (0.01)

Table 3. *Fixed effects of the contrasts of the linear mixed effects models for eye movements measures on the target word*.

Measures	Contrast	b	SE	|t|	p
First fixation duration	Identical vs Plausible+Implausible	-5.220	1.066	-5.059	<0.001
	Plausible vs Implausible	-3.028	1.843	-2.008	<0.05
Single fixation duration	Identical vs Plausible+Implausible	-4.876	0.988	-4.618	<0.001
	Plausible vs Implausible	-4.041	1.686	-2.697	<0.01
Gaze duration	Identical vs Plausible+Implausible	-7.300	1.320	-5.636	<0.001
	Plausible vs Implausible	-4.702	2.253	-2.839	<0.01
Go-Past time	Identical vs Plausible+Implausible	-7.687	2.631	-4.459	<0.001
	Plausible vs Implausible	-11.606	4.491	-4.138	<0.001
Total time	Identical vs Plausible+Implausible	-10.913	3.278	-6.503	<0.001
	Plausible vs Implausible	8.696	5.595	0.877	0.38
Measures	**Contrast**	**b**	**SE**	**|z|**	**p**
Fixation probability	Identical vs Plausible+Implausible	-0.05	0.033	-1.53	0.124
	Plausible vs Implausible	0.007	0.059	0.13	0.894
Regressions out of the target	Identical vs Plausible+Implausible	-0.007	0.036	-0.19	0.8476
	Plausible vs Implausible	-0.172	0.062	-2.75	<0.01
Regressions into the target	Identical vs Plausible+Implausible	-0.086	0.029	-2.97	<0.01
	Plausible vs Implausible	0.175	0.048	3.624	<0.001

Fixation-Related Potentials

Pre-analysis stage. After performing the mass univariate analysis, we considered at least 12 consecutive compared points with significant p values to consider a temporal window for the mixed model analysis, following the Guthrie & Buchwald (1991) method. For the FRPs time-locked to the pretarget word, there was an effect of the preview between the 350 and 450 ms, reflecting the N400 component. For the FRPs time-locked to the target word, there were significant preview effects, which started at 100 ms and lasted until 400 ms. Since we were interested in studying the N400 component and to test the effects in earlier and later semantic and plausibility processing, we split the window and selected the 100-250 and 250-400 time windows for the mixed effects analyses (see figures 3 and 4). For the analysis of the parieto-occipital electrodes, the preview effect was located between the 150 ms and 300 ms for the FRPs time-locked to the target word, so we chose that temporal window for the mixed model analysis (see Figure 5).

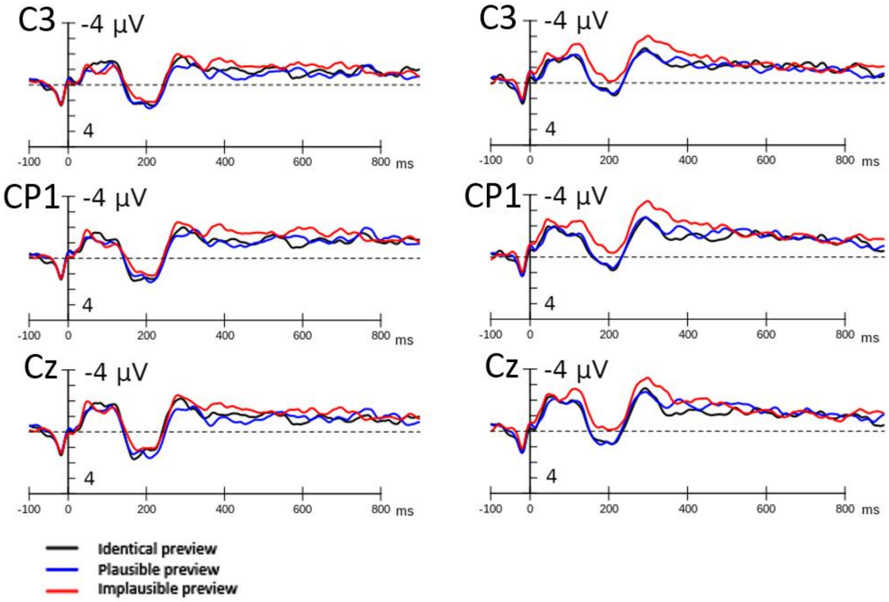

Figure 3. *Grand average FRPs at the C3, CP1 and Cz electrodes for the fixation onset on the pretarget word (left) and on the target word (right) for the identical, plausible and implausible preview conditions.*

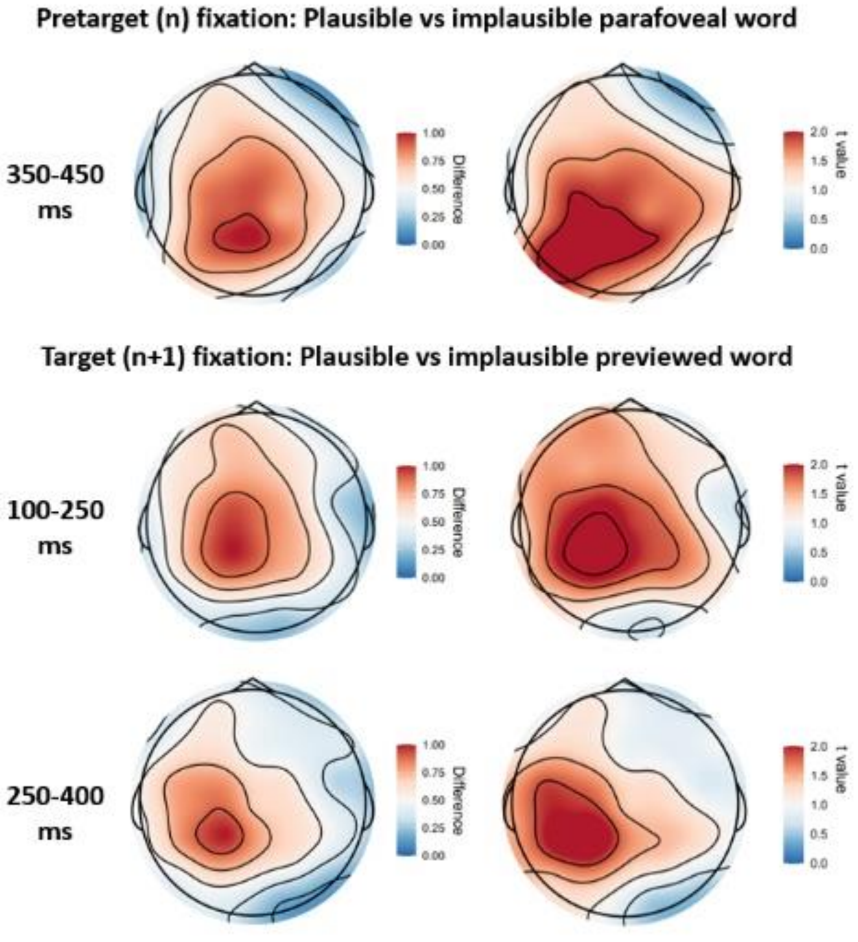

Figure 4. *Topographic maps for the FRPs time-locked to the target word, showing semantic parafoveal processing for the 350-450 ms temporal window during the fixation of the pretarget (n) word (up) and semantic preview effects for the 100-250 ms and 250-400 ms temporal windows during the fixation of the target (n+1) word (down). The maps display the mean differences and t values of the comparison of plausible and implausible preview conditions.*

Mixed effects analysis. Since a maximal random model did not converge (Barr et al., 2013), we selected a model with random intercepts for subjects and items and random slopes for the preview factor for subjects in both the FRP time-locked the pretarget and target words.

The mixed effects analysis for the FRP time-locked to the pretarget word in the 350-450 temporal window revealed that the implausible condition showed a greater negativity when compared to the plausible condition ($t = 2.26$, $p < 0.05$), with no differences between the identical and the combination of plausible and implausible conditions ($t = -0.42$, $p = 0.66$) and no influence of the topographical factors.

Looking at the analysis of the FRP time-locked to the target word, in the 100-250 ms temporal window there was a greater negativity for the implausible condition compared to the plausible condition ($t = 2.6$, $p < 0.01$), with no differences between the identical and the combination of plausible and implausible conditions ($t = 1.5$, $p = 0.12$). In terms of interactions with the topographical factors, in the *anova* output of the lmerTest, the preview factor interacted with the laterality topographic factor $F(2, 52064) = 3.83$, $p < 0.05$ in the 100-250 ms temporal window, revealing that the difference between implausible and plausible conditions was mainly present in medial electrodes ($t = 3.2$, $p < 0.01$) but not in lateral electrodes ($t = 1.8$ $p = 0.14$). The analysis of the 250-400 temporal window showed that the implausible condition had a greater negativity compared to the plausible condition ($t = 2.1$, $p < 0.05$). Additionally, the identical condition was marginally different from the combination of implausible and plausible condition ($t = 1.8$, $p = 0.07$), with a reduced negativity in the 250-400 ms temporal window. In addition, for the analysis of the parieto-occipital electrodes in the 150-300 temporal window, we found that the identical condition had a greater positivity when compared to the combination of plausible and implausible conditions ($t = 3.35$, $p < 0.01$) while there was no differences between the plausible and implausible conditions ($t = 1.39$, $p = 0.17$).

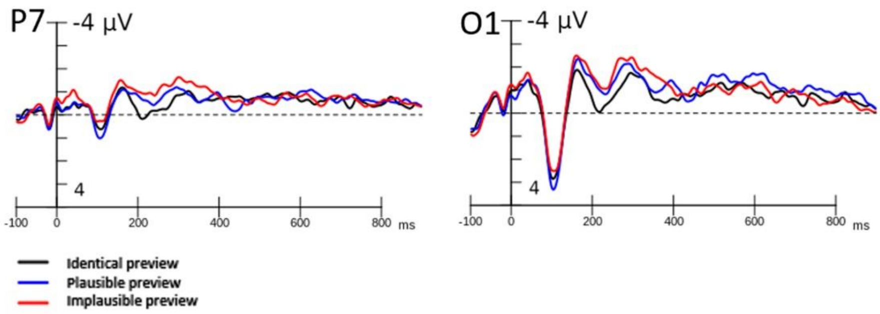

Figure 5. *Grand average FRPs at the parieto-occipital (P7 and O1) electrodes for the fixation onset on the target word for the identical, plausible and implausible preview conditions.*

4.2.4. Discussion

In this study, we explored the processing of semantic information perceived in the parafovea during sentence reading. We investigated whether semantic parafoveal information can be accessed and integrated during natural reading and aimed to describe the time-course of the parafoveal semantic effects. In order to do so, we used an EEG-EM co-registration set-up, which brought us two main benefits: 1) We were able to extract ERPs associated with fixations and therefore to study comprehension processes during a free reading task. In this way, we were able to test if previous EEG effects obtained in highly controlled RSVP paradigms are also observed in a more ecologically valid situation. 2) We simultaneously obtained two online measures of the processes related to reading that previously have resulted in slightly different interpretations. This allowed us to track the time course of sentence comprehension integrating two complementary approaches. Furthermore, we used the invisible boundary paradigm to manipulate parafoveally previewed words with varying plausibility. The plausibility manipulation allowed us to study the semantic processing in the parafovea independently of orthographic predictions.

Exploring the time-course of plausibility preview effects, we expected first-pass reading durations of the target words being affected by the semantic manipulation of the previews. This result would fit with amplitude modulations on early time windows in FRPs time-locked to the target (n+1) word. However, based on previous EEG studies (Kretzschmar et al., 2009; Barber et al., 2013; Stites et al., 2017) we also expected effects in later time windows (e.g. N400 effects) in spite of the fact that previous EM evidence has suggested that plausibility preview effects are short-lived (Schotter & Jia, 2016; Veldre & Andrews, 2016, 2017, 2018b). Additionally, we expected to find a modulation in the N400 component in FRPs time-locked to the pretarget (n) word, replicating flanker-RSVP-ERP evidence of semantic parafoveal processing in the absence of EMs (Barber et al., 2013; Stites et al., 2017).

Eye-tracking Results

Eye Movements measures related to the target word show a display change effect, consistent with trans-saccadic integration processes. Readers obtained a benefit from the identical preview compared to the display change conditions in both first-pass reading duration and total reading duration measures, reflecting the cost of integrating previews unrelated to the target word (for a review, see Schotter et al., 2012). More interestingly, first-pass reading measures (but not total reading duration) revealed longer fixation durations for the implausible condition compared to the plausible condition, consistent with recent evidence of preview plausibility effects (Schotter & Jia, 2016; Veldre & Andrews, 2016, 2017, 2018b; see Andrews & Veldre, 2019). Both plausible and implausible unrelated previews shared little to no orthographic or semantic features with the target word, suggesting this effect is not due to trans-saccadic integration. Instead, such effects could only be explained by a contextual fit account, in which integrating the implausible previews to the sentence context would have a greater cost. This supports the idea that both contextual and trans-saccadic integration processes are independent of each other, probably operating at different levels (Veldre & Andrews, 2017). It is important to clarify that such preview plausibility effects were not influenced by anticipatory predictions of upcoming words, since all previews and targets had extremely low cloze probability values (i.e., below 2-3%). Thus, these findings were not enhanced by a facilitatory effect of predictability (Staub, 2015).

Fixation Related Potentials: Display change effects

The analysis of the FRP time-locked to the target word for the parieto-occipital electrodes revealed a preview effect related to the display change between the 150 and 300 ms. More specifically, a greater positivity in this temporal window was found when the previewed word was identical, compared to when the preview word was different from the target word. Our findings replicate previous evidence from Dimigen et al., (2012), who found that identical previews lead to facilitatory effects reflected in shorter fixation durations and more positive amplitude that emerged from around 170 ms to 280 ms in the PO9 and PO10 electrodes, compared to the other conditions where a display change was present. As they also indicated, both their and our findings in fixation durations and FRPs amplitudes may support the classic idea that the display change effect is related to a pre-activation of orthographic codes before lexical access, an idea established from both EM (Rayner, 1998) and ERP research in visual word recognition paradigms (see Barber & Kutas, 2007). Additionally, the analysis of all electrodes revealed modulations of the N400 component, being the identical condition marginally less negative than the average of the implausible and plausible unrelated conditions, consistent with a later facilitation effect in FRPs for valid previews with the boundary paradigm

(Li et al., 2015; López-Perez et al., 2016). Following Dimigen et al. (2012), the N400 attenuation derived from a valid preview could be equivalent to the repetition priming effect derived from visual word recognition studies (see Holcomb, & Grainger, 2006; 2007), which could suggest that similar mechanisms of trans-saccadic integration of low-level features are involved in both word recognition and natural sentence reading paradigms. The full repetition priming effect involves the activation of words at multiple levels since the activation of form and orthography leads to higher levels like phonology, morphology and semantics (see Barber & Kutas, 2007). This would explain the early activation of pre-activation of orthographic codes and the late activation reflected in the N400, related to a semantic access of words (Kutas & Federmeier, 2011), which would be consistent with the behavior of readers reflected in both, ours and previous, EM data in natural sentence reading (see Schotter et al., 2012).

Fixation Related Potentials: Semantic and plausibility effects

Moving on to semantic and plausibility effects in the electrophysiological record, FRPs time-locked to the pretarget word revealed semantic parafoveal processing reflected in the modulation of the N400 component. Specifically, the implausible condition showed a greater negativity when compared to the plausible condition, meaning that a contextually implausible preview had greater processing costs. Hence, during natural reading, words located in the parafoveal region are semantically accessed and their meaning interacts with sentence-level context information. On the one hand, this finding could be surprising based on EM literature, since semantic parafoveal effects during the fixation of the pretarget words had been absent in EM experiments with the boundary paradigm (for a review, see Schotter et al., 2012). On the other hand, the semantic processing of parafoveal words during the fixation of the pretarget word replicates previous evidence of semantic parafoveal processing from ERPs in more artificial reading situations and in visual word recognition paradigms (Barber et al., 2011; Barber et al., 2010; Li et al., 2015; López-Pérez et al., 2016; Snell, Meeter, Holcomb, & Grainger, 2019). Our data suggest that these prior findings can be extended to more naturalistic reading situations, supporting the idea that evidence from artificial reading situations (e.g. flankers-RSVP or word-pairs paradigms) may be valid for drawing conclusions about what may be happening in sentence reading. Even though Kretzschmar et al, (2009) previously reported semantic modulations in the N400 component during the fixation of a pretarget word, they were associated with semantically incongruent parafoveal words compared to congruent predictable words in highly constraining sentence constructions, which may suggest, as they also pointed out, that their findings may be better described as orthographic in nature, rather than semantic. Additionally, the use of the boundary paradigm in this experiment ensures that any semantic effects are derived from the parafoveal word and not from the meaning of the target word, isolating parafoveal effects. More interestingly, these findings also extend pure plausibility effects from flanker-RSVP-ERPs paradigms without the presence of EM (Stites et al., 2017) to natural sentence reading. Both their and our findings of plausibility parafoveal processing confirm that semantic access of parafoveal words is independent from orthographically-related predictions of the upcoming words, in both artificial and natural reading scenarios. In addition, such consistency between EEG measures from different paradigms would support the idea that semantic and plausibility parafoveal processing during the fixation of the pretarget word involves cognitive mechanisms that are independent from saccade programming. It should be mentioned that in our sentences, pretarget words and previews were not formally or semantically related. Consequently, effects at the time of the processing of the pretarget cannot be explained as a facilitation of the parafoveal information (preview word) over the foveal processing. Instead, our results show that the parafoveal meaning activation is modulated by the previous sentence context. Previous ERP studies did not find evidence of independent processing of foveal and parafoveal words, especially attending to the morphology and latencies of the foveal and parafoveal N400 effects (Barber et al, 2013). Keeping that in mind, the pretarget effect in our study would be compatible with an interactive view in which foveal and parafoveal meaning activations take place simultaneously and are determined by the previous state of the memory system.

Looking at the FRPs time-locked to the target word in the 100-250 ms temporal window, analyses revealed more negative amplitudes in the implausible condition when compared to the plausible condition. These results align with our findings in first-pass reading measures, revealing a greater processing cost when a contextually implausible word was previewed before fixating the target word. These results replicate previous FRPs findings of López-Pérez et al., (2016) of early semantic preview effects, but contrast with Antúnez et al., (2021), who only found such effects in the N400 component in FRPs time-locked to the target word. In both studies, readers had to read word-pairs in Spanish and had to indicate if they were semantically related or not. With the invisible boundary paradigm, López-Pérez et al., (2016) manipulated the previewed word, so it was semantically related or not to the pretarget word. In the first study of the tesis (Antúnez et al., 2021), readers were Basque-Spanish bilinguals and the preview was either a Basque non-cognate translation of the Spanish target word or a totally unrelated Basque word. A possible explanation of the replicability between these FRPs studies in word-pair paradigms and our results may be related to the presence of N400-related semantic parafoveal effects during the fixation of the pretarget word. In our study, similarly to the semantic parafoveal-on-foveal effects reported by López-Pérez et al., (2016), we found a previous activation of the meaning of the parafoveal words during the fixation of the pretarget word, followed by the early semantic preview effect during the fixation of the target word. In contrast, we failed in the first study (Antúnez et al, 2021) to find either parafoveal-on-foveal or early preview benefit effects. A potential explanation is that previous activation of semantic parafoveal information during the fixation of the pretarget word could have boosted early plausibility preview effects during the fixation of the target word. The discrepancies between Antúnez et al (2021) and both ours in the second study and López-Perez et al.'s (2016) findings may be owed to the fact that the manipulation used in the first study involved a more subtle semantic manipulation (i.e. preview non-cognate translations of target words in a bilingual sample). Additionally, while we manipulated the contextual fit of parafoveal words and López-Pérez et al (2016) manipulated the semantic relationship between preview and pretarget words, Antúnez et al., (2021) focused on manipulating the preview-target semantic relationship across languages, which may have reduced the semantic parafoveal effects during the fixation of the pretarget word. Future research may explore different semantic parafoveal manipulations in FRP studies in natural sentence reading paradigms.

