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Parafoveal perception during sentence reading?: An ERP paradigm using rapid serial visual presentation (RSVP) with flankers

Horacio A. Barber[#1], **Shir Ben-Zvi**[#2], **Shlomo Bentin**[2,3], and **Marta Kutas**[4]

[1] Cognitive Psychology Department, University of La Laguna, Spain

[2] Psychology Department, University of Jerusalem, Israel

[3] Interdisciplinary Center of Neural Computation Hebrew, University of Jerusalem, Israel

[4] Department of Cognitive Science, and Department of Neurosciences and Center for Research in Language, University of California-San Diego, USA

[#] These authors contributed equally to this work.

Abstract

We describe a new procedure using event related brain potentials to investigate parafoveal word processing during sentence reading. Sentences were presented word-byword at fixation, flanked two degrees bilaterally by letter strings. Flanker strings were pseudowords, except for the third word in each sentence, which was flanked by either two pseudowords, or a pseudoword and a word, one on each side. Flanker words were either semantically congruent or incongruent with the sentence context. P2 (175-375 ms) amplitudes were less positive for contextually incongruent than congruent flanker words but only with flanker words in the right visual field for English, and in the left visual field in Hebrew. Flankered word presentation thus may be a suitable method for the electrophysiological study of parafoveal perception during sentence reading.

INTRODUCTION

Visual acuity varies across the retina due to the heterogeneous concentration of visual receptors, maximal at the fovea with a diameter of about 2° of the visual field around fixation, smaller parafoveally (between 2° and 5°), and minimal in the periphery (beyond 5°). This characteristic of the visual system has critical implications for reading. A basic finding is that reading (in English) is reliably slower when information to the right of the fixated word is not available than when it is (Rayner, Well, Pollatsek, & Bertera, 1982). However, parafoveal word perception is not equivalent across the two visual hemifields, with the asymmetry depending on the direction in which letters and words are scanned. For scripts in which reading is from left to right, as in Western writing systems, there is a right visual field (RVF) advantage (Rayner, Well, & Pollatsek, 1980). By contrast, the opposite asymmetry is found when reading is from right to left as in Hebrew (Pollatsek, Bolozky,

Corresponding author: Dr. Horacio A. Barber Departamento de Psicología Cognitiva Universidad de La Laguna Campus de Guajara s/n La Laguna, Tenerife, 38205 Spain Phone: +34 922317508 hbarber@ull.es.

Well, & Rayner, 1981; Deutsch, Frost, Pelleg, Pollatsek & Rayner, 2003). On the assumption that parafoveal perception is used for pre-processing of upcoming words, both saccadic programming and the asymmetrical allocation of attentional resources to the hemifields should be influenced by a directional preference based on reading habits, and the side on which new information is located. Important contributions of eye-tracking techniques notwithstanding, much remains to be determined about the nature and amount of linguistic information garnered from the parafovea, under what circumstances, and how this information is integrated with foveal information in real time. In this report we introduce a new method for using event related brain potentials (ERPs) associated with parafoveal perception during sentence reading, which we tested in two groups of participants reading sentences with opposite reading directions (Hebrew, English).

Electrophysiological signatures of words perceived in the parafovea

ERPs have become an increasingly popular tool in the study of language comprehension in general and in reading in particular (see reviews in Kutas, Van Petten, & Kluender, 2007; and Barber & Kutas, 2007). One of the limitations of this technique, however, is that electroencephalographic recording is also affected by field potentials caused by eye movements; indeed, such activity can produce undesirable artifacts in the average response (see Berg & Scherg, 1991). For this reason, psycholinguistic researchers typically study reading with ERPs in absence of lateral movements by presenting sentences one word at a time at a single (usually fixation) point, asking the reader to minimize eye movements (e.g. Kutas & Hillyard, 1980). ERP studies using this rapid serial visual presentation (RSVP) method have provided considerable insights on word processing in sentential contexts. This paradigm however is non-ecological and cannot be used to investigate the role of parafoveal perception during reading.

One potentially promising approach to the study of parafoveal perception during reading relies on the simultaneous recording of eye-movements and ERPs. Pioneer attempts by Marton and Szirtes (1988a and 1988b), e.g., demonstrated that brain responses could be time-locked to the onset of a saccade leading to the “presentation” of the sentence final word. With the advent of new signal processing techniques, there has been a resurgence of interest in this type of saccade-ERP approach (Baccino & Manunta, 2005; Hutzler, Braun, Võ, Engl, Hofmann, Dambacher, Leder, & Jacobs, 2007; Simola, Holmqvist & Lindgren, 2009; Kretzschmar, Bornkessel-Schlesewsky, & Schlesewsky, 2009). Baccino and Manunta (2005), for instance, recorded Eye-Fixation-Related Potentials (EFRPs) to French word pairs, one at fixation and the other in the right parafovea. They reported effects on early components (N1 and P140) contingent on the lexical status (word/non-word) of the parafoveal stimulus and on subsequent components (P2), reflecting the associative relationship between the two words. Simola and colleagues (2009) extended this design to include words either in the right or in the left visual field, and showed P2 lexical effects for target words in right but not left visual field. Kretzschmar et al. (2009) examined saccadic-locked ERPs to sentence final words and found a dissociation between foveal and parafoveal processes: predictability affected the foveal processing of the final word while context congruency modulated the responses to the previous word. Clearly, this is a very promising line of investigation. The co-registration of EEG and eye-tracking measures during sentence reading, however, raises several methodological difficulties. In addition to those imposed by ocular artifacts, it is not easy to disentangle overlapping signals obtained when words are read at the fast rates characteristic of natural reading even with certain assumptions.

The present study

We thus describe a complementary method for examining parafoveal processing based on a modification of the canonical word-by-word sentence presentation (i.e., RSVP) procedure, in which sentences are presented foveally as usual, but each word is flanked bilaterally by letter strings, one string on each side. In the two ERP experiments reported herein, short sentences were presented one word at a time on a computer screen at fixation, flanked two degrees bilaterally by letter strings. All but the third word in each sentence was flanked by two pseudowords, one on each side. The third word in each sentence was flanked bilaterally either by two pseudowords, or by a pseudoword on one side and a word on the other. The flanker word appeared either on the left or on the right side, and was either semantically congruent with the sentence context (identical to the upcoming fourth word) or not. For example, in “*Chatty barbers trim beards while talking*”, the critical third word “*trim*” was flanked on one side by a 6 letter pseudoword, and on the other side either by the semantically congruent (upcoming) word “*beards*” or the semantically incongruent word “*crises*”. Based on the (small) extant literature, we expected that semantic congruence of the parafoveal (flanker) word would modulate the P2 and perhaps the N400 components of the ERPs to target items or to the following triad, although any reliable ERP effect would be evidence of parafoveal influence. The P2 is a sensory component sensitive to manipulations of visual feature extraction, attention, and contextual constraint (Luck & Hillyard, 1994; Skrandies, 2003; Federmeier & Kutas, 1999; 2002). Therefore, to the extent that congruent flanker words, compared to incongruent flanker words, would show more positive P2 amplitudes we would infer facilitation of the word recognition and/or integration processes triggered by the critical triad. The subsequent N400 component of the ERP is sensitive to both semantic congruity and word level associative/semantic priming (for a recent review see Kutas, Van Petten, & Kluender, 2007). Accordingly, smaller negative N400 amplitudes for the congruent vs. incongruent word flankers would be taken to indicate activation of the semantic system triggered by parafoveal information.

As our primary aim was to demonstrate the utility of this flankered RVSP procedure for the study of parafoveal processing, we conducted two different experiments, with two different languages that differed in their orthography and reading direction (from left to right in English, and from right to left in Hebrew). In so doing, whatever the nature of the specific ERP effects, we expected to see evidence of parafoveal perception during sentence reading interacting with the visual field in which the critical information was presented. For English, read from left to right, we expected to see parafoveal influences driven by words appearing in the left but not right visual field, whereas for Hebrew, read from right to left, we expected to see the reverse – parafoveal influences from words in the left but not the right visual field.

METHOD

Two similar experiments were conducted, one using English sentences as stimuli and English native speakers as participants, and the other with native Hebrew speakers reading Hebrew sentences. As experimental procedures were kept as similar as possible for both experiments, they are jointly described below.

Participants

In the English experiment, the participants were 24 overseas students at the Hebrew University of Jerusalem aged 19 through 38 (mean age 21.5 years, 5 males) who were native English speakers; likewise, in the Hebrew experiment the participants were 24 students at the Hebrew University of Jerusalem aged 22 through 34 (mean age 25.8 years, 10 males), who were native Hebrew speakers. All of the participants were right-handed and all reported normal or corrected-to-normal sight and no history of neurological disorders. They received experimental credits or payment for their participation in the study. Informed consent conforming to the requirements of the Hebrew University experimental ethics committee was obtained after the experimental procedures were explained to them.

Stimuli

Sentences with a similar structure were used in the English and Hebrew experiments. Each sentence comprised five to ten words. The Hebrew sentences comprised 5 words, whereas English sentences had between 6 and 10 words (mean = 7.17). The third word (the “critical” word) was always a verb and the fourth was always a noun. The words of the sentence were presented sequentially, one-at-a-time at fixation on a CRT monitor, each flanked by two letter strings. The distance between fixation and the most medial external letter of the flankers was 2°. Note that whereas in English this was the first letter of the right flanker and the last letter of the left flanker, in Hebrew the order is reversed. For all words in the sentence but the critical word (the third), the flankers were pseudowords. The critical word was flanked either by two pseudowords (like the rest of the words in the sentence) or by a word (noun) in the left or in the right side and a pseudoword in the contralateral side. The nature of the stimuli flanking the third (critical) word defined a 2x2 factorial design, with the factors Flanker position (left versus right), and Condition (semantically congruent versus incongruent). This design thus yielded four conditions: 1) In the Congruent-right condition, the right flanker was a noun identical to the subsequent fourth word in the sentence (hence, semantically congruent with the first three words of the sentence). 2) In the Congruent-left condition the left flanker was identical to the fourth word. 3) In the Incongruent-right condition the right flanker was a noun different from and unrelated to either the critical word or the subsequently presented fourth word (and it was also semantically incongruent with the sentence). 4) In the Incongruent-left condition the left flanker was an unrelated noun. Table 1 gives examples of the stimuli in both languages. It should be noted that indefinite plurals were used in English as subjects (e.g. “Chatty barbers”) in order to equate the number of words in noun phrases across two languages, because Hebrew determiners (e.g. “the” or “a”) are morphologically integrated in the nouns. Also, note that although noun phrases were composed of a noun and an adjective in both languages, the canonical word order in the two differs (adjective preceding the noun in English, and adjective following the noun in Hebrew).