In line with our hypothesis, modulations of the N400 time-locked to the target word also revealed a greater processing cost for the implausible condition compared to the plausible condition. This replicates the N400 findings of semantic preview effects in FRP studies (the first study of the thesis, Antúnez et al., 2021; López-Perez et al., 2016), indicating that the meaning of parafoveal words is accessed and used to facilitate the consequent processing of target words. We present evidence for the first time of semantic preview effects in the electrophysiological record in natural sentence reading. Because our results are consistent with the word-pair paradigms of Antúnez et al. (2021) and López-Perez et al. (2016), FRP studies with controlled-reading paradigms may be valid for drawing conclusions about how the meaning of parafoveal words are accessed and integrated in natural sentence reading. Having said that, it would be important to point out that the semantic modulation of the N400 found here involved contextual integration processes, rather than a semantic integration between preview and target words like in word-pair paradigms, so future research should add further control to better understand the role of high-order semantic parafoveal processing in word recognition and natural sentence reading paradigms.

Time-course of parafoveal semantic processing

The findings related to semantic N400 modulations in the FRPs time-locked to the target word are of great assistance when delving into the time-course of plausibility preview effects. The modulation in the temporal window of the N400 component contrasts with our EM measures and with previous EM evidence suggesting that processing difficulties of the target word after previewing a contextually implausible unrelated word could be short-lived (see Andrews & Veldre, 2019). More specifically, our results from EM, in line with previous evidence, showed that plausibility effects were limited to early processing, as revealed by first-pass reading measures (Schotter & Jia, 2016; Veldre & Andrews, 2016, 2017, 2018b). No significant differences were found between plausible and implausible previews in total reading time, which could suggest that plausibility may not affect later processing. Even though not significant, the patterns in EMs differ from early to late processing, since participants had longer total reading times in the plausible condition. This could be explained by the greater probability of regressing into the target in the plausible condition, as our results show, which could have diluted the greater cost derived from the implausible condition. Nevertheless, readers were still more prone to regress to the region before the target word in the implausible condition, suggesting that later costs linked with difficulties in contextual integration processes. More importantly, the modulation of the N400 component shows that plausibility effects are still present during later processing, contrasting with our findings in EMs. Since the temporal window of the N400 is not affected by the greater probability for readers to regress into the target in the plausible condition, the electrophysiological measure would be more suitable to isolate the effects derived from greater integration costs after an implausible preview. Therefore, as opposed to previously suggested in the literature, the high-order integration of the previewed word with the sentence context affects both early and later processing of the target word and reading behavior. Finally, the inconsistencies between FRPs and EM measures would also suggest that later plausibility preview effects are linked to different cognitive processing mechanisms related to semantic processing and oculomotor behavior, making it necessary to use a co-registration set-up to better understand the time-course of parafoveal effects.

Methodological considerations

In line with our question of interest, our results also raise new concerns and questions about the study of semantic parafoveal processing and the experimental paradigm of choice. As previously discussed, most neural evidence for semantic parafoveal processing has come from electrophysiological studies using more artificial reading paradigms (derived from ERP designs), where EMs are absent. Our results show that artificial tasks that allow the adequate experimental control of multiple variables are necessary and recommended for isolating questions and consolidating hypotheses. However, the co-registration technique in natural reading situations offers a number of advantages to be considered. First, and probably the most obvious one, is the ecological validity associated with recording electrophysiological brain activity during a natural sentence reading situation where oculomotor behavior is present. Second, the patterns of the FRP signal in free-viewing reading vary from more classical ERP paradigms (for a review, see Degno & Liversedge, 2020). For instance, the modulation of the N400 component in the fixation of the target word here was found between the 250-400 ms, reflecting an earlier onset of the effect than in semantic preview studies with more artificial paradigms, in which it arises between 300-500 ms (the first study of the thesis, Antúnez et al., 2021; Dimigen et al., 2012, López-Perez et al., 2016). Our earlier onset of semantic parafoveal effects in natural sentence reading scenarios is not completely surprising, though. Previously, Kornrumpf et al. (2016) manipulated the preview of the upcoming word by changing the number of visible letters in the parafoveal region in two different scenarios: a flanker-RSVP and a free-reading of word-lists. They found a preview effect starting at 230 ms under flanker-RSVP reading, but the same effect started at 160 ms in natural reading of lists of words, which, in combination with our findings, raises new questions about the nature and timing of processing during reading. For example, our earlier N400 onset may reflect a more accurate estimation of word recognition processes during natural reading. Finally, co-registration of EMs and EEG provides additional insight into natural reading studies where only EMs are recorded. For instance, EM research uses direct measures of reading behavior to infer what kind of cognitive processing is taking place. However, as the evidence provided here suggests, not all cognitive activity modulates behavior in the same way, so electrophysiological measures can capture some information that goes undetected by behavioral EM measures. Exploring the consistency between FRPs and EM measures may offer a clearer explanation of which processes are linked to oculomotor behavior and which ones may be independent from them.

Having said that, all the advantages of the co-registration mentioned here come at some cost. First, we may face a greater loss of trials owing to the filtering and processing criteria of both EM and FRPs data streams, which may lead to more difficulties in detecting smaller effects owing to less statistical power. Additionally, we may face an overlapping activity from multiple fixations that may contaminate the effects of interest. A recent alternative approach is related to non-linear deconvolution models, where regression-ERPs can be extracted before entering them into a second-level group analysis (see Dimigen & Ehinger, 2020). Here, we applied linear mixed-effects models since they have important advantages, such as including crossed random effects for subjects and items, which allows us to analyze trial-level data rather than average across participants first. Having said that, computational and statistical research may focus on integrating both deconvolution and mixed-effects models to obtain the advantages of both approaches. Future lines of research may take into account these considerations when co-registering EM and FRPs in natural sentence reading, so they may use a tool with several advantages that provides complementary evidence of the multiple cognitive processes taking place during reading.

Conclusions

In summary, we provided evidence for the first time of semantic-plausibility parafoveal processing in natural sentence reading in the electrophysiological record during the fixation of both the pretarget and target words. By using an EEG-EM co-registration set-up in a more ecological reading situation, our findings support the validity of previous highly controlled reading paradigms. Importantly, both complementary data-streams allowed us to disentangle the time-course of parafoveal semantic access determined by sentence-level context information. The co-registration technique during natural reading may be of great assistance in the study of the cognitive mechanisms involved in semantic parafoveal processing.

Acknowledgments

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4.3. Study 3 – The role of individual differences in the perceptual span of readers over semantic parafoveal processing in natural sentence reading.

This study is ready for submission.

Abstract:

There is evidence that the ability of attentional resources across the visual field plays an important role in parafoveal processing. Here, we collected individual differences measures of the perceptual span of readers, to test if their perceptual span can modulate the depth of parafoveal processing,by allocating more attentional resources into the parafoveal region. In addition, we collected spelling ability measures of readers to test if linguistic ability may also affect the depth of parafoveal processing and if it may be linked to the perceptual span. The sample of readers was the same one as the study 2, in order to use the electrophysiological and EM data of the second study to test the predictive power of the perceptual span and the spelling ability of readers. We provided evidence that both, perceptual span and spelling ability measures affect the depth of semantic parafoveal processing in FRPs measures. The variance in attentional distribution of readers must be considered when exploring to parafoveal effects, bearing also in mind their individual differences in linguistic ability.

Keywords: Parafovea – FRPs – Attentional distribution – Perceptual span – Spelling ability

4.3.1. Introduction

It is common knowledge that, during reading, we extract a large amount of information from the text across the visual field. More specifically, we are able to extract information from both, the fovea and the parafoveal visual region, which is located between 1 and 5 degrees away from the fixation point. Despite the lower resolution of words located in the parafoveal región, it is solidly stablished that we can accessed them at an orthographic and phonological level (for a review, see Schotter et al., 2012). The extracted and processed parafoveal information may affect the consequent reading behavior. For instance, a preview effect may occur when the previous parafoveal information facilitates the processing of the incoming word when fixated. This facilitation can be considered as a preview benefit but preview costs can also be observed when abnormal previews hampers consequent reading behavior, meaning that the extraction of parafoveal information is far from a simple process.

For a time, it was thought that semantic information could not be accessed parafoveally (Altarriba et al., 2001; Hyönä & Häikiö, 2005; Rayner et al., 1986; White et al., 2008; see Schotter et al., 2012). However, later on, subsequent experiment recording eye movements used the boundary paradigm of Rayner (1975) to manipulate parafoveal previews and started supporting the possibility that the meaning of parafoveal words could be accessed in natural reading (e.g. Hohenstein et al., 2010; Schotter, 2013; Schotter et al., 2015; Schotter & Jia, 2016; Veldre & Andrews, 2016, 2017, 2018). Strong evidence of semantic parafoveal processing also come from EEG studies in more artifitially controlled reading situations that obtained Event-Related Potentials (ERPs) (Barber et al., 2011; Barber et al., 2010; Barber et al., 2013; Li et al., 2015) and Fixation-Related Potentials (FRPs) (Dimigen et al., 2011; Dimigen et al., 2012; Kretzschmar et al., 2009; Kretzschmar et al., 2015; López-Pérez et al., 2016; for more recent refined evidence, see the first study of the thesis, Antúnez et al., 2021). Semantic parafoveal effects were usually reported in such studies by looking at modulations in the N400 component, which has been classically linked with semantic processing (Kutas & Federmeier, 2011). More recently, the second study of the current thesis (Antúnez, Milligan, Hernández-Cabrera, Barber, & Schotter, under review) found FRP evidence of semantic parafoveal processing in natural sentence reading with the boundary paradigm, supporting the ecological validity of the mentioned EEG evidence and extending previous ERP and FRP semantic parafoveal findings to more naturalistic reading situations.

Even though there is proof that we can access words at an orthographic, phonological and semantic level, it is not yet understood why readers differ in their ability to extract parafoveal information and in how they use this information to increase their reading efficiency. Since the extraction and integration of parafoveal information is a complex activity with multiple phases, it is very likely that multiple sources related to individual differences of the subjects are the ones to determine the parafoveal impact in reading. Among these differences, it has been reported that parafoveal processing may be affected by the reading strategy (Wotschack & Kliegl, 2013) or even the age (e.g. Payne & Stine-Morrow, 2012; Rayner et al., 2010) of skilled readers. Other individual differences that have proven to be particularly relevant to the extraction of parafoveal information are the ones related to linguistic ability. For example, Veldre & Andrews (2016) collected Reading and spelling ability scores of readers that had to read sentences. They used the gaze-contingent boundary paradigm (McConkie & Rayner, 1975; Rayner, 1975) to manipulate the availability of relevant semantic and orthographic information in the parafovea. Veldre & Andrews (2016) presented previews that could be identical, semantically related, non-word orthographically related or completely unrelated to the presented target Word (e.g. Melanie thought that the man was really [psycho, insane, psyrla, circus] after learning of his crimes). They found that higher reading ability increases semantic preview effects, while higher spelling ability increases the preview costs of a orthography mismatch between previews and targets. They suggested that individual differences between skilled readers in linguistic ability would directly affect the depth of semantic parafoveal processing. To explain how a greater linguistic ability does facilitate the depth of processing of parafoveal words, they based on the lexical quality hypothesis of Perfetti (1992; 2007). According to the lexical quality hypothesis, a high-quality lexical stored representation of a word supports its rapid and synchronous activation at an orthographic, phonological and semantic level. Skilled readers with greater language ability would have be exposed to multiple words and they would have increased lexical quality of the representations stored in their mental lexicon, which would lead to a faster and more efficient activation of parafoveal words. There is evidence that the lexical quality of stored words of readers may affect parafoveal processing at an orthographic (Veldre & Andrews, 2015b), lexical (Veldre & Andrews, 2015a), phonological (Chace et al., 2005) and even semantic (Veldre & Andrews, 2016) level.

On the other hand, less attention has it given to how individual differences in the ability to distribute attention into the parafoveal region may directly affect the depth of parafoveal processing. This is quite surprising, since evidence of how the depth of parafoveal processing can be enhanced by increasing the availability of attentional resources through modification of properties of the task is not scarce (e.g. Barber et al. 2013; Payne et al., (2016); White, Rayner & Liversedge, 2005; Veldre & Andrews, 2018). In one of these studies, Barber et al., (2013) wated to know how the availability of cognitive resources could modulate the depth of processing of parafoveal words, that could be predictable or unpredictable. Through the extraction of ERPs in a flanker-RSVP experiment, they found that the extraction of semantic parafoveal information was altered by different contextual and temporal constraints of the task. This was reflected in a modulation of the N400 component, which has been classically linked with semantic processing in language (Kutas & Federmeier, 2011). More specifically, parafoveal N400 effects in low constraint sentences were observed only at a slow stimulus presentation rate (SOA = 450 ms) but not when words were presented to a faster speed, similar to that of natural reading (SOA = 250 ms). The authors argued that the greater cognitive load would reduce the availability of attentional resources allocated into the parafoveal region, disturbing parafoveal access. In another experiment with the flanker-RSVP paradigm, Payne et al. (2016) manipulated the semantic expectancy and congruity of the currently fixated word and parafoveal previews could be valid or orthographically invalid. They found that a greater foveal load reduced the processing of parafoveal words, through disruption of attentional resources allocated onto the parafoveal region. According to the foveal load hypothesis (Henderson & Ferreira, 1990, 1993; see also Henderson, Pollatsek, & Rayner, 1987), when a fixated word is more difficult to process or less accessible, less attentional resources are available to distribute and to process upcoming words, which may hinder parafoveal processing by reducing the size of the called perceptual span of readers.

The perceptual span refers to the extension of the attended region at a given fixation in which visual input can be accessed and processed and it reflects an asymmetric distribution of attentional resources, extending only to 3-4 character to the left of fixation while reaching about 15 characters to the right of fixation in skilled readers (see Rayner, 2009; 2014). It also yields the classic idea that that spatial area from which useful information can be extracted is limited in readers (Huey, 1908). The perceptual span has been assessed with the gaze-contingent moving window paradigm (McConkie & Rayner, 1975; Rayner, 1975). In this paradigm, participants have to read sentences where letters are replaced by "X" masks, except for a predefined window that extends to the left and right from the fixated point. With each fixation, the window changes, so readers are always exposed to the same amount of visible letters. In experiments using this paradigm, multiple experimental conditions are used, where the amount of information available to the right of fixation can vary. This conditions, in combination with a full free-viewing condition, allow researchers to estimate the approximate size of the perceptual span, i.e. the extend of the visual field that can be attended and accessed at a given fixation. The size of the perceptual span and the amount of attentional resources available to distribute across the visual field may vary depending on properties of the text (e.g. the foveal load, see Henderson & Ferreira, 1990, 1993; see also Henderson et al., 1987) and, more importantly, it may be affected by multiple variables of the individual (e.g. Choi et al., 2015; Rayner, 1986; Rayner et al., 2010; Veldre & Andrews, 2014). For instance, Choi et al., (2015) examined individual differences in the size of the perceptual span of readers by using the gaze-contingent moving window paradigm and collecting a large battery of individual-difference measures grouped into two composed factors: language ability and oculomotor processing speed. They found that language ability (but not oculomotor processing speed) modulated the size of the perceptual span. In addition to this, Veldre & Andrews (2014) followed a similar approach where he found that readers with lower scores in reading and spelling ability had shorter perceptual spans than readers with higher scores in these individual differences measures. Both studies suggested that readers with greater linguistic ability might recognize the fixated foveal word easily, having more attentional resources avaible to process information in the parafoveal region (in line with the mentioned foveal load hypothesis of Henderson & Ferreira, 1990).

Even though, as illustrated, the role of the perceptual span and the availability of attentional resources over parafoveal processing has awakened a special interest, no study has yet addressed directly how individual differences of readers in their perceptual span and their ability to distribute attentional resources across the sentence affect parafoveal processing directly. Having said that, some studies that took different individual differences measures have highlighted its importance. As an example, while studying the effects of age over parafoveal processing, Payne & Federmeier (2017) used the flanker-RSVP-ERP paradigm to manipulate the previewed parafoveal word and reported that young adults were able to use parafoveal pre-processing to facilitate subsequent processing of foveal words, while older showed a deficit in their ability to integrate parafoveal and foveal semantic representations. The authors suggested that such differences between younger and older readers could be owed to a deficit in integrating parafoveal information and to a poorer distribution of attentional resources, since older adults tend to have a smaller perceptual span (see also Rayner et al., 2009). However, it would be important to assess directly how individual differences in the availability and distribution of attentional resources in skilled readers affect parafoveal processing, since it would allow us to know the role of attention without confounding it with other individual differences of subjects (i.e. reading strategy or age-related degenerated visual acuity, see Wotschack & Kliegl, 2013; Rayner et al., 2010). In this sense, the perceptual span of readers may be an individual difference measure that perfectly fits to approach these questions.

In our study, we wanted to know if the perceptual span of readers can modulate the depth of parafoveal processing owing to an increased attentional allocation onto the parafoveal region. We were particularly interested in knowing if these individual differences in attentional distribution could modulate how we access the meaning of parafoveal words, considering how recent the evidence of semantic parafoveal processing in natural reading from EM (e.g. Schotter & Jia, 2016; Veldre & Andrews, 2016, 2017, 2018) and FRPs (the second study of this thesis, i.e. Antúnez et al., under review) is, we have yet a long way to discover the mechanisms behind semantic parafoveal access. For answering these questions, we took the electrophysiological and EM data of the second study of the thesis and collected individual differences measures from their participants. In the mentioned study, we obtained Fixation Related Potentials (FRPs) through the co-registration of EM and EEG during a natural sentence-reading task and used the boundary paradigm to manipulate the previews. Participants could preview an identical word, an unrelated but plausible word and an unrelated and implausible word (e.g. Harry bought a broken watch/chair/peace to repair for fun). We selected readers from this study for two main reasons: first, the electrophysiological measures (FRPs) in a natural reading situation can be complementary to EM measures, since they have proven to be particularly useful in delineating the time course of word processing by exploring specific components (e.g. the N400 for the semantic access of words, see Kutas & Federmeier, 2011). Secondly, their parafoveal manipulation with identical, plausible and implausible previews with the boundary paradigm would allow us to explore how individual differences of subjects interact with both, orthographic and semantic parafoveal processing in natural sentence reading.

We collected measures of individual differences in the perceptual span of readers. Readers performed a reading task where the moving window paradigm was used to manipulate the number of visible letters, in order to obtain a measure of the perceptual span of the subjects, we run a predictive model for each subject where the reading rate was predicted by the size of the moving window. The predicted beta value from each subject was obtained and used as a predictor in later analyses in the boundary paradigm task, since these beta values can be considered as an individual difference measure of the size of the perceptual span. Therefore, readers with a greater beta value will benefit from greater windows, suggesting that they would have a greater perceptual span that will allow them to use more parafoveal information. On the other hand, readers with smaller beta values will not benefit from different windows, indicating that they would have a small perceptual span and that they would benefit less from parafoveal information.

Additionally, we collected an index of the lexical quality the representations of words of the readers. Our aim was to test if evidence of individual differences in language ability modulating the depth of parafoveal processing (Veldre & Andrews, 2016) may be replicated in FRPs measures in a co-registration set-up. Additionally, we wanted to add it as a control measure, since language ability may be related to the size of the perceptual span (Veldre & Andrews, 2014). Readers had to complete a spelling recognition and production task in order to obtain spelling ability. Spelling ability has been argued to be the best index of orthographic precision, which is central to lexical quality (see Andrews, 2012; Perfetti, 1992). Both spelling measures involve different encoding and response cognitive processes, so including both of them may isolate any undesired variance associated with the spelling ability measure (see Andrews, Veldre & Clarke, 2020).