Lexical frequency of congruent and incongruent flankers was matched for the stimulus lists of the Hebrew experiment. The average written word frequency of the Hebrew flankers (Hebrew Word Frequency Database: http://homepages.inf.ed.ac.uk) was 32 (SD=129,89) per million for Congruent flankers and 16,95 (SD=65,10) per million for Incongruent flankers. A one-way ANOVA carried out on both lists confirmed that they were not significantly different ($F_{1,159}$=2,57, p=0.1). The average written word frequency of the English flankers (CELEX database; Baayen, Piepenbrock, & van Rijn, 1995) was 54,42 (SD=184,14) per million for Congruent flankers and 17,66 (SD=47,46) for Incongruent flankers. A one-way ANOVA carried out on the Congruent-Incongruent lists showed that this difference was statistically significant ($F_{1,159}$=5,97, $p<0.05$). Pseudowords of different lengths were created in English and in Hebrew to be used as flankers in each experiment. The English pseudowords were taken from the ARC Nonword Database (Rastle et al., 2002); the Hebrew ones were generated by a group of native Hebrew speakers. Pseudowords were defined as letter strings that fulfill the orthographic and phonological rules of the respective language but with no meaning associated with them. To avoid attentional biases due to flanker length, the two flankers for any specific word were matched in length (number of letters) to the subsequent central word in the sentence, and the length of the final flankers was determined by the final central word. The Hebrew as well as the English words varied in length of 2 to 11 letters. The average number of letters per word at the critical position was 4.3 in the Hebrew sentences and 5.7 in the English sentences. The average number of letters per flanker at the critical position was 4.5 in the Hebrew sentences and 6.6 in the English sentences. Semantically congruent and incongruent flanker-words were matched in length. It should be noted that all sentences at central position were semantically plausible and grammatically correct, and participants were instructed to read only those central words.

One hundred sixty experimental sentences in English and in Hebrew were created by native speakers and four different sentence lists were constructed for each experiment in order to counterbalance the different conditions. Across participants each sentence was presented in the four conditions, whereas within participants each sentence was presented only once. Additionally, there were 80 filler sentences for each experiment, in which the critical word also was flanked by two pseudowords.

Procedure

The experimental procedure was identical in both experiments. Participants were seated comfortably in a semi-darkened sound-attenuated booth after being fit with an electrode cap. All stimuli were presented on a high-resolution monitor (1024 x 768) positioned at eye level 70 cm in front of the participant. All the string letters were displayed in black lowercase against a white background. A single trial consisted of the presentation of the fixation point (a red dot) for a random duration between 1250 and 1400 ms, followed by the sentence presentation in five to ten displays, each consisting of three letter strings as described above exposed for 260 ms, with an inter-display duration of 60 ms (Figure 1).

Participants were asked to read the sentences silently and be ready to answer comprehension questions related to sentence meaning. The questions were presented randomly at the end of the sentence on about 25% of the trials, and required a yes/no answer via one of two button presses. These questions were to ensure that subjects read the sentences for meaning. Participants did not report any difficulties comprehending the sentences and the number of errors was less than 5% in both experiments. Although participants were not explicitly asked to ignore flankers, they were told that lateral information was irrelevant for task performance (and sentence meaning) and were asked to maintain focus on the center of the screen and to avoid eye movements and blinks during the interval spanning the fixation point until the end of the trial. The interval between trials varied randomly between 1.5 and 2 sec. The experiment was divided into 6 blocks of 40 sentences each with a short rest between blocks. The sentences were presented in a different random order for each participant. Twelve practice trials with characteristics similar to those of the experimental trials were presented at the beginning of the session, and were repeated when necessary.

EEG recording

EEG was recorded via 64 Ag-AgCl electrodes attached to an elastic electrode cap (ECI Inc Eaton, Ohio) according to the extended 10-20 system (see Figure 2), and 3 external electrodes; two placed at the two mastoids and, a third one on the tip of the nose that was used as on-line reference. Eye movements and blinks were monitored via 4 additional external electrodes providing bipolar recordings of the horizontal and vertical electro-oculogam (EOG): two electrodes were located at the outer canthus of the right and left eyes and two at the infraorbital and supraorbital regions of the right eye. Both EEG an EOG were sampled at 256 Hz using the Biosemi Active II digital 24-bit amplification system (http://www.biosemi.com) with an active input range of −262 mV to +262 mV per bit and a low-pass filter of 64 Hz to avoid aliasing. The digitized EEG was saved and processed off-line.

Data analysis

Raw data were band-pass filtered between 0.1 and 30 Hz (dB) and re-referenced to the average of the two mastoid electrodes before analysis. Ocular artifacts were corrected using independent components analysis, and remaining artifacts exceeding ±100 μV in amplitude, or containing a transient of over 100 μV in a period of 100 ms were rejected along with an epoch of 300 ms symmetrical around the event. Following this procedure, average ERPs resulted from individual segments starting 100 ms before and ending 500 ms after the critical triad onset (word/pseudoword- word 3- word/pseudoword) [1], separately for each of the 4 conditions, each electrode, and each participant. The baseline was adjusted by subtracting the mean amplitude of the pre-stimulus activity from all the data points in the epoch.

Twelve separate regions of interest were computed from 48 lateral electrodes, each comprising the mean of 4 electrodes (Figure 2). There were six electrode groups in each hemisphere: two in each of the anterior, posterior and central scalp areas, one in the lateral,

[1]Analyses of the ERPs time-locked to the onset of the following triad were also performed, but not reported here because there were no significant effects.

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and one in the medial position of the hemisphere: left anterior lateral (F7, F5, FT7, FC5), left anterior medial (F3, F1, FC3, FC1), left central lateral (T7, C5, TP7, CP5), left central medial (C3, C1, CP3, CP1), left posterior lateral (P7, P5, P9, PO7), left posterior medial (P3, P1, PO3, O1), right anterior medial (F2, F4, FC2, FC4), right anterior lateral (F6, F8, FC6, FT8), right central medial (C2, C4, CP2, CP4), right central lateral (C6, T8, CP6, TP8), right posterior medial (P2, P4, O2, PO4) and right posterior lateral (P6, P8, PO8, P10). The mean amplitude, of two different epochs compromising the P2 and N400 components (175-375 and 375-475 ms respectively), was analyzed using a mixed-model ANOVA with Language as a between-subjects factor and Flanker position (left, right), Condition (congruent, incongruent), and Area (12 electrode groups) as within-subjects factors. In cases where the sphericity assumption was violated, Greenhouse-Geisser-corrected degrees of freedom and p-values are reported. Effects of the Area factor will be reported only when it interacts with the experimental manipulations. In addition, post hoc Sidák contrasts (Sidák, 1967) were performed after interactions or main effects of Flanker Word to control for type I error in multiple comparisons.

RESULTS

ERPs time-locked to the onset of the critical triads included a series of negative and positive peaks during the first 500 ms identified as N1, P2 and N400 components (even when the N400 partially overlaps with the N1-P2 complex of the following triad). Figures 3 and 4 shows the grand average waveforms corresponding to the congruent and incongruent conditions in the experiment in English (Figure 3) and in the experiment in Hebrew (Figure 4). Twelve representative electrodes are plotted, corresponding with the analyzed electrode groups. ERPs elicited by congruent and incongruent flanker words revealed amplitude differences starting at about 175 ms after stimulus onset, and lasting for about 200 ms. During that epoch the P2 elicited in the Congruent condition was larger (more positive) than that elicited in the Incongruent condition. Critically, this effect is unilateral, appearing on opposite sides for Hebrew and English. Conforming to reading direction, in English sentences the effect emerged when relevant information appeared in the right parafovea (see Figure 3), whereas in Hebrew, it emerged when information appeared in the left parafovea (see Figure 4). This interaction can be observed in Figure 5, in which P2 mean amplitudes in the right posterior medial region (C2, C4, CP2, CP4) are graphed. Figure 6 represents the topographical distribution of the P2 differences across the scalp (Incongruent minus Congruent ERPs). The effect in English is localized at posterior areas; the effect in Hebrew shows a broader distribution maximum at frontal electrodes. These observations were corroborated by the mixed-model ANOVA.

P2 time-window: 175 - 375 ms

The analyses in this time window showed a significant three-way interaction of Flanker position x Condition x Area ($F_{11,506} = 2.95$, $p < 0.05$; $\varepsilon = 0.34$; MSE= 2.02; $\eta^2 = 0.06$), which was further modulated by a four-way interaction with Language ($F_{11,506} = 2.51$, $p < 0.05$; MSE = 2.02; $\eta^2 = 0.05$).

The differential pattern of effects in English and Hebrew (as substantiated by the 4-way interaction) was further investigated by separate Flanker position x Condition X Area ANOVAs for each language. For English sentences the ANOVA resulted in a significant second-order interaction between the 3 factors (F11,253 = 4.14, p<0.01; ε = 0.29; MSE = 2.8; η2 = 0.15). Post-hoc tests revealed that in the right parafovea, congruent flanker words produced more positive mean values than incongruent flanker words, but only in the right posterior lateral area (F1,23 = 5.01, p<0.05). No significant differences were found in any other area, confirming the posterior distribution of the effect in this experiment. Additionally, no significant differences were obtained when the flanker manipulation occurred in the left parafovea (F<1). This analysis supports a modulation of ERP amplitude associated with lexical-semantic information displayed in the right parafovea in English, which is read from left-to-right.