First, in the moving-window paradigm task, we would expect to find a modulation of spelling ability over the size of the perceptual span, reflected in changes in reading rate, replicating previous evidence using the moving window paradigm (Veldre & Andrews, 2014), since readers with high-quality representations of words may extract more effitiently the available parafoveal information and have a quicker access of fixated words (e.g., Ashby, Rayner, & Clifton Jr,, 2005), which may also provide more attentional resources into the parafoveal region, considering the foveal load hypothesis. Secondly, in the boundary paradigm task, we also expect to replicate previous evidence of spelling ability modulating lexical (Veldre & Andrews, 2015a,2015b) and semantic (Veldre & Andrews, 2016) parafoveal processing, which may reflect a more efficient extraction of the representation of previewed words.

More importantly, in line with our main hypotheses, we expect that the size of the perceptual span may modulate semantic and orthographic parafoveal processing in the boundary paradigm task, meaning that more attentional resources would be available from readers to allocate into the parafoveal region, therefore affecting the strength of preview effects. This individual measure would support previous studies that modified properties of the task and suggested that attentional resources are a key factor to direct parafoveal processing (e.g. Barber et al., 2013; Payne et al. , 2016), extending their findings to individual differences in attentional resources in natural sentence reading. Where we to find such effects, we woud confirm that semantic parafoveal processing in natural sentence reading relies on both the availability of attentional resources allocated in the parafovea and the high-quality lexical representations of words of each reader and that both individual differences measures should by no means be accounted separately.

4.3.2. Method

Subjects

We recruited thirty-seven psychology students (21 female, 16 male; age: M=20.7, SD=4.1) from University of South Florida (Florida, United States) in exchange of course credits. They were the same subjects whose data was previously collected in the second study of the thesis in a different Reading task. As in the original study, they all were monolingual native English speakers with normal or corrected vision, right-handed and with no history of neurological disorders.

Materials

Spelling tasks

The ítems from the spelling recognition task were extracted from Andrews & Hersch (2010). From the 88 items, two were excluded because they had British rather than American English spelling. Half of the items were correctly spelled while the other half were misspelled. Items were presented printed in columns on an A4 sheet and readers had to circle the ones they considered as incorrectly spelled. The spelling recognition test score was a d' value calculated from the Hit and False Alarm rates.

39 ítems from the spelling production task were obtained from the 59 item Woodcock-Johnson Test of Achievement spelling sub-test (McGrew & Woodcock, 2001). Participants had to listen to a recording of all 39 items and they had to write them down. The items were

pronounced alone, contextualized in a sentence and alone again. The total number of correctly spelled produced words were considered as the spelling production test score. In order to minimize the number of variables in the final model, we merged both the recognition and production spelling scores into one spelling score, by obtaining the z values and averaging them together.

Moving window paradigm reading task

156 sentences were taken from Belanger et al. (2012). All sentences had between 10 to 17 words and had a simple syntactic structure to minimize reading difficulties (one independent clause or two independent clauses joined by a conjunction).

Design and procedure

Moving window paradigm task

Subjects were seated 60 cm away from a 20" HP p1230 CRT monitor, with a refresh rate of 150 Hz and a screen resolution of 1024 x 768 pixels. After arriving, participants read and signed the informed consent and performed the spelling recognition and production tasks. After that, they were instructed to read sentences and to answer occasional yes-no comprehension questions._Participants could either read unmasked sentences or masked sentences where only a specific number of characters close to the fixation point could be visible, being the non-visible characters replaced by lowercase "X" letters, without including the spaces between words. Therefore, the sentences could either show 6, 10, 14, 18, 22 or all visible characters to the right of the current fixation (see figure 1). In all masked sentences, four letters were visible to the left of fixation.

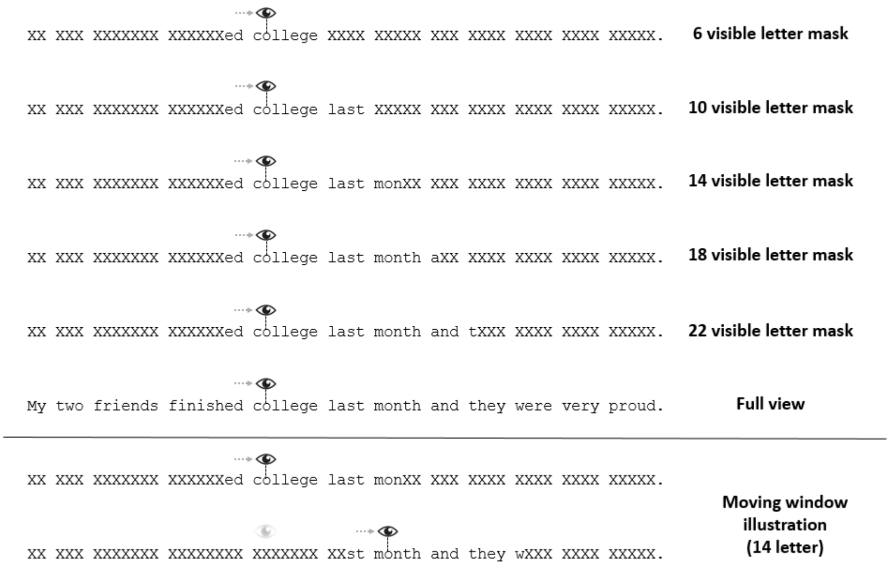

Figure 1. *Example of the different moving window conditions (up). The eye represents the fixated point in the sentence. Except for the full view condition, 4 characters were always available to the left of fixations, being the characters to the right variable. In the down part of the figure, the moving window is illustrated by showing two consecutive fixations in the 14 visible letter mask condition.*

At the beginning of each trial, a fixation point was presented in the center of the screen to ensure an accurate calibration of the eye movements. After starting the trial, a fixation box appeared on the left side of the screen, located at the beginning of the sentence. Fixation detection over the box triggered the sentence presentation, which stayed on the screen until the subject pressed a button on a response controller, indicating that they finished reading the sentence. They were instructed to look at a target sticker located on the right side of the screen before pressing the button, so they would not artificially look back to a word.

Participants read 10 practice sentences prior to the real experiment. In the experiment, readers were instructed to read all sentences and to answer the “yes-no” comprehension questions that could sometimes appear after finishing the sentence. All sentences were counterbalanced across participants and conditions and the order of presentation was randomized for each participant. Questions were presented in 20% of the trials. Readers answered 93% of the trials correctly, equally distributed across conditions ($p>0.05$ in all comparisons).

Boundary paradigm reading task

FRP and EM information were obtained from the second study of the thesis. Participants read sentences freely and the boundary paradigm of Rayner (1975) was used to manipulate the preview of unpredicted previewed words to the sentence context. Therefore, readers could preview an identical word, an unrelated but plausible word and a totally unrelated word. For more detailed information, the readers can see the method section of the study 2 (page 59).

Processing and analysis

EM were recorded with a SR Research Ltd. Eyelink 1000 eye tracker, with a sampling rate of 1000 Hz. Viewing was binocular and all measures were taken from the right eye. Calibration was performed on a standard nine-point grid with eye position errors below 0.3º, at the beginning of the experiment and during the task if calibration errors were above the threshold. SR Research DataViewer was used for processing and inspecting EM. EM related to blinks were discarded for the analysis. Fixations shorter than 80 ms and within one-letter space were combined into one fixation (< 3 %). For the analyses, we calculated the reading rate of subjects in words per minute (wpm). Reading rate has been classically used in the moving-window paradigm to determine the size of the perceptual span, since it seems to be the most sensitive and meaningful dependent variable and it is a measures that includes the number of fixations, average fixation duration and average saccadic movement time combined into total reading time (e.g. Rayner, Inhoff, Morrison, Slowiaczek, & Bertera, 1981, Rayner, Well, Pollatsek, & Bertera, 1982; Rayner et al., 1986).

For the analyses, we used the ULLRToolbox (https://sites.google.com/site/ullrtoolbox/home) from the R software (http://www.rproject.org). EM and FRPs measures from the boundary paradigm task, as well as the reading rate from the moving-window paradigm task were analyzed by running linear mixed effects models with the lme4 and lmerTest R packages (Bates et al., 2011; Bates et al., 2015; Kunzetsova et al., 2017). For each analysis, we always aimed to follow a maximal random effects model (Barr et al., 2013). In case of non-convergence, we used a stepforward method and the likelihood radio test (Barr et al., 2013; Luke, 2017; Pinheiro & Bates, 2006) to assess the inclusion of fixed or random effects to get a superior model fit to the data. We used the Satterthwaite's method to calculate the pooled degrees of freedom of the variances (Khuri et al., 1941). In case of the non-normality of the residuals of the estimated models, a scaled power (box-cox) transformation was performed with the estimated lambda of the model (Box & Cox 1964; Fox & Weisberg, 2018). For fixation targeting measures, the model was conducted using a logistic link function.

For obtaining the Individual Differences of the subjects, we considered the averaged z score of the production and recognition spelling tasks as an indicator of spelling ability. To get a measure per subject of the size of the perceptual span, we run a predictive model for each subject where the reading rate was predicted by the size of the moving window. Since the prediction of the reading rate by the window size manipulation was non-linear (see figure 2), we used a logarithmic transformation of the window size. In order to do that, we converted the categorical variable into a numerical variable, by giving the free viewing condition an assumed window size of 26, since the window size difference between each condition was of 4 characters. The predicted beta value from each subject would be obtained and used as a predictor in later analyses in the boundary paradigm task, since these beta values can be considered as an individual difference measure of the size of the perceptual span. More specifically, readers with a greater beta value would have a similar non-linear trend than in Figure X, where there is a benefit of the reading rate from greater window size. This was benefit visually greater in smaller windows (from 6 to 14 characters) and visually smaller when they read more than 14 characters, which agrees with previous evidence indicating that the span of skilled readers extends 14-15 spaces to the right of fixation (Rayner, 2009, Rayner & Schotter, 2014) On the other hand, readers with small beta values will have no benefit from the window size, having a more linear – horizontally shaped line, where the differences in reading rate between conditions would be reduced (see Figure 2).. Therefore, readers with a greater beta value will benefit from greater windows, suggesting that they would have a greater perceptual span that will allow them to use more parafoveal information. On the other hand, readers with smaller beta values will not benefit from different windows, indicating that they would have a small perceptual span and that they would benefit less from parafoveal information.

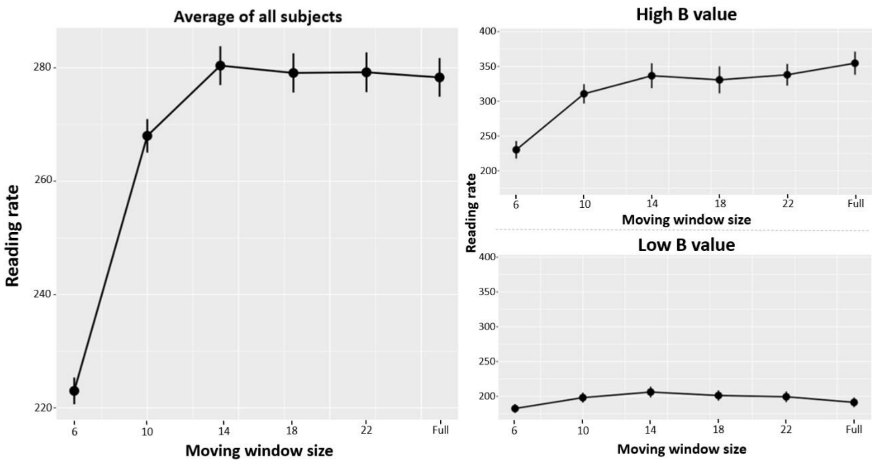

Figure 2. *Average reading rate (in WPM) of all subjects per moving window condition (left). In the right, there are displayed subjects with high and low B values respectively.*

Additionally, we did a general analysis in the moving-window task. We run a predictive model where the reading rate was predicted by the size of the moving window, but in this case, the analysis was performed for all subjects together and not for each subject, since we were interested in how reading rate is generally affected by the available window size and not for the individual value of each subject. Since we also wanted to know if the linguistic ability was linked to the size of the perceptual span, as suggested by previous evidence (see Choi et al., 2015), for the analyses of all subjects we additionally included the spelling score as a predictor of reading rate, to test if they may interact with the window size manipulation. Were there to be an interaction between both predictors, that would mean that window size condition may affect reading rate differently depending on the linguistic ability of readers.

For the analyses of the EEG and EM measures in the boundary paradigm task (performed in study 2, see page 59 for more detailed information about the methodology used), we included the original preview factor, as well as the individual differences measures, as predictors. In order to simplify the number of the analyses in the study, we re-analyzed the models from the second study of the thesis where it was reported significant preview effects, including the perceptual span and the spelling ability as predictors in the model. Both individual differences were not collinear ($r = 0.12$, $p = 0.45$) so their interaction was also included in the model.

As in the previous study, we analyzed first fixation durations, single fixation durations, gaze durations, go-past time durations, total reading time, probability of fixating the target word during first-pass reading, probability of re-reading the target word a probability of making a regression out of the target word. For the FRP analyses, we analyzed the averaged amplitude 350-450 ms temporal windows for the FRPs time-locked to the pretarget word, the averaged amplitude 100-250 and 250-400 ms temporal windows for the FRPs time-locked to the target word and the averaged amplitude of the parieto-occipital electrodes of the 150-300 ms temporal window for fixations in the target word, as in our previous study. Since in the original study only the laterality factor interacted with the main manipulation, we included it in our model for the analyses in order to explore possible topographic distribution of preview effects. We would use pos-hoc comparisons to explore main effects of the preview factor and possible interactions with the topographic laterality factor. On the other hand, we would use the fixed effects table to explore main effects and interactions of the numerical predictors (i.e. the perceptual span and spelling ability factors).

4.3.3. Results

Moving window paradigm task

For the reading rate analysis, we run mixed models with random intercepts for items and subjects, random slopes for the logarithmic transformation of the window size for items and subjects and random slopes for the spelling ability for subjects. The fixed effects table revealed a main effect of the logarithmic transformation of the window size factor over reading rate ($t(5381) = 8.86$, $p<0.001$), no effect of the spelling ability of participants over the reading rate ($t(53)=0.56$, $p=0.57$) and an interaction between the logarithmic transformation of the window size and the spelling ability of the participants ($t(5392)= 2.08$, $p<0.05$). To explore the interaction of the numerical predictors, we plotted the reading rate against both variables (see Figure 3). The interpretation of the graphs and effects are shown in the discussion.

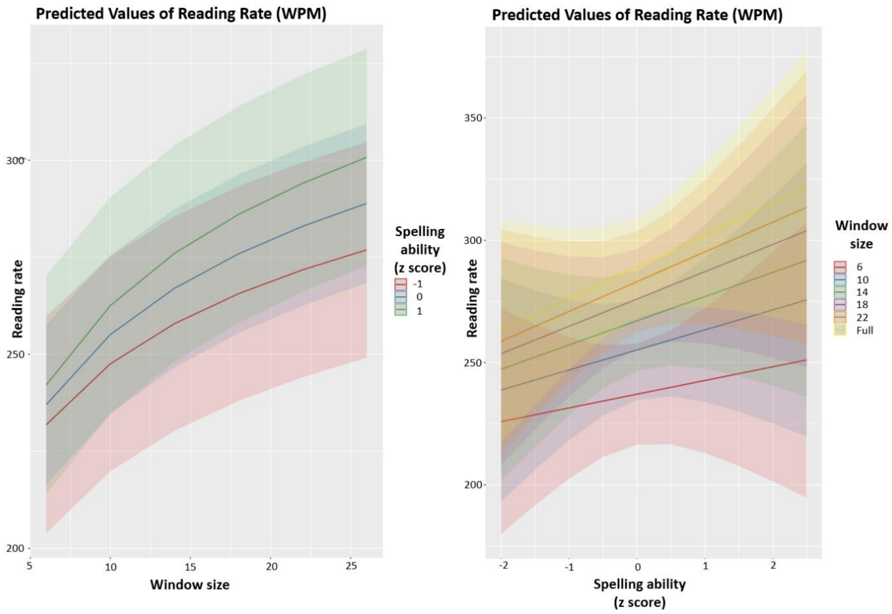

Figure 3. *Predicted reading rate (in WPM) by window size at different subject's spelling ability (left) and predicted by spelling ability at different window size conditions (right).*

Boundary paradigm task

Eye movements

For the EM analysis, we run mixed model with random intercepts for items and subjects. The *anova* output of the mixed model analysis showed a main effect of preview on single fixation duration F(2, 2742) = 2.95, p = 0.05; first fixation duration F(2,3537) = 3.11, p < 0.05; gaze duration F(2, 3535) = 3.04, p < 0.05; and total reading time F(2, 3537) = 4.03, p < 0.05 but it only approached significance in go-past time F(2, 3535) = 2.47, p=0.08. No effects of preview were found in fixation targeting measures (all p > 0.05). All b, t and p values of the poshoc contrasts of significant main effects can be seen in table 1 (see also Figure 4, also figure 2 in study 2).