For Hebrew sentences ANOVA showed a significant Position x Condition interaction ($F_{1,23} = 4.44$, $p<0.05$; MSE = 16.05; $\eta^2 = 0.16$). Post-hoc tests revealed that the mean amplitude elicited in the Congruent-left condition was bigger than in the Incongruent-left condition, but only for flankers presented in the left parafovea ($F_{1,23} = 4.6$, $p<0.05$). There were no significant differences when the flanker words were presented in the right parafovea (F<1). Although the interaction with the factor area did not reach the level of significance (F<1), post-hoc tests showed significant differences for specific areas (mostly at right hemisphere sites): right central medial ($F_{1,23} = 4.6$, $p<0.05$), right posterior medial ($F_{1,23} = 4.45$, $p < 0.05$), right posterior lateral ($F_{1,23} = 5.88$, $p<0.05$) and also at left anterior medial ($F_{1,23} = 4.7$, $p<0.05$). This analysis supports a modulation of the ERP amplitude when lexical-semantic information is displayed in the left parafovea in Hebrew, which is read from right-to-left.

N400 time-window: 375 - 475 ms

As can be seen in Figure 4, the congruency effect of the left flankers in the Hebrew sentences lasts beyond the analyzed window for the P2 component. These differences remain visible in the time window of the N400 component, which peaks around 425 ms across conditions. For this reason, additional ANOVAs were performed on the mean amplitude values between 375 and 475 ms after stimulus onset. However, these analyses did not yield any significant interaction involving the Condition factor.

DISCUSSION

The present study explored the processing effects of words presented in the parafovea during the (foveal) reading of Hebrew or English sentences using ERPs. To that end, we assessed the efficacy of a new stimulus presentation procedure. Specifically, we recorded ERPs as sentences appeared one word at a time at fixation, flanked on either side by letter strings. Of experimental interest were the ERP modulations to letter string flankers time-locked to the third word of each sentence, as these included a word that was congruent or incongruent with the sentence context on either the right or left side of the word at fixation. In brief, our findings revealed that this paradigm may indeed be a useful way to study the effects of parafoveal information on word reading. We found that ERPs to the manipulated triads (left visual field, center, right visual field) were sensitive to the nature of the parafoveal information. Specifically, amplitudes of the P2 component (measured 175-375 ms after the onset of the critical triads) of the ERP were larger when the flanker word was congruent with the overall sentence context than when it was incongruent. Moreover, this parafoveal effect interacted with the visual field in which the flanker word appeared, with the pattern of the interaction varying with reading direction: for English, normally read from left to right, the flanker effect was reliable only when the contextually-incongruent flanker word appeared in the right parafovea. In contrast, for Hebrew, read from right to left, the effect of the flanker was reliable only when the contextually-incongruent flanker word appeared in the left parafovea – i.e., the reverse. Future studies will need to replicate these findings and delve into the differences in the scalp topography of the P2 effects in the two languages. Distributional differences notwithstanding, the ERP measures reveal an impact of parafoveal information on central word processing. Importantly, an effect of reading direction obtained despite the fact the sentences were presented word-by-word in the same location, that is, with no horizontal scanning as in natural reading. Although eye-tracking was not implemented in these experiments, the early onset of the effect (175 ms) is inconsistent with the interpretation of this effect as due to foveal stimulus perception consequent to lateral eye movements. The earliest reliable reported ERP effects associated with lexical variables, when one single word is presented at fixation, ranges also between 100 and 200 ms (see Barber & Kutas, 2007). It is thus relatively unlikely that two words can be sequentially perceived by means of a saccade, producing ERP effects in a similar time range.

In sum, with this RSVP flanker paradigm, we found P2 amplitude modulations by parafoveal information similar to those reported with event fixation related potentials, namely, when participants are moving their eyes (Baccino & Manunta, 2005; Simola et al., 2009). Although our P2 modulation is consistent with semantically driven contextual effects (e.g. Federmeier & Kutas, 1999; 2002), with the present design and data we can conclude only that words in the parafovea were processed, at least at a form level.

We did not observe any reliable and consistent effects on the N400 component of the ERP to the critical (third) word triad, nor to the following word. The absence of N400 modulation by flankers' semantic congruence suggests that the flankers probably did not activate the semantic system extensively. This result is not without precedent. Some eye-tracking studies of reading have consistently failed to demonstrate semantic effects in the parafovea, leading to the conclusion that words outside fixation are processed only at the level of form (e.g. length or orthography: see review in Rayner, White, Kambe, Miller, & Liversedge, 2003). In contrast, however, one study using concurrent EEG and eye-movement recordings reported a semantic N400 effect which the authors attributed to parafoveal perception (Kretzschmar et al., 2009). For the moment, different pattern of effects are inexplicable. As the primary goal of our experiment was not to determine the specific information extracted from the parafovea but rather to assess the RSVP-flanker paradigm, the words in our semantically congruent and incongruent conditions were not carefully matched in all lexical or sub-lexical variables (e.g. lexical frequency[2] or orthographic regularities). Our ERP data, thus, cannot help resolve these inconsistencies, though our findings demonstrate that the presentation method we introduce could be informative, in principle.

In the present study, the use of (meaningless) pseudowords as flankers for almost all the central words could reasonably have led our participants to adopt an (unconscious) strategy of focusing their processing resources on the analysis of the formal aspects of the flankers (e.g., orthographic regularities) at the expense of meaning construction and contextual integration – processes to which the N400 has been variously linked. Our flanker RVSP method, however, can be modified such that all flankers for central words at every sentential position are words, thereby making flanker information more ecologically valid as well as methodologically more relevant for inferences about reading (and parafoveal) processes.

In line with eye-movement research on sentence reading in both writing systems (Rayner et al., 1980; Pollatsek at al., 1981; Deutsch et al., 2003), as well as psychophysiological word pair experiments (Pernet, Uusvuori & Salmelin, 2007; Simola et al., 2009), we observed an interaction of the parafoveal effects with the flanker's position to the left or the right side of the fixated word in a direction that varied with the direction typical of reading in each of the different orthographies. In English the flanker effect was reliable only when the flanker word was positioned to the right of the fixated word, while the opposite pattern obtained in Hebrew. Previous studies have shown left hemisphere superiority for language processing even in languages with left-to-right reading such as Hebrew (Bentin, 1981; Nazir, Ben-Boutayab, Decoppet, Deutsch, & Frost, 2004; Smolka & Eviatar, 2006). However, cerebral specialization cannot account for the visual field effects in the present study, opposite in Hebrew and English. Similarly, the assumption that parafoveal effects are related to the programming for the upcoming saccade, which has been entertained by eye-tracking studies, is not supported by these ERP data. Although eye movements were not monitored in the present study, participants were instructed to refrain from moving the eyes, and the sequential presentation of the sentence words at fixation coupled with non-informative pseudowords in the parafovea did not encourage systematic saccades.

The visual field effects in the present study could reasonably be explained by an asymmetry in the natural deployment of visual attention during reading, imposed by reading direction. Behavioral studies have shown that the typical RVF advantage for visual word recognition can be reduced or even eliminated when lateralized words are pre-cued. Pre-cues are presumed to guide exogenous spatial attention mechanisms, thereby leading to more efficient lexical processing in the pre-cued visual field (Ortells & Tudela, 1996; Ducrot & Grainger, 2007). Along with this account, as well as with the present pattern, effects of covert attention (in absence of gaze shifting) on parafoveal lexical processing have been demonstrated in several priming studies in which lateral eye movements were controlled or eliminated (Hyönä & Koivisto, 2006; Marzouki & Grainger, 2008; Calvo & Nummenmaa, 2008). It is also worth noting that parafoveal information did not play any role in the specific task demands for our participants and the majority of the parafoveal stimuli were meaningless pseudowords, which did not add to the sentence meaning. Indeed, most participants reported being unaware that any words were presented in the parafovea. Therefore, the observed flanker effect in the present study seems most reasonably associated

[2]However, it is important to note that the parafoveal effect was larger in the Hebrew experiment, where mean lexical frequent values of congruent and incongruent flankers were not statistically different. Therefore, it is unlikely that lexical frequency accounts for the reported effects.

with uncontrolled (or, at least veiled controlled, Shiffrin & Schneider, 1977) processing of sublexical/lexical information in the parafovea, rather than with task goals or reading strategies. These speculations clearly call for more controlled studies using this new presentation paradigm.

In summary, we show that ERP data collected using an RSVP paradigm with letter string flankers, in the absence of directional scanning, can offer reliable evidence of the word processing effects of at least some word form information appearing in the parafovea. This appears to be the case when the flankers appear in locations consistent with reading location. We suggest that this effect may be accounted for by attentional factors resulting from reading habits, and encourage the adoption of this flanker-RSVP ERP methodology to complement other approaches to the investigation of the influences of parafoveal information during reading.

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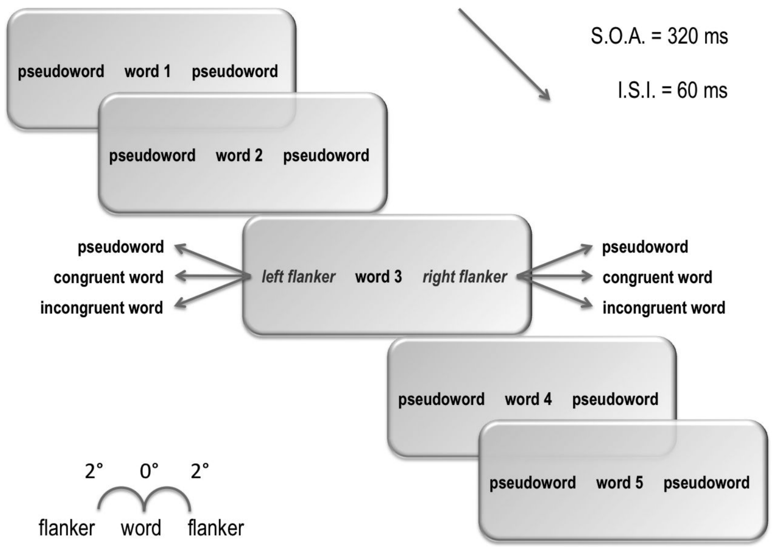

Figure 1.
Sentence presentation procedure.