Table 1. *Poshoc contrasts of fixation and reading duration on the target word*

Measures	Contrast	Estimate	SE	|t|	p
Single fixation duration	Identical vs Plausible	-10.48	3.71	-2.82	P < 0.01
	Identical vs Implausible	-18.86	3.73	-5.05	P < 0.001
	Plausible vs Implausible	-8.38	3.72	-2.25	P < 0.05
First fixation duration	Identical vs Plausible	-12.75	3.45	-3.69	P < 0.001
	Identical vs Implausible	-19.03	3.42	-5.56	P < 0.001
	Plausible vs Implausible	-6.28	3.40	-1.847	P = 0.06
Gaze duration	Identical vs Plausible	-18.22	4.60	-3.957	P < 0.001
	Identical vs Implausible	-27.94	4.57	-6.121	P < 0.001
	Plausible vs Implausible	-9.72	4.54	-2.143	P < 0.05
Go-Past time	Identical vs Plausible	-13.3	9.18	-1.44	P = 0.14
	Identical vs Implausible	-36.5	9.10	-4.01	P < 0.001
	Plausible vs Implausible	-23.2	9.05	-2.56	P < 0.05
Total reading time	Identical vs Plausible	-41.30	7.10	-5.814	P < 0.001
	Identical vs Implausible	-34.22	7.04	-4.863	P < 0.001
	Plausible vs Implausible	-7.08	7.01	-1.01	P = 0.31

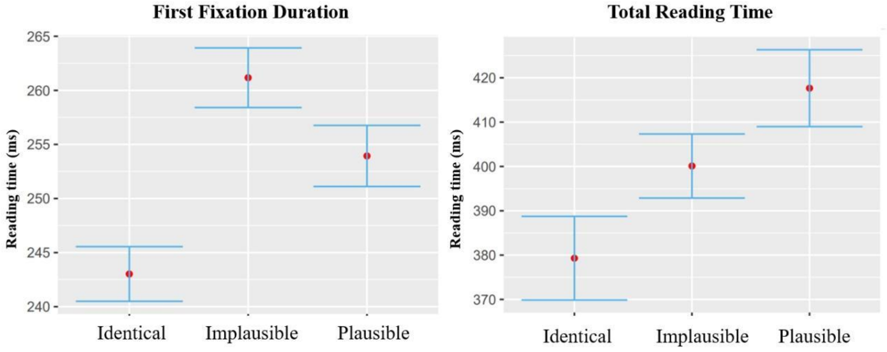

Figure 4 (figure 2 in study 2). *Early (left) and late (right) reading measures on the target word for the identical, plausible and implausible conditions*

Considering the individual differences measures, the perceptual span variable was significant in the probability of re-reading the target word X^2 (1, N=37) = 8.76, $p < 0.01$; and total reading time $F(1, 33) = 6.16$, $p < 0.05$. For looking at the direction of the effects, we repeated these two analyses but only including the main effect of preview and the perceptual span factors with no interaction, to follow a more parsimony approach and better observed the fixed effects. The fixed effects table still showed the main significant effects of probability of the probability of re-reading the target word ($z = -2.03$, $p<0.01$) and in total reading time ($z = -2.57$, $p < 0.01$) (see also Figure 5). No other main or interactive effects of perceptual span or spelling ability was found (all $p > 0.05$)

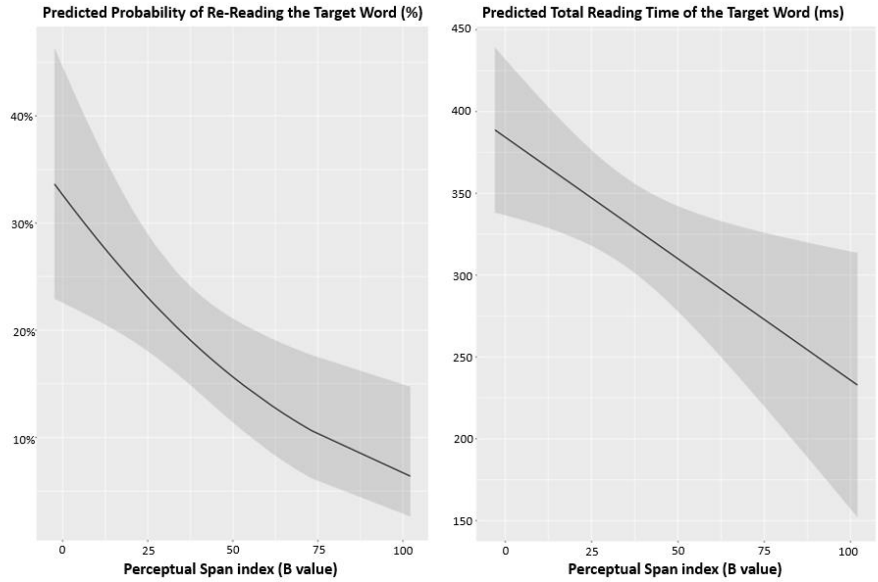

Figure 5. *Probability of re-reading the target word (left) and total reading time of the target word (right) predicted by the individual perceptual span of the subjects.*

Fixation-Related potentials

Owing to a non-convergence of the maximal model, we selected a model with random intercepts for subjects and items and random slopes for the preview factor for subjects in the FRP time-locked to the pretarget word. For the FRP time-locked to the target word, after non-convergence, we selected a model with random intercepts for subjects and intems and random slopes for the preview factor for items in both temporal windows. Since the model had multiple predictors, we first looked at the *anova* output in order to look for possible effects in the fixed effect tables and to perform poshoc comparisons. Figure 6 displays the waveforms of the FRP time-locked to the pretarget and target words (it corresponds to Figure 3 from study 2).

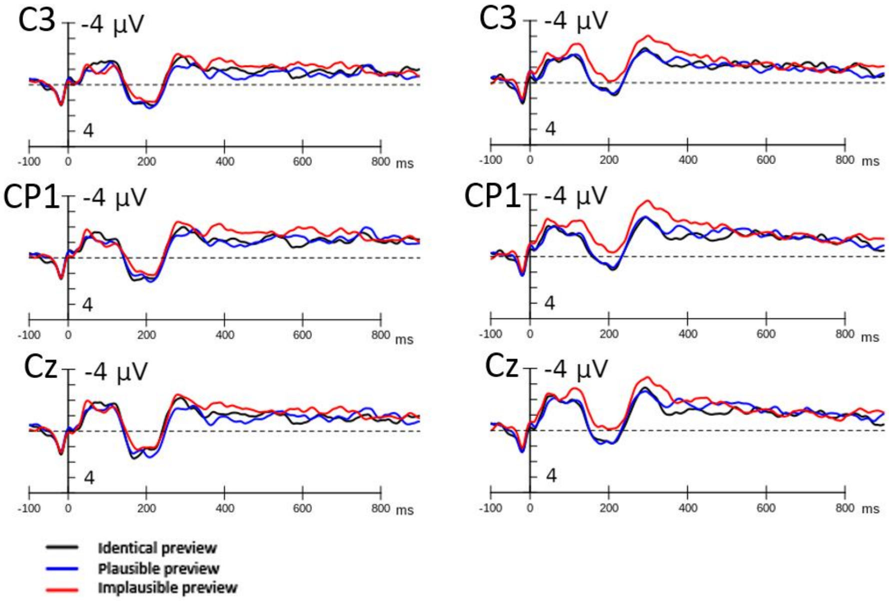

Figure 6 (Figure 3 in study 2). *Grand average FRPs at the C3, CP1 and Cz electrodes for the fixation onset on the target word for the identical, plausible and implausible preview conditions.*

First, the analysis of the 350-450 ms temporal window time-locked to the pretarget word showed a near-marginal significant effect of the preview factor $F(2, 32) = 3.18$, $p = 0.05$. However, there was no main effect of the perceptual span $F(1, 34) = 0$, $p = 0.99$ or the spelling ability $F(1,33) = 1.64$, $p = 0.2$. There were also no interactive effects between preview factor with the perceptual span $F(2,33)=1.41$, $p=0.25$ or the spelling ability $F(2,32)=1.06$, $p=0.35$ and no interactive effects between both individual differences measures $F(1,35)=1.61$, $p=0.21$. The three interaction between the preview, perceptual span and spelling ability also remained non-significant $F(2, 35) = 1.79$, $p = 0.18$. The poshoc comparisons of the preview factor showed a greater negativity for the implausible condition when compared to the plausible preview condition ($t = 2.22$, $p < 0.05$) but the identical condition was not different from either the plausible ($t = -1.49$, $p = 0.13$) or implausible preview conditions ($t = 0.9$, $p = 0.36$).

Looking at the specific analyses of the parieto-occipital electodes of the 150-300 ms temporal window of the FRP time-locked to the target word, we found a main effect of the preview factor F(1,32) = 7.46, $p < 0.01$ with no main effect of the perceptual span F(1, 32) = 0.79, p = 0.37 or of the spelling ability F(1,32) = 0.22, p = 0.63. The preview factor interacted with the spelling ability factor F(2, 30) = 3.38, $p < 0.05$, but not with the perceptual span factor F(2, 30) = 0.17, p = 0.84. There was no two interaction of the perceptual span and spelling ability factors F(1, 32) = 1.01, p = 0.32 and no three interaction of the individual differences factors with the preview factor F(2, 31) = 1.47, p = 0.24. The poshoc revealed that the identical condition was positively and significantly different from the plausible (t = 2.01, p = 0.05) and implausible (t = 3.86, $p < 0.001$) preview conditions, with no differences between the plausible and implausible conditions (t = 1.23, p = 0.22). Exploring the interaction of the preview factor with the spelling ability, the fixed effects table showed a non-significant slope of the spelling ability over the amplitude in the identical condition (t = 1.17, p = 0.25). The slope of spelling ability over the amplitude was similar in the plausible condition (t = -0.22, p = 0.82) and significantly more negative in the implausible condition (t = -2.34, $p < 0.05$).

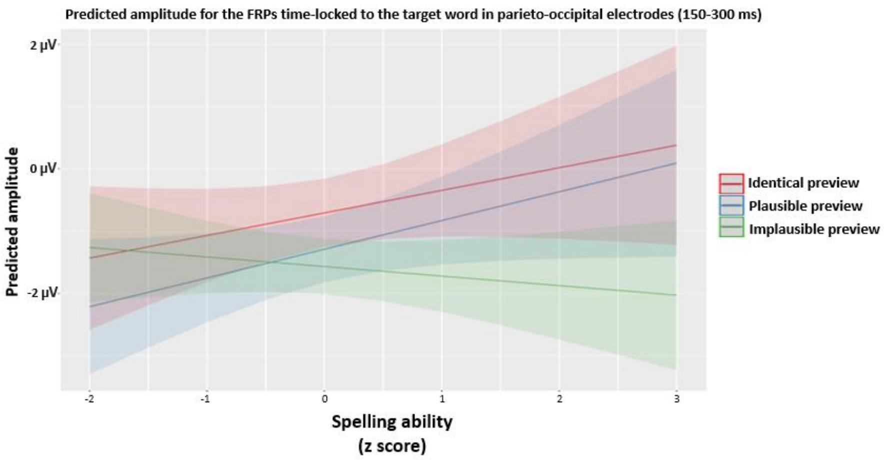

Figure 7. *Average amplitude in the 150-300 ms temporal window of the FRP time-locked to the target word for the parieto-occipital electrodes, predicted by the spelling ability in each preview condition.*

The analysis of the 100-250 ms temporal window of the FRP time-locked to the target word showed a main effect of the preview factor F(2, 123) = 3.79, $p < 0.05$ which also interacted with the topographic laterality factor F(2, 51931) = 3.96, $p < 0.05$. The preview factor also interacted with the spelling ability factor F(2, 52144) = 23.03, $p < 0.001$. Additionally, there was a three interaction between the preview, perceptual span and spelling ability factors

$F(2, 52008) = 7.23$, $p < 0.001$. Having said that, there was no main effect of the perceptual span F(1,33 = 0.41, p = 0.52) or of the spelling ability $F(1, 33) = 0.001$, $p = 0.96$; and there were no effects of the interaction between the perceptual span with the preview factor $F(2, 51900) = 1.4$, $p = 0.24$; or interaction of the perceptual span with the spelling ability $F(1,33) = 1.15$, $p = 0.28$.

The poshoc comparisons of the preview factor showed that the amplitude in the implausible preview condition was significantly more negative when compared to the identical ($t = 2.47$, $p < 0.05$) and plausible ($t = 2.44$, $p < 0.05$) preview conditions. However, there were no differences between the identical and plausible preview conditions ($t = 0.06$, $p = 0.94$). Looking at the interaction of the preview factor with the topographic laterality factor, the contrasts reveal that the implausible preview condition was more negative compared to the identical and plausible conditions in medial electrodes (for both comparisons, $t = 3$, $p < 0.01$). However, no differences between preview conditions were found in lateral electrodes (all $p > 0.05$).

Looking at the fixed effects table, the analysis showed a marginally positive slope of spelling ability over the amplitude in the identical preview condition ($t = 1.98$, $p = 0.05$). The slope of the spelling ability was significantly smaller in the plausible ($t = -2.8$, $p < 0.01$) and implausible ($t = -6.7$, $p < 0.001$) preview conditions compared to the identical one (see figure 8 to better understand the effects). Looking at the three interaction, we saw that the perceptual span and the spelling ability did not interact in the identical preview condition ($t = -0.98$, $p = 0.32$). However, we saw that this interaction was significantly greater in the implausible preview condition ($t = -2$, $p < 0.05$), while there was no significant difference between the interactions between plausible and identical preview conditions ($t = 1.9$, $p = 0.6$). We used figure 8 for a better interpretation of the results.

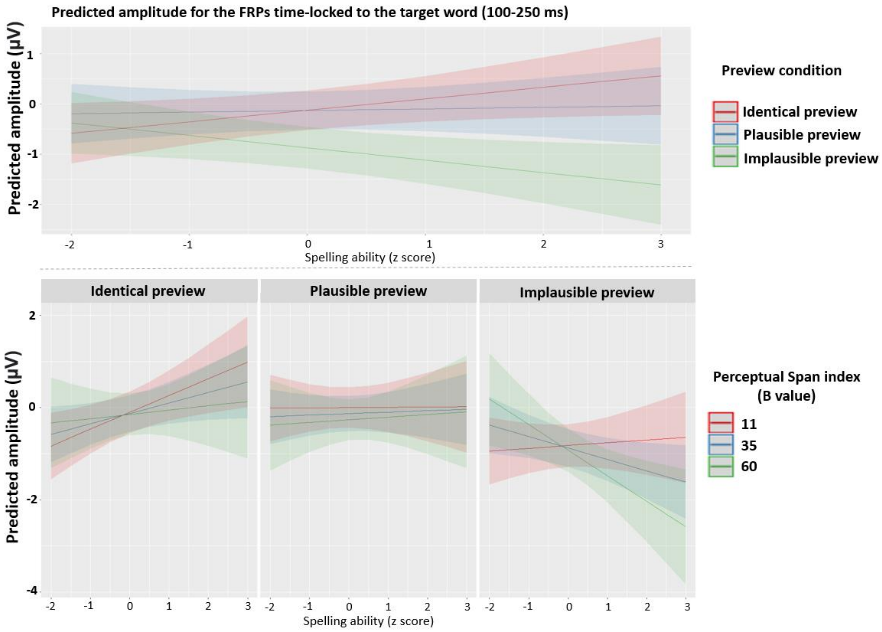

Figure 8. *Average amplitude in the 100-250 ms temporal window of the FRP time-locked to the target word, predicted by the spelling ability in each preview condition (up). The slopes are also displayed by different levels of perceptual span of the subjects in each preview condition (down).*

On the other hand, the analysis of the 250-400 ms temporal window showed a main effect of the preview factor $F(2, 122) = 3.78$, $p < 0.05$, that interacted with the perceptual span factor $F(2, 51982) = 8.36$, $p < 0.001$ and spelling ability factor $F(2, 52165) = 52.57$, $p < 0.001$. In addition, there was a three interaction between the preview, perceptual span and spelling ability factors $F(2, 52062) = 31.39$, $p < 0.001$. There was no main effect of the perceptual span F(1,33 = 0.2, $p = 0.64$) or of the spelling ability $F(1, 32) = 0.71$, $p = 0.4$; and no interaction between the perceptual span and spelling ability variables $F(1, 33) = 0.55$, $p = 0.46$.

The poshoc comparisons of the preview factor showed a greater negativity in the implausible condition, when compared to the identical preview condition ($t = 2.7$, $p < 0.05$). No differences between the identical and plausible conditions ($t = 0.83$, $p = 0.4$) and plausible and implausible conditions ($t = 1.75$, $p = 0.16$) were found.

The fixed effects table showed a non-significant slope of the perceptual span (t = -0.3, p = 0.76) or the spelling ability (t = 1.55, p = 0.12) in the identical preview condition. However, the slope of the perceptual span was significantly more negative in the implausible condition (t = -2.44, p<0.05) (see figure 9) and the slope of the spelling ability was more negative in the plausible (t = -3.66, p < 0.001) and implausible (t = -10.14, p < 0.001) preview conditions (see figure 10). While the perceptual span and spelling ability did not interact in the identical preview condition (t = -0.6, p = 0.54), their interaction was significantly different in the plausible (t = 3.7, p < 0.001) and implausible (t = -4.31, p < 0.001) conditions, following different trends. We used figure 9 and figure 10 to better interpret the results during the discussion.

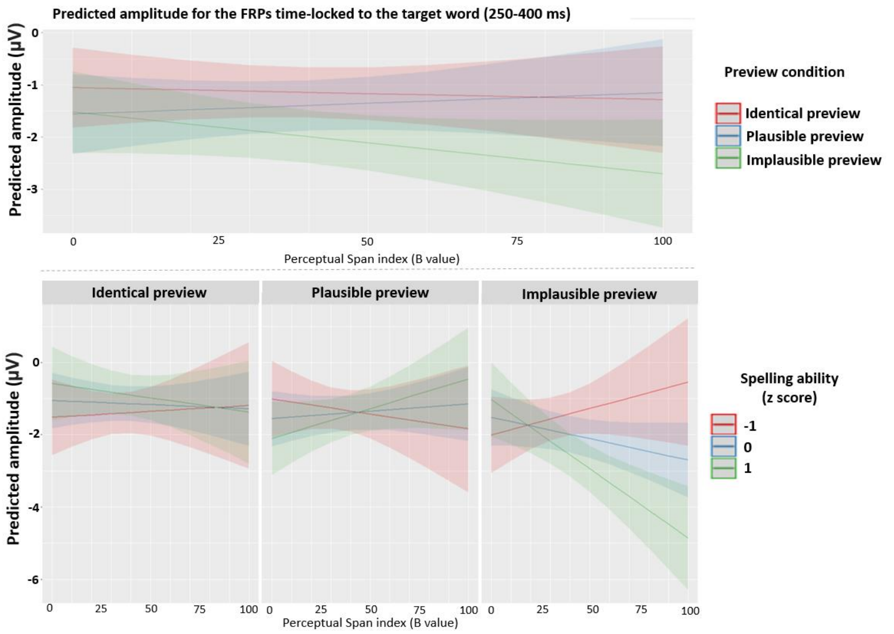

Figure 9. *Average amplitude in the 250-400 ms temporal window of the FRP time-locked to the target word, predicted by the perceptual span in each preview condition (up). The slopes are also displayed by different levels of spelling ability of the subjects in each preview condition (down).*

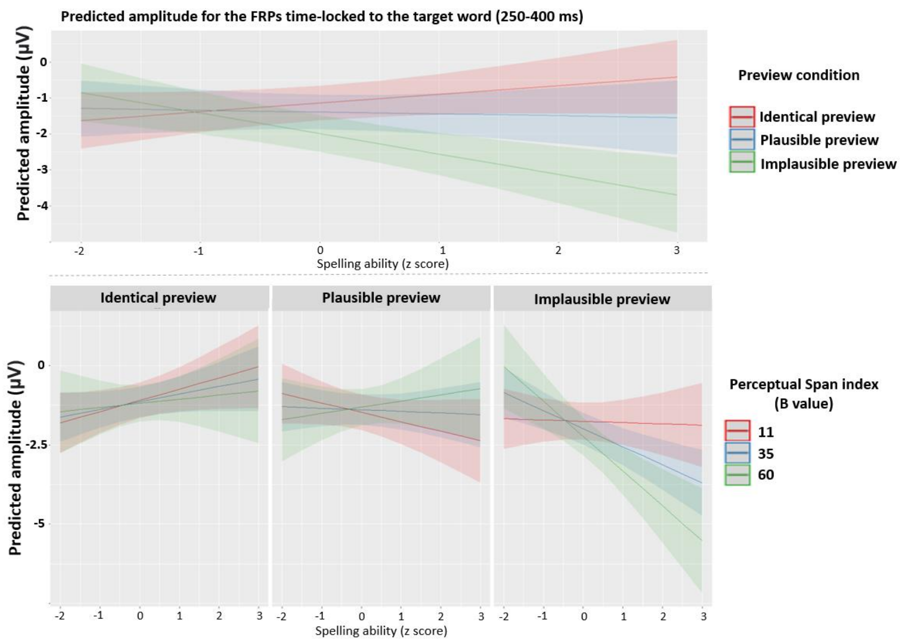

Figure 10. *Average amplitude in the 250-400 ms temporal window of the FRP time-locked to the target word, predicted by the spelling ability in each preview condition (up). The slopes are also displayed by different levels of perceptual span of the subjects in each preview condition (down).*

4.3.4. Discussion

In this study, we explored whether individual differences in the ability of distributing attentional resources of readers may affect the depth of parafoveal processing during sentence reading. In order to do so, we collected measures of the size of the perceptual span of readers to test how it may predict the preview effects in a boundary paradigm reading task. Additionally, we collected spelling ability measures of readers, since the lexical quality of the representations of words in readers may also affect the depth of parafoveal processing. Spelling ability may also affect the size of the perceptual span in the moving-window paradigm reading task (see Veldre & Andrews, 2014), since a more efficient processing of the foveal load (i.e. a reduced foveal load owing to an increased lexical quality) may increase the availability of attentional resources to be allocated into the parafoveal region. More importantly, the depth parafoveal processing and preview effects in the boundary paradigm may be affected in two different ways: 1) a greater spelling ability will reflect an increased lexical quality of the representation of words in readers, meaning that they may have an easier access orthographically and semantically to the parafoveal Word. 2) a greater perceptual span will mean that readers will devote more attentional resources into the parafoveal region strengthening the access to the parafoveal word at an orthographic and semantic level. During the discussion, we comment one by one all the significant and null effects found in both data-streams.