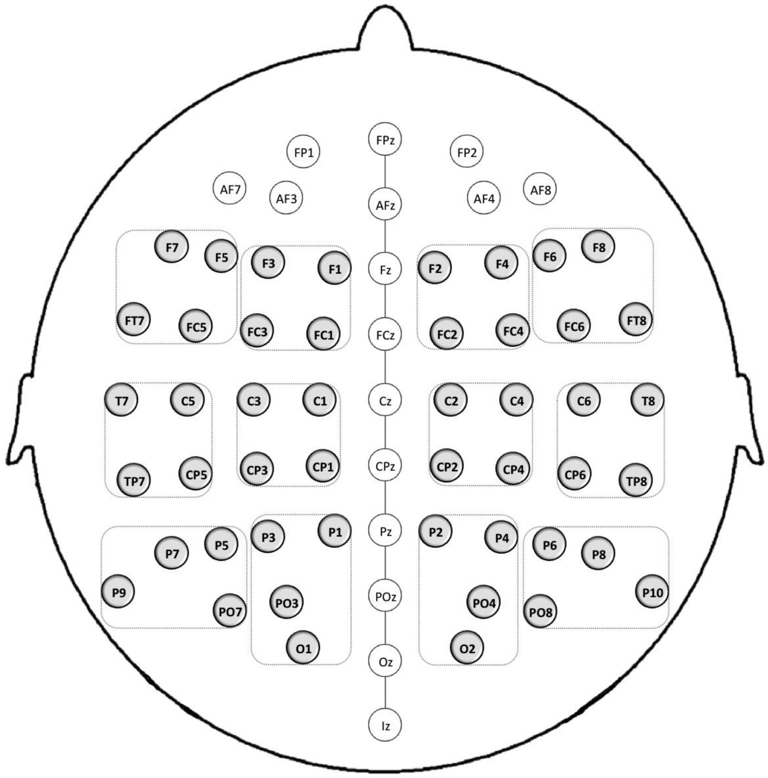

Figure 2.

Schematic flat representation of the 64 electrode positions from which EEG activity was recorded. The grouped electrodes are those analyzed in the twelve critical regions.

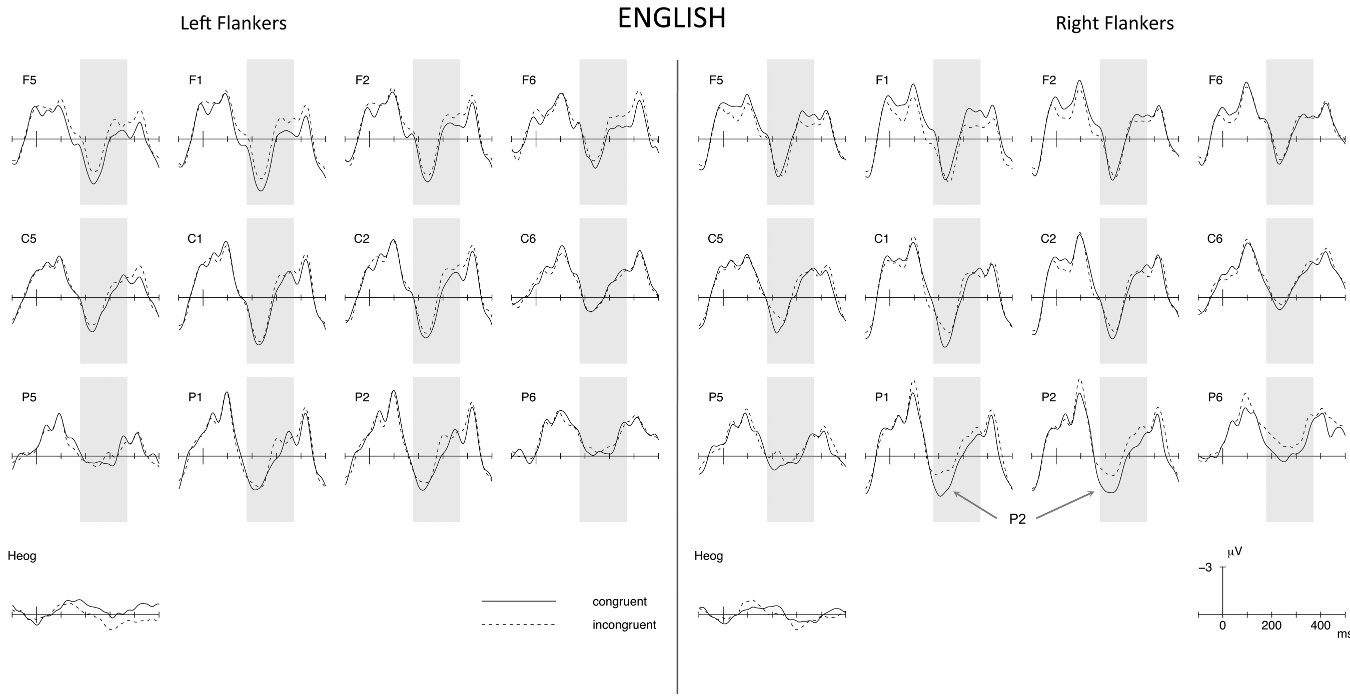

Figure 3.

ERPs showing congruent and incongruent flanker words presented to the Left Visual Field in the English sentences.