The moving window task and the size of the perceptual span

First, the reading rate during moving-window paradigm was predicted by the window size, with slower reading rates as the number of visible letters were reduced, as usually reported in the literature (Rayner, 2009). The benefit was visually greater in smaller windows (i.e. 6 and 10 visible characters), reaching asymptote at windows of 14 visible characters or greater, in line with previous evidence indicating that the span of skilled readers extends 14-15 spaces to the right of fixation (Rayner, 2009, Rayner & Schotter, 2014). More importantly, the spelling ability of readers interacted with the window size manipulation. As it can be interpreted in figure 3 (left), high spellers benefited more as the window size increased, while the benefit for the low spellers was much subtler. In addition, the predicted benefit of spelling ability was much greater in larger window sizes, where parafoveal information was more available, while the slope in the smallest window size was flatter (see figure 3 right). This replicates previous evidence from Veldre & Andrews (2014) who also found that individuals that were high in Reading and spelling ability showed the greatest benefit from greater window sizes. As they suggested, the high-quality representations of skilled readers may facilitate the extraction and use information of parafoveal words, as well as fixated words. According to the foveal load hypothesis of Henderson and Ferreira (1990; 1993), the easier and quicker access to fixated words may have allowed readers to have more attentional resources available to distribute to the parafoveal region, increasing their perceptual span, and therefore enhancing even more the use of parafoveal information. This finding plays its part in understanding the role of the individual differences in the size of the perceptual span, who has been already described to be affected in the moving-window paradigm by age (Rayner, Catelhano & Yang, 2009), language ability (Choi et al., 2015) or reading speed (Ashby et al., 2012; Rayner et al., 2010).

Fixation-Related potentials: the predictive power of the perceptual span and the spelling ability of readers

Looking at the FRP measures, we first explored the influence of individual differences measures over the found semantic parafoveal effects during the fixation of the pretarget word found on the second study (Antúnez et al.,under review)). With the model considering the individual differences measures, we still found that the implausible condition had a greater negativity when compared to the plausible condition, reflecting that semantic parafoveal processing was taking place during the fixation of the pretarget word. Having said that, the described effects in the FRP time-locked to the pretarget word were not modulated by the perceptual span nor the spelling ability of the subjects. Since previous evidence found specifically modulations of linguistic ability over preview effects during the fixation of the target word, it is posible that parafoveal processing during the fixation of the pretarget Word is less sensible to these differences. Preview effects usually are enhanced by trans-saccadic integration processes which are absent during the fixation of the pretarget word, where only integration of the meaning of the parafoveal word with the sentence context in taking place at this point. Therefore, it may be possible that the availability of attentional resources and lexical quality of the representations of readers may interact with trans-saccadic integrations processes between previews and targets, having a less impact over the earlier access of parafoveal words. Another point to consider is that effects of interest in FRPs may be more subtle and difficult to detect, owing to a greater contamination for the overlapping activity of multiple fixations and visual inputs (see Degno & Liversedge, 2020). In contrast, most evidence of semantic parafoveal processing while fixating the pretarget word comes from ERP studies using more artifitially controlled reading scenarios where these problems from ecological paradigms are absent (e.g. Barber et al., 2013; Stites et al., 2017). Therefore, an interesting opened question would be if the perceptual span and spelling ability of readers may interact with the depth of parafoveal processing in controlled-reading-ERP paradigms, where parafoveal effects has been more solidly stablished.

Despite the null explicative effect of individual differences in the FRP time-locked to the pretarget word and in the eye movements' measures, results in the FRP time-locked to the target word shows a completely different pattern. Moving onto the FRP time-locked to the target Word, we explored the influence of the individual differences over preview effects in the 100-250 and 250-400 temporal windows. We also specifically analyzed the 150-300 ms temporal window only for parieto-occipital electrodes, where we found that the identical condition was more positive than the other conditions, showing a display change preview effect (see Dimigen et al., 2012). The implausible condition was more negative compared to the identical condition in the three temporal windows analyzed and also more negative than the plausible condition in the 100-250 ms earlier window. This confirms that semantic preview effects were taken place and that the meaning of parafoveal words were accessed and integrated. In the three temporal windows analyzed, we found that the spelling ability interacted with the preview factor (see figure 8 up, 10 up and 7 respectively). In the 100-250 ms early window, the preview benefit obtained from an identical preview was enhanced when readers had a greater spelling ability, resulting in more positive amplitudes. However, the slope became more negatively oriented in the plausible and implausible conditions, meaning that the advantage of good spellers is lost when the preview is unrelated to the target word. In fact, the implausible condition, being the most disruptive one since it has no orthography in common to the target and it is not plausible to the sentence context, showed that greater negativity in amplitude was predicted by greater spelling ability in the three analyses. This would mean that the greater cost from a totally unrelated Word would be enhanced by a greater spelling ability, meaning that the high-quality lexical representation of the parafoveal Word resulted in a greater disruption from an implausible and unrelated preview when it had to be integrated with both the target and sentence context. Even though in the later window the slope in the identical condition was non-significant, the greater disruption from implausible and unrelated previews was also present from better spellers. These findings matches the findings of Veldre & Andrew (2016) who found that high speller had greater disruption for unrelated previews in gaze duration and total reading durations. They argued that better spellers show a greater interference from the mismatch in orthographic information between preview and target and such cost counteracts any effect benefit of sharing semantic features. However, while they found an equivalent interference from non-identical (i.e. semantically related and unrelated) word previews, we found that the preview cost was even more enhanced in the implausible condition, meaning that good spellers also had a greater disruption when integrating the meaning of the implausible preview to the sentence context. It is possible that we succeeded in finding a semantic preview effect interaction with spelling ability because of the use of the FRPs, instead of merely EM. Once again, the complementing electrophysiological measures can be greatly beneficial in studying parafoveal processing during natural sentence reading, since they may be more suitable to detect semantic preview effects that may be undetected by behavioral measures. Consequently, exploring the consistency between FRPs and EM measures may offer a clearer explanation of which processes are taking place during semantic parafoveal processing (see also Degno & Liverdsedge, 2020).

Even though we found that the linguistic ability of readers directly affect the depth of parafoveal processing, what is the role of their ability to distribute attentional resources? Answering the main big question we found that the perceptual span of the subjects interacted with the preview manipulation showed here, in the 250-400 ms temporal for the FRP time-locked to the target word. More specifically, while the perceptual span did not seem to predict the amplitude in the identical and plausible conditions (i.e. the slope in the identical condition was non-significant and the slope in the plausible condition was not different from the identical condition), the negativity increased in the implausible condition as the perceptual span of the subjects was greater (Figure 9 up). The implausible condition had a greater salience and disruption caused by being unrelated to the target word and implausible to the sentence context. Since readers with greater perceptual spans would have more attentional resources devoted to the parafoveal region, they would be more efficient in extracting the information from the parafoveal word, which would result in having greater preview costs (reflected in greater negativity in the N400 component) from an unrelated and implausible preview. Therefore, we provided evidence for the first time that the size of the perceptual span of readers successfully predicted the depth of parafoveal preview effects. More importantly, our findings extends previous evidence that suggested that attentional resources were a key factor to access to parafoveal words by modifying properties of the task (see Barber et al., 2013; Payne et al., 2016) to research of individual differences. Therefore, the evidence provided here suggests that isolate cognitive function in artificial designs by manipulating properties of the task may be suitable to explore what kind of cognitive mechanisms variations across subjects could affect parafoveal processing. In addition, this finding also reinforces previous evidence of individual differences modulating the depth of parafoveal processing that highlighted the importance of the availability of attentional resources. For instance, differences between younger and older readers has been argued to be partly owed to differences in the distribution of attentional resources and in the size of the perceptual span (see Payne & Federmeier, 2017; Rayner et al., 2009). Future research collecting individual differences should aim to also obtain the size of the perceptual span of readers to better understand the mechanisms behind individual differences in the depth of parafoveal processing.

Knowing that both individual differences measures play a role in the depth of semantic parafoveal processing, we also have to consider if both effects can be considered independently or if they both together can better explain parafoveal processing. In the interest of the question, there was a triple interaction between the perceptual span and spelling ability of the subjects and the preview manipulation, in both the 100-250 and 250-400 ms temporal windows for the FRP time-locked to the target Word. In the earlier window, the perceptual span and spelling ability factors did not interact in the identical condition, but with a greater interaction in the implausible condition. As reflected in Figure R5 (down) the greater preview disruptive effects caused by an implausible condition in better spellers were modulated by the perceptual span of the subjects. Therefore, when subjects had a small perceptual span, their spelling ability did not modulate the amplitude in the implausible condition. However, as they had a greater perceptual span, a better punctuation in spelling ability predicted more negative amplitudes for the implausible conditions. These findings suggest that having a high-quality lexical representation of parafoveal words is only useful if readers have the ability to distribute enough attentional resources into the parafoveal region. Similar findings were found in the 250-400 ms temporal window, however it was also found that the perceptual span and spelling ability of readers also interacted in the plausible condition (see Figure 9 and 10 down). In this case, the trend in the plausible condition was different than in the implausible condition. When readers had a greater perceptual span, a better punctuation in spelling ability resulted in more positive (instead of negative) amplitudes for the plausible conditions (as opposed to the implausible condition). This difference in trend could be owed to the facilitative and disruptive effect of the plausible and implausible preview, respectively. Despite being orthographically disimilar to the target, the plausible preview had a facilitatory preview benefit related to integration processes to the sentence context. Even though such facilitatory effect should be also found in the identical condition, it is posible that the orthographic mismatch created a greater saliency of preview effects, therefore enhancing the interactive effects in conditions where the preview was unrelated to the target Word. However, this enhances the fact that spelling ability affects semantic parafoveal processing, as reflected in earlier windows and in the N400 component as long as enough attentional resources are deployed.

Having said that, as the perceptual span also interacted with the preview factor and therefore modulated parafoveal processing, we also should consider an additional hypothesis of the triple interaction between perceptual span, spelling ability and preview factor (see Figure 9 down). Similarly to Figure 10, better spellers had more positive amplitudes in the plausible preview condition and more negative amplitudes in the implausible preview condition as they had a greater perceptual span. Such modulation of perceptual span over preview effects were reduced for bad spellers. An alternative explanation is that distributing attentional resources into the parafoveal region do not automatically allow readers to extract the semantic parafoveal information, but they need to have a high-quality representation of the parafoveal Word in order to do so. Even though with our current results we cannot know whether preview effects are more dependent on the availability of attentional resources in the parafoveal region or the high-quality lexical representations of words of readers or a causal direction of the effects, we know that both variables modulate parafoveal processing in a summatory manner and that we should not consider one measure without consider the other. Future research may tackle directly the question of which processes are taking place during semantic parafoveal processing and how these processes can be enhanced by individual differences of readers.

Limitations of the study: Scarce evidence from eye movements

The current study is not free from limitations. Moving onto the data obtained from the boundary paradigm task and analyzed with the individual differences measures obtained from the moving window paradigm task, we did not find any interaction between any individual differences measures and the preview presented in the parafoveal region in eye movements measures. Even though the identical preview led to shorter fixation durations and the implausible preview to greater fixation durations than in the other conditions, reflecting orthographic trans-saccadic integration of parafoveal information and semantic access and integration of the preview with the sentence context respectively, those differences were not modulated by the perceptual span and spelling ability of the readers. Our results contrasts with Veldre & Andrews (2016), who found a semantic preview benefit to first-pass reading, modulated by reading and spelling ability. Having said that, their semantic manipulation included conditions where the preview word could be semantically related or unrelated to the target word. On the other hand, in our manipulation, even though the preview word could be unrelated to both the context and the target Word, in the other condition the word could be related to the context but not to the target Word, which may suggest that individual differences better influence oculomotor behaviour through semantic trans-saccadic integration processes and not by semantic integration with the sentence context. Having said that, it would be important to mention that, to explore EM measures, our study has an important limitation when compared to Veldre & Andrews (2016). While they had a sample size of 99 students, we only analyzed the data with a sample size of 37 readers. The reduced sample size was owed to greater loss of trials owing to the filtering and processing criteria of both EM and FRPs data streams, which reduced the number of subjects with the minimum amount of trials (see study 2). Future research may collect additional participants with EM measures alone to see if the findings of Veldre & Andrews (2016) can be replicated with our preview manipulation.

Nevertheless, despite not finding any interaction between the preview factor and the individual differences measures, we found that readers with greater perceptual span lead to reduced probability of re-reading the target word and, probably as a consequence, a reduced total reading time of the target word (see Figure 5). That would imply that readers with greater perceptual span read more efficiently and use the information located away from the foveal region to determine saccades and oculo-motor programming (see also Engbert, Nuthmann, Richter, & Kliegl, 2005) to determine where and when to move the eyes (see Schotter et al., 2012). Parallely, Rayner et al. (2009), who found that older readers had a smaller and more symmetrical perceptual span, suggested that since they do not process information to the right of fixation as effectively, they need to access to more information located to the left of the fixation in the sentence, explaining why they had more symmetrical perceptual spans, which would also explain why they tend to execute more backward movements in the text (Kemper, Crow, & Kemtes, 2004; Kemper & Liu, 2007; Kemper & McDowd, 2006; Kliegl, Grabner, Rolfs, & Engbert, 2004; Rayner, Chace, Slattery, & Ashby, 2006) and regress more to target words(see also Laubrock, Kliegl, & Engbert, 2006; Rayner et al., 2006). Future research may collect the size of the perceptual span in younger and older readers as an individual difference measure to understand what is really happening in reading, replicating previous studies to better understand how attentional resources may be differently distributed in different populations.

Conclusions

In summary, we provided FRPs evidence of the influence of two individual differences measures from readers over semantic parafoveal processing in natural sentence reading. First, readers with greater spelling ability had high-quality lexical representation of parafoveal words, allowing them to easily access and extract their meaning. More importantly, readers with greater perceptual span were able to distribute more attentional resources into the parafoveal region, enhancing semantic preview effects. Additionally, the influence of each measure over semantic preview effects were enhanced by an increase in the other, meaning that we should not consider the availability of attentional resources and the high-quality lexical representation of words separately when assessing their influence over parafoveal processing. Future co-registration research may add control for the spelling ability and perceptual span of readers to more effectively detect and explain all cognitive processes and individual differences involved in semantic parafoveal processing.

Part 5. General discussion

The objective of this doctoral thesis was to contribute to the knowledge related to parafoveal processing during reading from a perspective of cognitive neuroscience and psycholinguistics and using a co-registration set up with two of the most important techniques of these fields: Eye Movements and Electroencephalography. Thanks to the three studies presented here, we were able to prove that the meaning of parafoveal words can be accessed during reading and that such semantic information is integrated during consequent reading behavior. More importantly, this the thesis provided proof that semantic parafoveal information is also used in natural sentence reading scenarios and that the availability of such information relies in the availability of attentional resources of the readers.

The first study demonstrated that meaning of parafoveal words could be accessed during controlled-reading situations and provided electrophysiological markers of semantic processing. The study followed the structured described in the first objective of the thesis. Volunteers consisted in a bilingual Basque-Spanish simple of readers that had to perform a Spanish reading task. Readers had to read Word pairs and the boundary paradigm (Rayner, 1975) was used to manipulate the previewed word (presented always in Basque) which could be a non-cognate Basque translation of the Spanish target word or a totally unrelated Basque word. Modulations on the N400 component, related to semantic processing (Kutas & Federmeier, 2011), were proof that the meaning of parafoveal words was accessed. More importantly, semantic effects were proved to be pure and not confounded by any other orthographic facilitation that could appear with similar semantically related words (see Hutzler et al., 2019; López-Pérez et al, 2016), enhancing the validity of findings of semantic parafoveal processing in reading. Even though it was not the main objective of the thesis, this study provided evidence for the first time of cross-linguistic semantic preview effects in alphabetic languages in the electrophysiological record (see also Snell et al., 2018, Wang et al., 2016). This highlights the importance of using Fixation-Related potentials to explore more subtle manipulations of parafoveal processing, such as exploring if the meaning of parafoveal words are non-selectively accessed in a lexicon integrated across languages in a bilingual sample of readers (as provided by this thesis, see also Dijkstra & Van Heuven, 2002; , Duñabeitia et al, 2009; Duyck & Warlop, 2009).

The second objective was to extend the semantic parafoveal findings of the first study to ecologically-valid scenarios of natural reading, in order to guarantee the validity of the electrophysiological markers of semantic parafoveal processing. For that study, english readers performed a natural reading task where they had to ask some comprehension questions. With the boundary paradigm, the preview was manipulated so it could be semantically related or not to the sentence context and FRPs were obtained. Modulations in the N400 component, as well as in earlier temporal windows, provided solid evidence of semantic parafoveal processing. This evidence was proves that the meaning of parafoveal words can be accessed in natural reading and that it can be linked to electrophysiological markers. This reinforces the validity of semantic parafoveal processing previously obtained through ERPs in more artificially-controlled reading situations and in visual word recognition paradigms (see Barber et al., 2011; Barber et al., 2010; Li et al., 2015; López-Pérez et al., 2016; Snell et al., 2019, see also Stites et al., 2017). The study also covers methodological questions presented in the introduction of the thesis. The co-registration set-up and exploring both FRP and EM data-streams proved useful to delineating the time-course of semantic parafoveal processing. For instance, while EM measures indicated that semantic effects could be short-lived, the FRP signal reflects that semantic parafoveal processing still takes place until later temporal windows (i.e. the N400 component). Therefore, the thesis supports the idea that different cognitive mechanisms may be interacting with semantic parafoveal processing and with reading behavior (for a review, see Degno & Liversedge, 2020) and opens a methodological approach to all future research interested in parafoveal processing.

The third study was the most complex one, since it demonstrated that variations in attentional distribution of readers can modulate the depth of parafoveal processing, reflected in the markers collected during study 2. During the third study, the same participants as in the second study were recruited and they performed a reading task with the moving-window paradigm (McConkie & Rayner, 1975; Rayner, 1975) in order to obtain individual differences measures of their perceptual span. Spelling ability measures were also collected to control for the role of linguistic ability. By running a predictive model of the found electrophysiological markers (obtained in the second study) predicted by the perceptual span and spelling ability of readers, the thesis provides two important outcomes through this study. The first, and most relevant for the objective of the thesis, was that readers with a greater perceptual span were able to have a greater access to the parafoveal region. This implies that individual differences in attentional distribution are key to the access of the semantic parafoveal processing (see also Barber et al., 2013; Payne et al., 2016 for the importance of the availability of attentional resources). Secondly, and in addition, it was shown that the individual differences in linguistic ability also directly modulates semantic parafoveal processing and also interacts with both the individual differences in the perceptual span of readers and with the preview manipulation of the task. Since such differences were found in the FRP data-stream but not in the EM one, it highlights again the importance of using electrophysiological measures in reading to detect subtle interactions between variables.

The results of the three studies can also be interpreted simultaneously. The meaning of parafoveal words is accessed in both artifitial and natural reading scenarios, where attentional distribution may be deployed differently and may not share the same cognitive mechanisms (Kornrumpf et al., 2016; Niefind & Dimigen, 2016). However, the first two studies provided here suggest that semantic access to parafoveal words is independent from the variations inherent from the task, since neural markers related to the N400 component were found in both reading paradigms with FRPs (as it was also found in traditional ERP studies, see Barber et al., 2013; Li et al., 2015; López-Pérez et al., 2016). Therefore, and as previously commented, our findings defies previous statements indicating that while higher-order parafoveal effects may be present in single-word reading paradigms, those may not be present in natural sentence reading tasks where sentence-level feedback to individual word positions constrains word recognition in the parafovea (Snell, Meeter & Grainger, 2017). However, N400-related higher-order parafoveal effects rely in the availability of attentional resources, as demonstrated in our third study in natural sentence reading (and in ERP-artifitial reading studies, see Payne et al., 2016; see also Antúnez, López-Pérez, Dampuré & Barber, under review). Since the third study considered the individual differences of the readers in their ability to distribute attentional resources to predict the depth of parafoveal processing, it is clear that the clean and ecologically-valid N400 markers of semantic parafoveal processing obtained in the other studies must be always been considered while controlling any possible variations in attentional distribution.

The outcomes from the dissertassion summarized here are of great assistant in building the theory of vision and language, more specifically related to the extraction and integration of parafoveal information during natural reading. In addition, knowing what individual differences are related to parafoveal processing and, by extension, reading behavior, this opens a number of new applied possibilities and future research direction. For example, we could now more deeply understand how reading behavior and reading strategy changes as readers get older. Since attentional distribution across the visual field has now be proven to be a crucial component to determine parafoveal processing and, by extension, reading behavior, we now could understand how this modulation of attentional resources may vary with the age of adult skilled readers (see Payne & Federmeier, 2017; Rayner et al., 2009). In addition, it can be beneficial to understand developmental reading disorders such as dyslexia. Readers suffering from dyslexia show deficits in reading processes related to word recognition and eye control (see Bouma & Legein, 1977). More specifically, there is evidence that deficient parafoveal processing plays a role in reading costs in dyslexic readers and that differences between dyslexic and non-dyslexic readers are influenced by orthographic and phonological parafoveal information (Moll & Jones, 2013; Jones, Ashby & Braningan 2013). Since parafoveal information is affected by the availability of attentional resources, there is a great chance that attention plays a crucial role in explaining the differences between dyslexic and non-dyslexic reading behavior. However, the implications are far more than just theoretical. Even more ambitious future research could aim to develop a Brain-Computer interface (BCI) to train the ability of readers to distribute their attentional distribution across the visual field, improving their reading performance. The BCI has been already used to improve the ability to enhance the EEG-Gamma band in visual perception tasks (see Wutz, Melcher, & Samaha, 2018; Merkel, Wibral, Bland, & Singer , 2018; Salari, Büchel, & Rose, 2014), and training the EEG-Alpha band in occipital areas may allow readers to deploy more attentional resources into the parafoveal region (see Kornrumpf, Dimigen & Sommer, 2017). Such approach may be used in older or dyslexic readers with abnormal reading behaviour, making it possible to create a therapeutic tool to improve the quality of reading and lives of many.

In summary, the current dissertation allowed to obtain electrophysiological markers of semantic parafoveal processing in both artificial and natural reading scenarios, contributing to the current literature of at what level parafoveal information is accessed and used to modulate reading behavior. More interestingly, the dissertation provided evidence that individual differences in attentional distribution of readers modulate the mentioned parafoveal processing and that understanding the visual spatial distribution of readers during natural reading is key to create future theoretical and applied research directions.

Part 6. Conclusions

The main conclusions extracted from the three studies of this thesis can be summarize as follows:

1- Semantic parafoveal preview benefits takes place in artifitial reading scenarios, such as the word-pair reading task of study 1, meaning that the meaning of parafoveal words can be directly accessed and integrated with the target word.

2- As unrelated preview words in a second language eliciter larger negativity in the N400 component than non-cognate previewed translations, meaning that the meaning of parafoveal words can also be activated across languages. This would be the first time evidence of cross-linguistic semantic preview effects in alphabetical languages.

3- Semantic parafoveal processing also takes place in natural sentence reading, as reflected in study 2, enhancing the ecological validity of semantic parafoveal findings. The semantic effects in study 2 indicates that traditional evidence coming from highly controlled reading scenarios (such as the flanker-RSVP-ERP paradigm) can be extrapolated to more ecologically-valid, reading scenarios such as natural reading.

4- Contextually implausible previews had greater processing costs than contextually plausible preview. Modulations in the N400 component demonstrated that such effects were not short-lived as previously believed, but that effects extends to later processing, as reflected in electrophysiological measures.

5- The co-registration set up of both eye movements and EEG has been proven to be of extraordinary assistance in reading research. Thanks to the information obtained from both data streams, not only can we approach more naturalistic scenarios, but also we can explore multiple cognitive activity that takes places at the same time but modulates behavior in different ways, allowing the researcher to know which processes are linked to oculomotor behavior and which ones are independt from them.

6- Semantic parafoveal processing in natural reading is modulating by individual differences in the perceptual span of readers, meaning that readers must have enough attentional resources available to devote into the parafoveal region in order to be able to access to the meaning and orthography of parafoveal words and that enhancing attention of readers may also improve reading performance.

7- Individual differences in the spelling ability of readers modulate the depth of parafoveal processing and interacted with the perceptual span of readers and the preview manipulation of the task, being the readers with both a great perceptual span and spelling ability the ones who greatly accessed to parafoveal information. The variability in linguistic ability of readers is crucial to understand the mechanisms behind reading and parafoveal processing and, by no means, should parafoveal processing and visual attentional distribution being studied without accounting for variances in linguistic ability.

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Appendices

Appendix 1. Set of items used in the first study

Ítem	Pretarget	Basque preview	Target	Condition
1	hombre	emakume	MUJER	Translation preview – Related target
2	área	gune	ZONA	Translation preview – Related target
3	café	esne	LECHE	Translation preview – Related target
4	lucha	borroka	BATALLA	Translation preview – Related target
5	estado	egoera	SITUACIÓN	Translation preview – Related target
6	aspecto	itxura	FÍSICO	Translation preview – Related target
7	cierre	ate	PUERTA	Translation preview – Related target
8	crédito	txartel	TARJETA	Translation preview – Related target
9	opinión	iritzi	JUICIO	Translation preview – Related target
10	seno	bular	PECHO	Translation preview – Related target
11	manos	oinak	PIES	Translation preview – Related target
12	bandera	herrialde	PAÍS	Translation preview – Related target
13	informe	berri	NOTICIA	Translation preview – Related target
14	prensa	aldizkari	REVISTA	Translation preview – Related target
15	regreso	itzulera	RETORNO	Translation preview – Related target
16	honor	harrokeria	ORGULLO	Translation preview – Related target
17	duro	bigun	BLANDO	Translation preview – Related target
18	gas	ikatz	BUTANO	Translation preview – Related target
19	masa	ogi	PAN	Translation preview – Related target
20	plaza	nagusi	MAYOR	Translation preview – Related target
21	nivel	maila	ALTURA	Translation preview – Related target
22	precio	garesti	CARO	Translation preview – Related target
23	recurso	giza	HUMANO	Translation preview –

				Related target
24	abeja	ezti	MIEL	Translation preview – Related target
25	zarpa	erpe	GARRA	Translation preview – Related target
26	yogur	esne	LECHE	Translation preview – Related target
27	vodka	edari	BEBIDA	Translation preview – Related target
28	visera	txapel	GORRA	Translation preview – Related target
29	vid	mahats	UVA	Translation preview – Related target
30	vértigo	zorabio	MAREO	Translation preview – Related target
31	verbena	ospakizun	CELEBRACIÓN	Translation preview – Related target
32	urbe	hiri	CIUDAD	Translation preview – Related target
33	plazo	denbora	TIEMPO	Translation preview – Related target
34	interno	kanpoko	EXTERNO	Translation preview – Related target
35	avenida	hiri	CIUDAD	Translation preview – Related target
36	riesgo	arrisku	PELIGRO	Translation preview – Related target
37	prisión	kartzela	CÁRCEL	Translation preview – Related target
38	grupo	lagunak	AMIGOS	Translation preview – Related target
39	largo	labur	CORTO	Translation preview – Related target
40	mostrar	erakutsi	ENSEÑAR	Translation preview – Related target
41	término	hitza	PALABRA	Translation preview – Related target
42	mercado	erosketa	COMPRA	Translation preview – Related target
43	arco	gezi	FLECHA	Translation preview – Related target
44	tierra	lokatz	BARRO	Translation preview – Related target
45	riqueza	txirotasun	POBREZA	Translation preview – Related target
46	pie	oinatz	PISADA	Translation preview – Related target
47	paquete	opari	REGALO	Translation preview – Related target
48	agencia	bidaiak	VIAJES	Translation preview –

				Related target
49	consejo	laguntza	AYUDA	Translation preview – Related target
50	cuenta	batuketa	SUMA	Translation preview – Related target
51	campaña	aterpe	REFUGIO	Translation preview – Related target
52	tío	iloba	SOBRINO	Translation preview – Related target
53	núcleo	erdigune	CENTRO	Translation preview – Related target
54	pared	zuri	BLANCA	Translation preview – Related target
55	tapón	ontzi	BOTE	Translation preview – Related target
56	tapia	horma	MURO	Translation preview – Related target
57	tapa	ontzi	BOTE	Translation preview – Related target
58	tacto	leun	SUAVE	Translation preview – Related target
59	tablero	xake	AJEDREZ	Translation preview – Related target
60	sucio	garbi	LIMPIO	Translation preview – Related target
61	stop	gelditu	PARAR	Translation preview – Related target
62	sotana	apaiz	CURA	Translation preview – Related target
63	sosiego	lasaitasun	CALMA	Translation preview – Related target
64	sorteo	zori	AZAR	Translation preview – Related target
65	uña	hatz	DEDO	Translation preview – Unrelated target
66	tumor	minbizi	CÁNCER	Translation preview – Unrelated target
67	trueno	tximista	RAYO	Translation preview – Unrelated target
68	trineo	elur	NIEVE	Translation preview – Unrelated target
69	tóxico	txar	MALO	Translation preview – Unrelated target
70	tos	hotzeria	CATARRO	Translation preview – Unrelated target
71	tortazo	min	DOLOR	Translation preview – Unrelated target
72	torpe	baldar	PATOSO	Translation preview – Unrelated target
73	torcido	zuzen	RECTO	Translation preview –

				Unrelated target
74	tomate	gorri	ROJO	Translation preview - Unrelated target
75	tijeras	moztu	CORTAR	Translation preview - Unrelated target
76	timbre	txintxarri	CAMPANILLA	Translation preview - Unrelated target
77	tender	eseki	COLGAR	Translation preview - Unrelated target
78	plan	askatu	SOLTAR	Translation preview - Unrelated target
79	hogar	ile	PELO	Translation preview - Unrelated target
80	rápido	zati	TROZO	Translation preview - Unrelated target
81	mirar	jabe	AMO	Translation preview - Unrelated target
82	destino	iragarki	ANUNCIO	Translation preview - Unrelated target
83	error	zuhaitz	ÁRBOL	Translation preview - Unrelated target
84	cabo	astelehen	LUNES	Translation preview - Unrelated target
85	trono	ikusi	VER	Translation preview - Unrelated target
86	comida	mendi	MONTAÑA	Translation preview - Unrelated target
87	cama	herri	PUEBLO	Translation preview - Unrelated target
88	querer	zain	VENA	Translation preview - Unrelated target
89	piedra	hotz	FRÍO	Translation preview - Unrelated target
90	datos	txori	PÁJARO	Translation preview - Unrelated target
91	débil	aukeratu	ELEGIR	Translation preview - Unrelated target
92	dueño	argi	LUZ	Translation preview - Unrelated target
93	calidad	huts	VACÍO	Translation preview - Unrelated target
94	estilo	bakarrik	SOLA	Translation preview - Unrelated target
95	domingo	hurrenkera	ORDEN	Translation preview - Unrelated target
96	norte	hazi	CRECER	Translation preview - Unrelated target
97	abierta	gezur	MENTIRA	Translation preview - Unrelated target
98	playa	itsu	CIEGO	Translation preview -

				Unrelated target
99	aire	bezero	CLIENTE	Translation preview – Unrelated target
100	vista	ogi	PAN	Translation preview – Unrelated target
101	réplica	lodi	GORDA	Translation preview – Unrelated target
102	repisa	hotzeria	CATARRO	Translation preview – Unrelated target
103	receta	txartel	BILLETE	Translation preview – Unrelated target
104	raqueta	minbizi	CÁNCER	Translation preview – Unrelated target
105	pus	sinadura	FIRMA	Translation preview – Unrelated target
106	pis	gauza	COSA	Translation preview – Unrelated target
107	picor	hiri	CIUDAD	Translation preview – Unrelated target
108	pétalo	sabai	TECHO	Translation preview – Unrelated target
109	peste	harri	PIEDRA	Translation preview – Unrelated target
110	peseta	esne	NATA	Translation preview – Unrelated target
111	pereza	argi	LISTO	Translation preview – Unrelated target
112	patín	soka	CUERDA	Translation preview – Unrelated target
113	patatas	irteera	SALIDA	Translation preview – Unrelated target
114	panda	itsaso	MAR	Translation preview – Unrelated target
115	palpar	janari	COMIDA	Translation preview – Unrelated target
116	ósea	luze	LARGA	Translation preview – Unrelated target
117	orar	zuzen	RECTO	Translation preview – Unrelated target
118	olfato	mugikor	MÓVIL	Translation preview – Unrelated target
119	ojal	alargun	VIUDA	Translation preview – Unrelated target
120	ofensa	amandre	MADRINA	Translation preview – Unrelated target
121	ocaso	ahots	VOZ	Translation preview – Unrelated target
122	nupcial	horma	MURO	Translation preview – Unrelated target
123	sordo	itsu	CIEGO	Translation preview –

				Unrelated target
124	sopera	koilara	CUCHARA	Translation preview – Unrelated target
125	soga	soka	CUERDA	Translation preview – Unrelated target
126	sirena	itsaso	MAR	Translation preview – Unrelated target
127	saldo	mugikor	MÓVIL	Translation preview – Unrelated target
128	salado	gozo	DULCE	Translation preview – Unrelated target
129	sable	aihotz	MACHETE	Translation preview – Unrelated target
130	ruleta	zorte	FORTUNA	Translation preview – Unrelated target
131	rugoso	lau	LISO	Translation preview – Unrelated target
132	rugido	lehoi	LEÓN	Translation preview – Unrelated target
133	rúbrica	sinadura	FIRMA	Translation preview – Unrelated target
134	rima	olerki	POESÍA	Translation preview – Unrelated target
135	reptil	musker	LAGARTO	Translation preview – Unrelated target
136	corta	itun	PACTO	Translation preview – Unrelated target
137	oficio	garagardo	CERVEZA	Translation preview – Unrelated target
138	manera	ardi	OVEJA	Translation preview – Unrelated target
139	página	itsasontzi	BARCO	Translation preview – Unrelated target
140	placer	lapurreta	ROBO	Translation preview – Unrelated target
141	partido	gezi	FLECHA	Translation preview – Unrelated target
142	derecho	argazkiak	FOTOS	Translation preview – Unrelated target
143	raíz	hegazkin	AVIÓN	Translation preview – Unrelated target
144	decreto	eki	SOL	Translation preview – Unrelated target
145	flota	gutun	CARTA	Translation preview – Unrelated target
146	lengua	garesti	CARO	Translation preview – Unrelated target
147	quedar	hotz	FRÍA	Translation preview – Unrelated target
148	escrito	kotxe	COCHE	Translation preview –

				Unrelated target
149	colonia	egur	MADERA	Translation preview - Unrelated target
150	abrir	zenbaki	NÚMERO	Translation preview - Unrelated target
151	premio	garbi	LIMPIO	Translation preview - Unrelated target
152	única	hatz	DEDO	Translation preview - Unrelated target
153	morir	ezpainak	LABIOS	Translation preview - Unrelated target
154	alma	kirol	DEPORTE	Translation preview - Unrelated target
155	dicha	zuri	BLANCA	Translation preview - Unrelated target
156	rural	garaikur	TROFEO	Translation preview - Unrelated target
157	local	porrot	FRACASO	Translation preview - Unrelated target
158	obesa	antiojoak	GAFAS	Translation preview - Unrelated target
159	noria	otoitz	REZAR	Translation preview - Unrelated target
160	nuca	olerki	POESÍA	Translation preview - Unrelated target
161	musa	hartu	COGER	Translation preview - Unrelated target
162	muela	bero	CALOR	Translation preview - Unrelated target
163	mueca	lasaitasun	CALMA	Translation preview - Unrelated target
164	moto	eder	HERMOSO	Translation preview - Unrelated target
165	moruno	lepo	CUELLO	Translation preview - Unrelated target
166	moratón	margolari	PINTOR	Translation preview - Unrelated target
167	montar	arrain	PESCADO	Translation preview - Unrelated target
168	miopía	buruko	CASCO	Translation preview - Unrelated target
169	melón	kirol	DEPORTE	Translation preview - Unrelated target
170	médula	oihan	BOSQUE	Translation preview - Unrelated target
171	mártir	leku	LUGAR	Translation preview - Unrelated target
172	maullar	lore	FLOR	Translation preview - Unrelated target
173	mareo	zizare	GUSANO	Translation preview -

				Unrelated target
174	mangas	geixo	ENFERMO	Translation preview – Unrelated target
175	maleta	pikor	GRANO	Translation preview – Unrelated target
176	maldad	atorra	CAMISA	Translation preview – Unrelated target
177	maceta	haserre	ENFADO	Translation preview – Unrelated target
178	licor	zangoak	PIERNAS	Translation preview – Unrelated target
179	liebre	gradu	TÍTULO	Translation preview – Unrelated target
180	lepra	ezti	MIEL	Translation preview – Unrelated target
181	parque	kenketa	NIÑOS	Unrelated preview – Related target
182	rápida	hare	LENTA	Unrelated preview – Related target
183	día	bular	NOCHE	Unrelated preview – Related target
184	sangre	maitasun	ROJA	Unrelated preview – Related target
185	mesa	arrazoi	SILLA	Unrelated preview – Related target
186	ruta	lauki	CAMINO	Unrelated preview – Related target
187	marco	haize	CUADRO	Unrelated preview – Related target
188	objeto	apaiz	COSA	Unrelated preview – Related target
189	arma	konpainia	PISTOLA	Unrelated preview – Related target
190	colega	zuhaitz	AMIGO	Unrelated preview – Related target
191	difícil	orlegi	FÁCIL	Unrelated preview – Related target
192	inglés	arrisku	FRANCÉS	Unrelated preview – Related target
193	campo	eskaintza	VERDE	Unrelated preview – Related target
194	inicio	mahats	FIN	Unrelated preview – Related target
195	río	musu	AGUA	Unrelated preview – Related target
196	éxito	garbitu	FRACASO	Unrelated preview – Related target
197	nuevo	laguntza	VIEJO	Unrelated preview – Related target
198	aumento	sukalde	SUELDO	Unrelated preview –

				Related target
199	cerrado	esaldi	ABIERTO	Unrelated preview - Related target
200	capilla	bidaia	IGLESIA	Unrelated preview - Related target
201	señal	harrokeria	TRÁFICO	Unrelated preview - Related target
202	jardín	bigun	FLORES	Unrelated preview - Related target
203	mandato	aulki	ORDEN	Unrelated preview - Related target
204	legua	beltz	MILLA	Unrelated preview - Related target
205	latido	zahar	CORAZÓN	Unrelated preview - Related target
206	larva	amona	GUSANO	Unrelated preview - Related target
207	ladrar	azal	PERRO	Unrelated preview - Related target
208	jugo	soinu	ZUMO	Unrelated preview - Related target
209	júbilo	ahozko	ALEGRÍA	Unrelated preview - Related target
210	jaula	erotasun	PÁJARO	Unrelated preview - Related target
211	intruso	moztu	LADRÓN	Unrelated preview - Related target
212	insecto	burdina	MOSCA	Unrelated preview - Related target
213	ibérico	geldo	JAMÓN	Unrelated preview - Related target
214	hurto	gorri	ROBO	Unrelated preview - Related target
215	hoyo	gihar	AGUJERO	Unrelated preview - Related target
216	hongo	txanpon	SETA	Unrelated preview - Related target
217	hola	aitita	ADIÓS	Unrelated preview - Related target
218	halago	oka	PIROPO	Unrelated preview - Related target
219	hada	arantzadi	MADRINA	Unrelated preview - Related target
220	guarro	min	CERDO	Unrelated preview - Related target
221	granero	aurpegi	PAJA	Unrelated preview - Related target
222	gorila	tximista	MONO	Unrelated preview - Related target
223	goma	onezi	BORRAR	Unrelated preview -

				Related target
224	glaciar	belarri	HIELO	Unrelated preview – Related target
225	girasol	umeak	PIPAS	Unrelated preview – Related target
226	llama	gau	FUEGO	Unrelated preview – Related target
227	tipo	ilun	CLASE	Unrelated preview – Related target
228	bancos	azterketa	DINERO	Unrelated preview – Related target
229	líder	gari	JEFE	Unrelated preview – Related target
230	motor	lagun	COCHE	Unrelated preview – Related target
231	régimen	sudur	DIETA	Unrelated preview – Related target
232	suma	mota	RESTA	Unrelated preview – Related target
233	piano	espetxe	MÚSICA	Unrelated preview – Related target
234	hijos	ezabatu	PADRES	Unrelated preview – Related target
235	reino	jaka	ANIMAL	Unrelated preview – Related target
236	obra	gogor	TEATRO	Unrelated preview – Related target
237	parte	babo	TROZO	Unrelated preview – Related target
238	comedia	aho	RISA	Unrelated preview – Related target
239	gestión	hitz	EMPRESA	Unrelated preview – Related target
240	griego	bukaera	LATÍN	Unrelated preview – Related target
241	normas	bular	LEYES	Unrelated preview – Related target
242	carne	helmuga	VACA	Unrelated preview – Related target
243	oscuro	geldo	NEGRO	Unrelated preview – Related target
244	conde	bizi	DUQUE	Unrelated preview – Related target
245	fuerza	polit	PODER	Unrelated preview – Related target
246	opción	gorputza	ELEGIR	Unrelated preview – Related target
247	arte	gose	PINTURA	Unrelated preview – Related target
248	gel	josi	DUCHA	Unrelated preview –

				Related target
249	fucsia	buruko	COLOR	Unrelated preview – Related target
250	fronda	neska	BOSQUE	Unrelated preview – Related target
251	frita	zaldi	PATATA	Unrelated preview – Related target
252	fresas	gau	NATA	Unrelated preview – Related target
253	fregar	eskakizun	LIMPIAR	Unrelated preview – Related target
254	fósforo	poz	CERILLA	Unrelated preview – Related target
255	follón	begi	LÍO	Unrelated preview – Related target
256	flexo	hartz	LUZ	Unrelated preview – Related target
257	fideos	ero	SOPA	Unrelated preview – Related target
258	fea	zuzena	GUAPA	Unrelated preview – Related target
259	facial	umea	CARA	Unrelated preview – Related target
260	éxtasis	urdaiazpikoa	DROGA	Unrelated preview – Related target
261	espinas	eliza	PESCADO	Unrelated preview – Related target
262	espiga	bidaia	TRIGO	Unrelated preview – Related target
263	espanto	ona	SUSTO	Unrelated preview – Related target
264	escoba	gizakia	BARRER	Unrelated preview – Related target
265	escalar	arrasta	MONTAÑA	Unrelated preview – Related target
266	eco	urrea	VOZ	Unrelated preview – Related target
267	dominó	zaharra	JUEGO	Unrelated preview – Related target
268	diploma	heriotza	TÍTULO	Unrelated preview – Related target
269	dibujar	epaiketa	PINTAR	Unrelated preview – Related target
270	depilar	altzari	PIERNAS	Unrelated preview – Related target
271	frase	esaldi	PISTOLA	Unrelated preview – Unrelated target
272	comité	bilkura	BOTELLA	Unrelated preview – Unrelated target
273	metal	burdin	CAMINO	Unrelated preview –

				Unrelated target
274	juez	mailu	DEPORTE	Unrelated preview – Unrelated target
275	cifra	zenbaki	TEATRO	Unrelated preview – Unrelated target
276	prueba	azterketa	REGALO	Unrelated preview – Unrelated target
277	verdad	gezur	CANARIA	Unrelated preview – Unrelated target
278	copa	edalontzi	PIES	Unrelated preview – Unrelated target
279	plata	urre	SUR	Unrelated preview – Unrelated target
280	escuela	ikastetxe	CUERNOS	Unrelated preview – Unrelated target
281	espacio	zuri	HAMBRE	Unrelated preview – Unrelated target
282	pobre	aberats	VACA	Unrelated preview – Unrelated target
283	sitio	leku	DUQUE	Unrelated preview – Unrelated target
284	cámara	argazkiak	SALIR	Unrelated preview – Unrelated target
285	social	talde	QUESO	Unrelated preview – Unrelated target
286	vía	errepide	RISA	Unrelated preview – Unrelated target
287	círculo	biribil	GUANTES	Unrelated preview – Unrelated target
288	pasión	maitasun	LISO	Unrelated preview – Unrelated target
289	calor	hotz	UÑAS	Unrelated preview – Unrelated target
290	papel	arkatz	LECHE	Unrelated preview – Unrelated target
291	labios	musu	COMA	Unrelated preview – Unrelated target
292	norma	arau	FUEGO	Unrelated preview – Unrelated target
293	efecto	arrazoi	NEGRO	Unrelated preview – Unrelated target
294	demente	eroa	BOTE	Unrelated preview – Unrelated target
295	dedal	josi	CERDO	Unrelated preview – Unrelated target
296	croar	igel	PIEL	Unrelated preview – Unrelated target
297	cordura	erotasun	BEBIDA	Unrelated preview – Unrelated target
298	comba	soka	HABLAR	Unrelated preview –

				Unrelated target
299	collar	bitxiak	FÍSICO	Unrelated preview – Unrelated target
300	colgar	beroki	SONIDO	Unrelated preview – Unrelated target
301	cofre	altxor	PATOSO	Unrelated preview – Unrelated target
302	cigarro	ke	ROSA	Unrelated preview – Unrelated target
303	charlar	berba	CONEJO	Unrelated preview – Unrelated target
304	caserío	gazta	PENAL	Unrelated preview – Unrelated target
305	cáscara	arrautza	PRIMA	Unrelated preview – Unrelated target
306	carroña	sai	ABRIGO	Unrelated preview – Unrelated target
307	canon	edertasun	ENSEÑAR	Unrelated preview – Unrelated target
308	cabreo	haserre	PLANTA	Unrelated preview – Unrelated target
309	butaca	aulki	RANA	Unrelated preview – Unrelated target
310	braga	neska	TRIGO	Unrelated preview – Unrelated target
311	boxeo	eskularruak	CEBOLLA	Unrelated preview – Unrelated target
312	botica	amama	RASCAR	Unrelated preview – Unrelated target
313	bobo	ergel	LIMÓN	Unrelated preview – Unrelated target
314	bíceps	gihar	LAGARTO	Unrelated preview – Unrelated target
315	bautizo	haur	PAJA	Unrelated preview – Unrelated target
316	punto	marra	OLOR	Unrelated preview – Unrelated target
317	paso	urrats	BRAZO	Unrelated preview – Unrelated target
318	acuerdo	itun	GARRA	Unrelated preview – Unrelated target
319	moderno	zahar	SEGUNDO	Unrelated preview – Unrelated target
320	cabeza	ile	TREN	Unrelated preview – Unrelated target
321	línea	zuzen	HUEVO	Unrelated preview – Unrelated target
322	miembro	beso	LÁPIZ	Unrelated preview – Unrelated target
323	esposa	senar	ACCIÓN	Unrelated preview –

				Unrelated target
324	lleno	huts	SUSTO	Unrelated preview - Unrelated target
325	minuto	erloju	CABALLO	Unrelated preview - Unrelated target
326	lima	azkazalak	SEXO	Unrelated preview - Unrelated target
327	piloto	hegazkin	CEBRA	Unrelated preview - Unrelated target
328	oferta	eskakizun	TRÁFICO	Unrelated preview - Unrelated target
329	temor	ikara	FRUTA	Unrelated preview - Unrelated target
330	vida	heriotza	TIENDA	Unrelated preview - Unrelated target
331	ataque	eraso	HIERRO	Unrelated preview - Unrelated target
332	carrera	helmuga	PISO	Unrelated preview - Unrelated target
333	toro	adarrak	REDONDO	Unrelated preview - Unrelated target
334	entrada	irteera	FLORES	Unrelated preview - Unrelated target
335	topo	itsu	MUJER	Unrelated preview - Unrelated target
336	materia	gai	ADIÓS	Unrelated preview - Unrelated target
337	amplio	zabal	PADRES	Unrelated preview - Unrelated target
338	batido	marrubi	PERRO	Unrelated preview - Unrelated target
339	barril	garagardo	POBREZA	Unrelated preview - Unrelated target
340	balanza	pisu	RICO	Unrelated preview - Unrelated target
341	baboso	barraskilo	CORAZÓN	Unrelated preview - Unrelated target
342	babosa	nazka	ZONA	Unrelated preview - Unrelated target
343	atrapar	hartu	COPIA	Unrelated preview - Unrelated target
344	atleta	kirol	VENTANA	Unrelated preview - Unrelated target
345	ático	solairu	PESO	Unrelated preview - Unrelated target
346	astuto	azkar	SUEÑO	Unrelated preview - Unrelated target
347	astilla	egur	PIROPO	Unrelated preview - Unrelated target
348	asa	kirten	NIEVE	Unrelated preview -

				Unrelated target
349	arteria	zain	HUMO	Unrelated preview – Unrelated target
350	apretar	askatu	BUITRE	Unrelated preview – Unrelated target
351	apodo	ezizen	NUDO	Unrelated preview – Unrelated target
352	anudar	korapilo	MONO	Unrelated preview – Unrelated target
353	alternar	aldatu	MOTE	Unrelated preview – Unrelated target
354	alergia	dominitiku	FERIA	Unrelated preview – Unrelated target
355	ajo	tipula	SOBRINO	Unrelated preview – Unrelated target
356	aguja	hari	PAÍS	Unrelated preview – Unrelated target
357	agrio	mingots	DUCHA	Unrelated preview – Unrelated target
358	agobio	itolarri	PINCHO	Unrelated preview – Unrelated target
359	adobado	kozinatu	CLUB	Unrelated preview – Unrelated target
360	abrazo	maitasun	LADRÓN	Unrelated preview – Unrelated target

Appendix 2. Set of items used in the second study

Ítem	Sentence	Identical preview	Plausible preview	Implausible preview
1	Jane will travel south on her trip to Los Angeles next week.	south	coach	pizza
2	Jane would never refuse a bonus from her boss.	refuse	report	sounds
3	The neighbor's kids were too awful to remember to clean up their mess.	awful	happy	found
4	The ghost suddenly appeared in the upper window of the house.	appeared	screamed	employed
5	Anna didn't want to remain friends with the weird kids in her class.	friends	popular	towards
6	Jenny prefers to purchase large bottles of lotion.	large	fancy	whale
7	There were many older men on the bus this morning.	older	quiet	mouth
8	Harry bought a broken watch to repair for fun.	watch	chair	peace
9	The new student answered the question boldly when no one else raised their hand.	boldly	easily	highly
10	The lawyer asked the witness to carefully explain what he saw on the day of the crime.	explain	restate	sputter
11	The children came up with a very clever way to fix the sink.	clever	clumsy	atomic
12	Everyone was pleased that the talented chef prepared such a wonderful meal.	chef	kids	door
13	David likes to eat extremely warm potato salad.	warm	soft	nose
14	Kaite had forgotten to take out several rollers from her hair and everyone stared.	rollers	flowers	opinion

15	Jen's classmate is always mean when they go on trips.	mean	dull	dime
16	Sam's train arrived just before dusk and we were able to give her a ride home.	dusk	ours	rent
17	The hike up the mountain was surprisingly hard but very fun.	hard	long	away
18	The little girl complained about her upset tummy and asked to skip soccer practice.	tummy	ankle	slice
19	Kevin's brother ate all their fresh bread in the apartment.	fresh	baked	draft
20	Tammy noticed many items were still blank when checking over her exam.	blank	wrong	three
21	Everyone looks like a skinny giant standing next to Henry.	giant	model	juice
22	The building was closed due to a recent attack that occurred inside.	attack	murder	handle
23	The box gradually became heavier the longer he carried it.	heavier	dirtier	checker
24	Jennifer went to watch the exciting video at the new theater.	video	dance	water
25	John should have baked more apples into the pie.	more	tart	bats
26	It was Kara's dream to live near the beautiful city after retiring from her job.	city	lake	eggs
27	The professor's coat is rather tight for him.	tight	short	north
28	Sal lost his notes somewhere in the messy center of his bedroom.	center	corner	member
29	The children are extremely quiet during storytime.	quiet	eager	stark
30	Greta's dog would always select the bowl with the treats inside.	select	ignore	inform

31	The boy tried to quickly clean the car window before rushing to his meeting.	clean	break	alone
32	Dana didn't realize his tattoo was actually permanent until almost four months later.	permanent	offensive	swallowed
33	Teresa's grandmother doesn't like to hear offensive jokes about the war.	jokes	songs	gates
34	Zoe insisted that her hair color wasn't fake but no one believed her.	fake	pink	bars
35	The man was a notorious murderer and stories about him can be found in many papers.	murderer	lecturer	dandruff
36	Everyone knew the girl was quite rich because of the neighborhood she lived in.	rich	lazy	mall
37	The ring had beautiful jewels around the band.	jewels	shapes	cleans
38	Olga set up the equipment wrong the first time.	wrong	badly	mercy
39	We received a warning that a dangerous tornado might hit the town this week.	tornado	tsunami	mandolin
40	All the vegetables have to be kept separate on the boy's plate or he will be upset.	separate	lukewarm	inhumane
41	We ran away from the overpowering smell of the stink bomb exploding.	smell	sound	vault
42	There were so many serious stories in the news today.	serious	strange	certain
43	After dinner, Wendy always rinsed the dishes right away.	rinsed	forgot	ground
44	The new event was such a great success that people were talking about it for weeks.	success	scandal	haircut

45	Jason was nervous walking around police who were standing outside the embassy.	police	people	matter
46	The man claimed that the dogs became tame after they were given to him.	tame	loud	fake
47	Buying a car seems fairly essential for most college students.	essential	expensive	chocolate
48	Jean says that somewhat dull clothing is all the rage these days.	dull	busy	glad
49	Pam almost forgot to return the heavy book in time.	book	tape	jump
50	The people suddenly imported all the goods they could before the embargo.	imported	snatched	believer
51	Brad thought his project idea was incredibly ingenious and wanted to tell everyone.	ingenious	efficient	strangled
52	Henry didn't allow anyone to be visibly sober at his party last week.	sober	angry	glass
53	The puppy was so extremely stubborn that it took three people to get him into the car.	stubborn	restless	stitches
54	There was a woman walking three tiny dogs at the park today.	tiny	gray	soup
55	Dan needed to have his damaged molar replaced after the accident.	molar	joint	storm
56	The student will reluctantly take his research paper to the professor.	take	show	love
57	George planned to get a beautiful lawn for his front yard.	lawn	tree	mama
58	The high school students always love running when they are tired.	love	stop	girl
59	Every year the children wish for new toys.	wish	yell	iron

60	The bakery's pastries are truly superior compared to the other place's.	superior	delicate	surgical
61	Heidi always packs too many shoes when she goes on vacation.	shoes	pants	stars
62	Bob was forced to repaint the building's exterior three times before getting it right.	exterior	insignia	bathrobe
63	Gary thought if he put on a costume he could excite the children in the class.	excite	baffle	thrift
64	The number of cookies in the jar seems decreased from the last time I looked.	decreased	unchanged	afterglow
65	George was afraid of stepping on a possibly lethal part of the abandoned building.	lethal	flimsy	floral
66	Darren managed to somehow lose the wedding ring down the storm drain.	lose	toss	bugs
67	Alice's perfume was quite aromatic and caught the attention of many men.	aromatic	specific	mistaken
68	The family left the garage door closed when they went on vacation.	closed	broken	honest
69	Peg thought Jen would be somewhat envious about her engagement ring and kept it hidden.	envious	excited	checked
70	Gary didn't expect to have to suddenly depart but he pulled it off without a hitch.	depart	refuel	frolic
71	Ann always stays at the same house in Tahoe for vacation.	house	place	money
72	The team expected a huge victory after seeing the competition.	victory	quarrel	pajamas
73	Jamie begged his parents to get him a nifty	device	outfit	drives

	device but they didn't have the money.			
74	Jeffrey didn't like the really soft music playing at the party.	soft	cute	less
75	Despite hearing many stories, Jan didn't notice a single tower on her trip to Prague.	tower	eagle	horns
76	This restaurant's broth is overly bland and spicy for my taste.	bland	clear	young
77	Dale's company gave him a huge prize for his hard work.	prize	party	weird
78	The swords in the museum were noticeably blunt and covered with jewels.	blunt	shiny	dizzy
79	Sheena wrote down the incorrect avenue and got lost on her way to the restaurant.	avenue	number	sister
80	My roommate's furniture is extremely fancy compared to mine.	fancy	dirty	upset
81	The company requires workers to slowly raise the crane to prevent accidents.	raise	drive	dream
82	There were renovations on the outdated lobby and hotel patrons need to use a back door.	lobby	bench	fifty
83	The directions state that you should push the lever when the red light is on.	push	drop	blue
84	When Betty couldn't stop the car fast enough she ran into the median.	stop	turn	ship
85	The chemical laboratory's danger area is marked by a large sign.	danger	office	family
86	Last night my dreams were unusually lucid so I wrote about them in my journal.	lucid	weird	class

87	The class noticed the repeated angel motifs in the paintings.	angel	daisy	crawl
88	The family put an evil looking devil decoration on their front lawn.	devil	ghost	sugar
89	The couple always agrees with each other and has a reputation.	agrees	drives	dancer
90	She thought that the bright thread was perfect for her art project.	thread	silver	threat
91	The kids always ignore when their shoes are untied.	ignore	scream	poison
92	The tall man looked rather thin wearing his new tuxedo.	thin	good	back
93	The court officials cannot enter before the emperor allows them to.	enter	drink	sleep
94	Peter was asked to point out on the large globe where Antarctica was.	globe	print	anger
95	The artist loved to paint rural landscapes as well as portraits.	rural	green	pants
96	The PTA was eager to talk about the expensive repair happening at the school.	repair	dances	donkey
97	Lucy thinks her parents will forbid her going to the dance.	forbid	escort	barrel
98	His stature was quite high for a boy of his age.	high	rare	earl
99	The kids were excited to leave for their summer vacation and could barely sleep.	summer	school	change
100	He was injured by the solid stone that was thrown at him.	stone	punch	kitty
101	Some people thought the parrot was actually mute but it just did not want to talk.	mute	dead	long

102	The chemist did not realize the reaction could arise without a spark.	arise	erupt	fable
103	She received a well used organ from her great grandmother.	organ	bible	argue
104	The students thought the long test was rather tedious.	test	book	food
105	The dog would always sniff the grass in front of the house.	sniff	shred	blush
106	The losing team's rebuttal was so legendary that it went viral on YouTube.	rebuttal	insanity	congress
107	No one lived in the house by the secluded beach for many years.	beach	hills	squad
108	The notorious gang defaced the statue in front of city hall.	defaced	painted	foreign
109	Roger made sure he was always ready for his exams so that he would do well.	ready	early	table
110	After the party the couch felt grimy from all the guests sitting on it.	grimy	comfy	lunar
111	They were able to quickly list everything they needed.	list	take	want
112	Everyone thought the student was incredibly astute after meeting him.	astute	smelly	canned
113	The students always save all their homework when the quarter is over.	save	burn	rain
114	The teacher always finds a relevant topic for the students to write about.	topic	movie	stick
115	There was a very short news story on TV last night.	short	awful	beach
116	The two cities lived in complete harmony for many years.	harmony	rivalry	forming

117	George was a skilled guide and had explored the trail many times.	guide	hiker	heron
118	Tommy decided he would fling the stone in the pond later that day.	fling	leave	ready
119	Will keeps a large knife in his backpack when he goes hiking.	knife	phone	honey
120	Registration for the event will finally start at the end of the month.	start	close	check
121	Kenny told his longtime rival to meet him outside after school.	rival	tutor	array
122	The criminal tried to stealthily avoid the cops in the building.	avoid	block	round
123	The junk mail would always inform its recipients with new offers.	inform	bother	attack
124	In the morning Jessica tallied all the sales from last weekend to her boss.	tallied	emailed	plodded
125	Katie watched the children jump in the pool at the rec center.	jump	swim	buck
126	Lisa taught the children a familiar song to keep them entertained.	song	poem	warp

Appendix 3. Set of items used in the third study

Ítem	Sentence
1	Mark goes swimming every Thursday with his best friend.
2	I am going to help my mother wash the windows of her apartment.
3	The teacher is a very funny man and he makes the students laugh.
4	Many students arrived late this morning because the bus broke down.
5	My friend would really like to visit New York City next summer.
6	I am going to read a good book after work and eat a healthy dinner.
7	My father sent several letters to his childhood friend last year.

8	My family and I did not go on a trip last summer because my father was sick.
9	My brother likes reading the newspaper in the morning before he eats breakfast.
10	My neighbor forgot his keys in his new car yesterday.
11	My friend met her mother at the bank today and talked to her for a long time.
12	This child always talks in class and disturbs the other children.
13	Suzie called her father and thanked him for the beautiful gift.
14	The children go to the park every Friday with their teacher.
15	Patty is going to help her friend paint her house next weekend.
16	The president of the company is a very intelligent woman.
17	The train often arrives late when it snows a lot and many people are angry.
18	The young woman really wanted to invite her boss to dinner.
19	My grandmother will work in her garden next week and plant many flowers.
20	Alex bought his daughter a plane ticket for her birthday.
21	My sister would like to go to the desert with her children this weekend.
22	Luke sent flowers to his mom for her birthday and she was very happy.
23	Brian did not eat before going to work this morning and now he is very hungry.
24	My friend likes to watch television when he cooks dinner.
25	My neighbor lost her job last month and she hopes to find a new job soon.
26	Peter often meets his neighbors at the pool and he plays with them all day.
27	The man always drives too fast on the road and had an accident last week.
28	Heather looked out the window and saw a cat running after a mouse.
29	Jay went to the cinema with his brother but they didn't like the movie.
30	I will ask my son to clean his room tomorrow because it is very dirty.
31	The little boy likes to play hockey with his brother every weekend.
32	Last night, the plane left late because of the snow storm.

33	Annie wants to go to the hairdresser after her mathematics class.
34	Nancy and her family are going to Los Angeles and San Francisco next month.
35	Christine asked her friend to taste her new chocolate and orange cake recipe.
36	Lauren would like to go to the Chinese restaurant with her father this week.
37	Patrick gave several pants, shirts and shoes to the poor man at the church.
38	Peter did not want to go to work yesterday because he was feeling very sick.
39	Michael really likes to sit in a park and read a good book on the weekend.
40	Kate talked to the bank manager last night and asked for another loan.
41	My brother often forgets his office keys at home in the morning.
42	Rebecca ate dinner really late last night and she could not sleep.
43	My father visited his mother after work and he had dinner with her.
44	My brother likes to ride his bike with his girlfriend every Saturday.
45	I will ask my cousin to help me repair my television again.
46	My friend really likes to ski in the winter but he does not like to skate.
47	There was a bad accident on the road and the school bus is very late.
48	My sister and her friend would really like to study Spanish in Mexico.
49	I will finally meet my new mother-in-law tonight after I finish work.
50	My cousin bought a little black dog for his younger son for Christmas.
51	The young woman would like to live alone in an apartment next year.
52	The young man gave a lot of money to the local high school.
53	Jake forgot to wear his hat this morning and now his head is cold.
54	Miranda likes to watch a good movie with friends on weekends.
55	Sharon talked to the new teacher about her son last week.
56	The little boy always forgets to feed his cat in the morning.
57	Connie takes a holiday every year and tries to visit a new country.

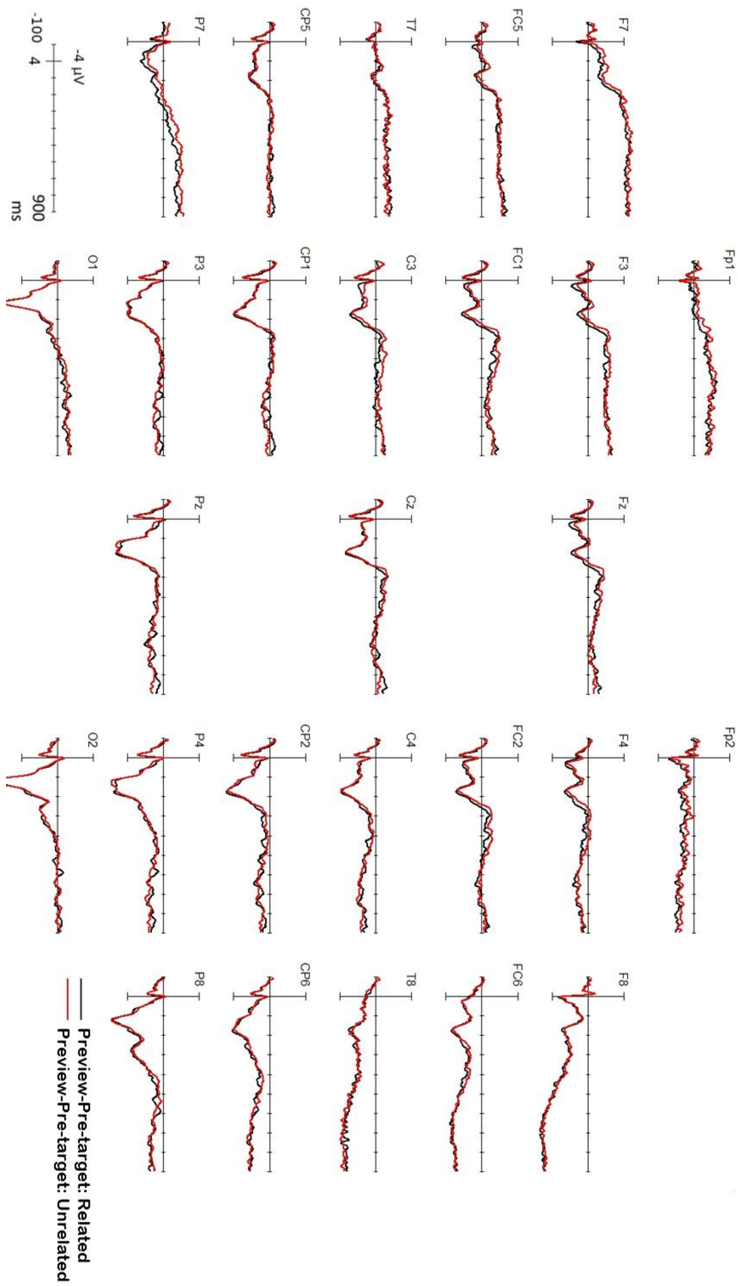
58	Jonathan asked for a book for his birthday but he got a coffee mug.
59	My friends live in a very small apartment and they want more space.
60	Martin will help his father decorate the house for Christmas.
61	The actor met a very interesting man and wanted to work with him.
62	The bank manager arrived late at the meeting and forgot important papers.
63	Diana would like to buy new clothes but she will wait until next month.
64	Timothy will buy a new car tomorrow but he will need help from a friend.
65	The little girl asked her father for a cat for her birthday next week.
66	Shelly wants to take a vacation next summer but she does not have enough money.
67	My friend sent a gift to his grandmother but he forgot to send her a card.
68	Victor took the bus everyday this week because his car was broken.
69	Esther likes to stay at home and paint on Friday after work.
70	Hannah lost her little dog last week and she is very sad.
71	My brother exercises for two hours every morning before school.
72	This woman really likes reading and going to the movies with her friends.
73	Monica ate many different fruits for breakfast and vegetable soup for lunch.
74	Their dog ran away from home yesterday and they still cannot find it.
75	The teacher gave us a lot of homework today and we had no time to play.
76	Michelle went to the zoo and saw lions, tigers, and monkeys.
77	Jenny likes to watch movies with her friends but only on the weekends.
78	The girl invited her friends to her birthday party and made a chocolate cake.
79	My favorite subjects in high school were mathematics and science.
80	David picked lemons from the tree and made lemonade for his mom.
81	Julian really likes to read mystery books during his free time.
82	Steve broke his arm last weekend because he fell off his bike.

83	John goes to church with his family every Friday and Sunday.
84	Bill ate a huge sandwich and lots of chips for lunch.
85	Last night, I ate pizza for dinner and cake for dessert.
86	Mary started working at the local high school and she loves her new job.
87	When Peter was a child, he really wanted to be a doctor like his father.
88	Emily loves swimming at the beach before she goes to work every day.
89	Her boyfriend gave her red roses for Valentine's Day every year.
90	Molly went to school with her new bike for the first time today.
91	The children went to the zoo with their parents and had a great time.
92	Julia was feeling very sad because her boyfriend forgot her birthday.
93	Barry's parents were happy because he was the best student in his class.
94	Joe loved to collect rocks and leaves when he was a little boy.
95	Jane likes to send photos and write a long letter to her parents every month.
96	Today, I went to the market and bought some fresh fruits and vegetables.
97	The new restaurant sells burgers, hot dogs and French fries.
98	This winter the new student will go camping in the desert with his friends.
99	Yesterday, Chris spent the day at the library and read two books.
100	The couple wanted to get married in the spring but they changed their plan.
101	Spring and summer are my favorite seasons because I can go camping.
102	Laura visits her grandmother once a week and brings her flowers.
103	Bob went to his first music show last night and really loved it.
104	Pamela went on a trip with her friends across the country.
105	Jessica learned to play piano when she was four years old.
106	My parents went on vacation to Hawaii for their wedding anniversary.
107	Christina missed school last week because she had many doctor's appointments.

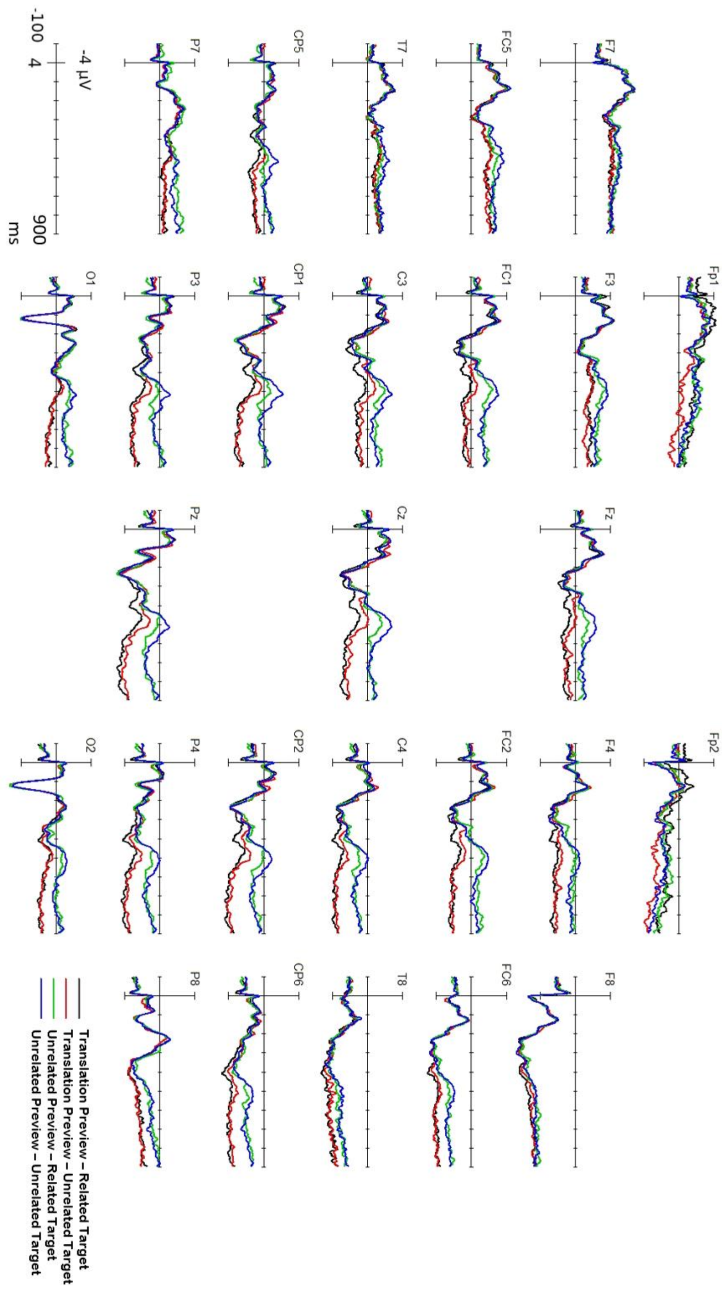
108	They went to the basketball game last weekend and sat in the front seats.
109	Harry was late to school because he forgot his lunch and missed the bus.
110	In the summer, Fred loves to play tennis, golf, baseball and basketball.
111	They forgot to bring sandwiches for the picnic but they remembered the beer.
112	Carl studied for his final exams all night and did not sleep at all.
113	The student made a sandwich for lunch but he left it in the fridge at home.
114	The high school band played a beautiful song and won the competition.
115	They like to spend their Saturday mornings at the local coffee shop.
116	Tom got a good grade on his test because he had studied a lot.
117	They took a walk to the park after dinner and met their old friends.
118	The baby boy is learning to walk and his grandmother helps him a lot.
119	Jill and Sarah studied in Spain last June because they wanted to learn Spanish.
120	The school was closed because there was not enough students anymore.
121	The little girl cried because her mother left the room and did not come back.
122	Brian always wanted to be a lawyer like his father.
123	Cathy was studying to be a nurse but she really wanted to be a doctor.
124	My little sister is scared of the dark and will not sleep alone in her room.
125	My sister is shopping for clothes because she needs new pants to go to school.
126	In San Diego, the sky is often blue and the sunsets are beautiful.
127	I could not hear the teacher's voice because she was too far from me.
128	The girl wanted long black hair but she had short blond hair.
129	Gary learned how to drive with his father last Saturday.
130	Danielle lost her wallet on the bus yesterday but someone found it today.
131	Frank wants to be a famous doctor one day but he is not studying very hard.
132	Nancy baked cookies with her mom yesterday but they were not very good.

133	My two friends finished college last month and they were very proud.
134	Cindy will babysit her brother on Friday night so she will not meet her friends.
135	My two brothers went fishing at the lake but they did not catch any fish.
136	He had a dentist appointment last week but he forgot and did not go.
137	Ashley was stopped by the police on her way to work today.
138	My grandfather prepares dinner every night because he loves to cook.
139	The woman wore a red dress because she forgot to wash her pants on the weekend.
140	Fred studies at the library every night but he is not a very good student.
141	They spent the whole day cleaning their house and painting the kitchen walls.
142	The boy wanted to play with his friends but he had to do his homework first.
143	Wendy listened to music on the radio every night before going to bed.
144	I washed my clothes in the washing machine but forgot to put them in the dryer.
145	Ted took out the garbage this morning before going to work.
146	William spent the weekend with his family and had a really good time.
147	Larry was the first one to finish the race on the weekend.
148	Taylor drinks two cups of coffee every day but she does not eat breakfast.
149	Micheal loves to call his friend and talk on the phone all evening.
150	Jenny finished reading the book and wanted to start reading a new one.
151	Tim was surprised to find two chocolate bars on his desk yesterday.
152	Liz took photography classes and became a really good photographer.
153	Emily loves to bike around the city on the weekends.
154	Bernard and his girlfriend love to bake cakes for their friends.
155	Jing and her husband are going on a camping trip next weekend.
156	Keith had a good time last night because he sang with his friends.

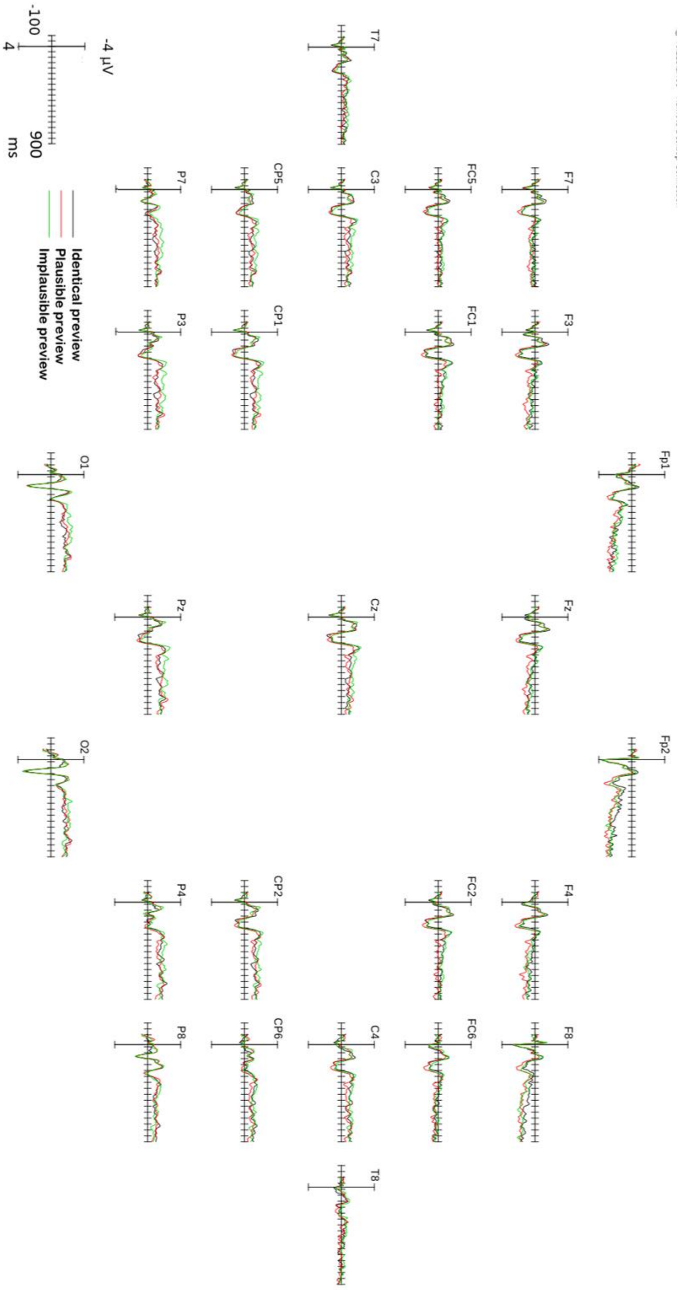
Appendix 4. Grand average FRPs of all electrodes for the fixation onset on the pretarget word (Study 1)



Appendix 5. Grand average FRPs of all electrodes for the fixation onset on the target word (Study 1)



Appendix 6. Grand average FRPs of all electrodes for the fixation onset on the pretarget word (Study 2)



Appendix 7. Grand average FRPs of all electrodes for the fixation onset on the target word (Study 2)