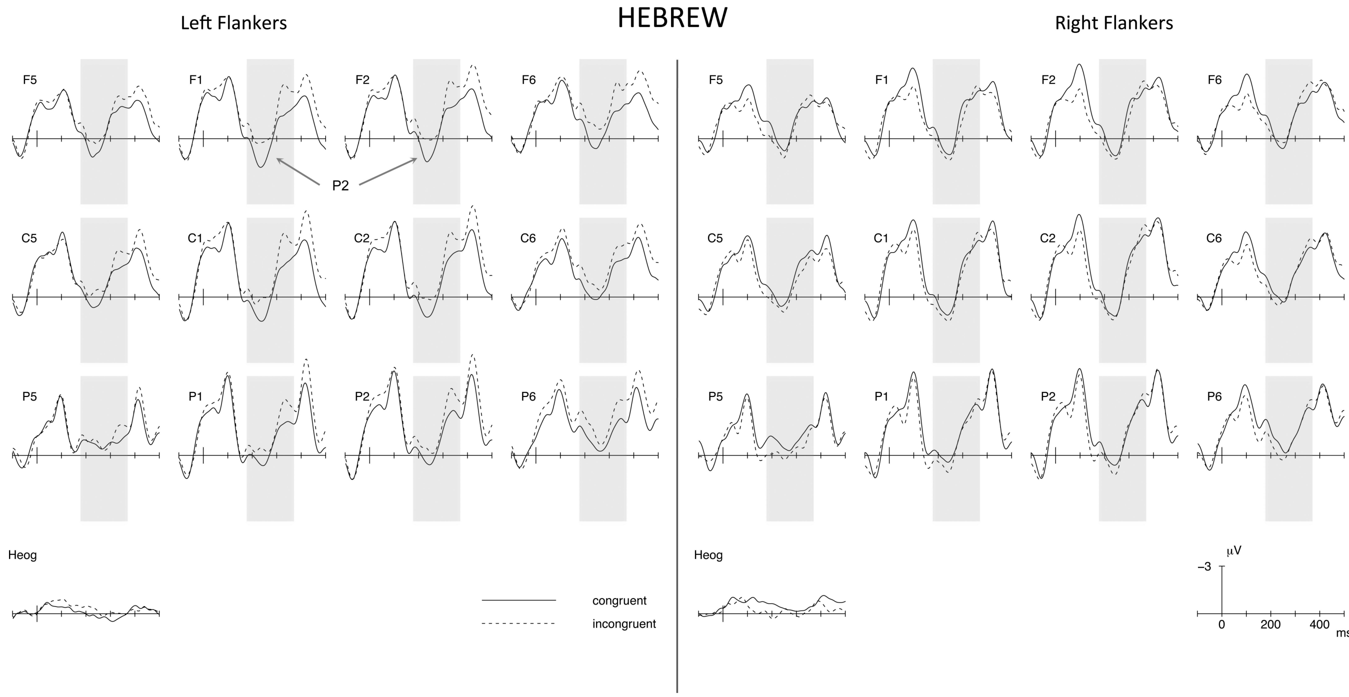

Figure 4.
ERPs showing congruent and incongruent flanker words presented to the Left Visual Field in the Hebrew sentences.

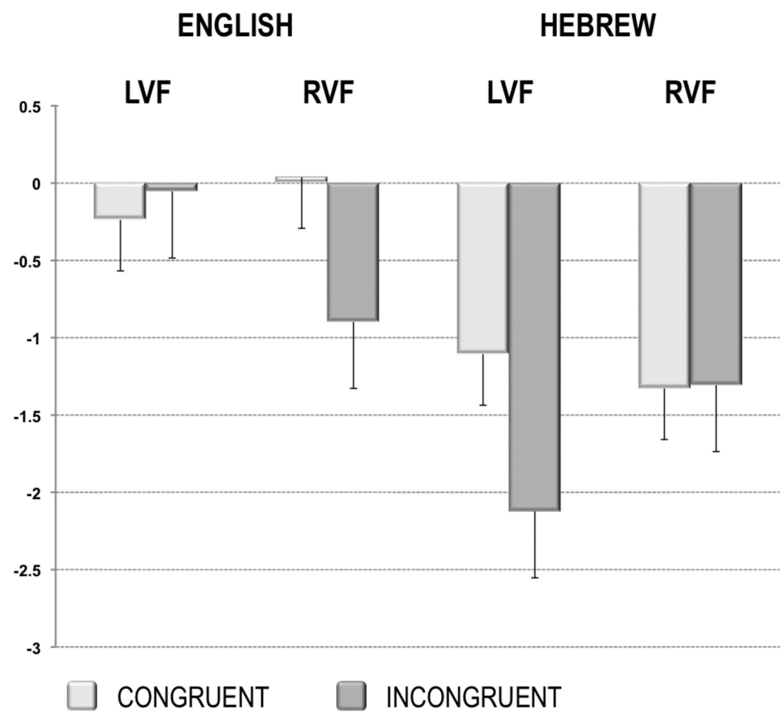

Figure 5.

Mean amplitudes of the P2 component (175-375 ms) in the right posterior medial region for both groups and both visual fields.

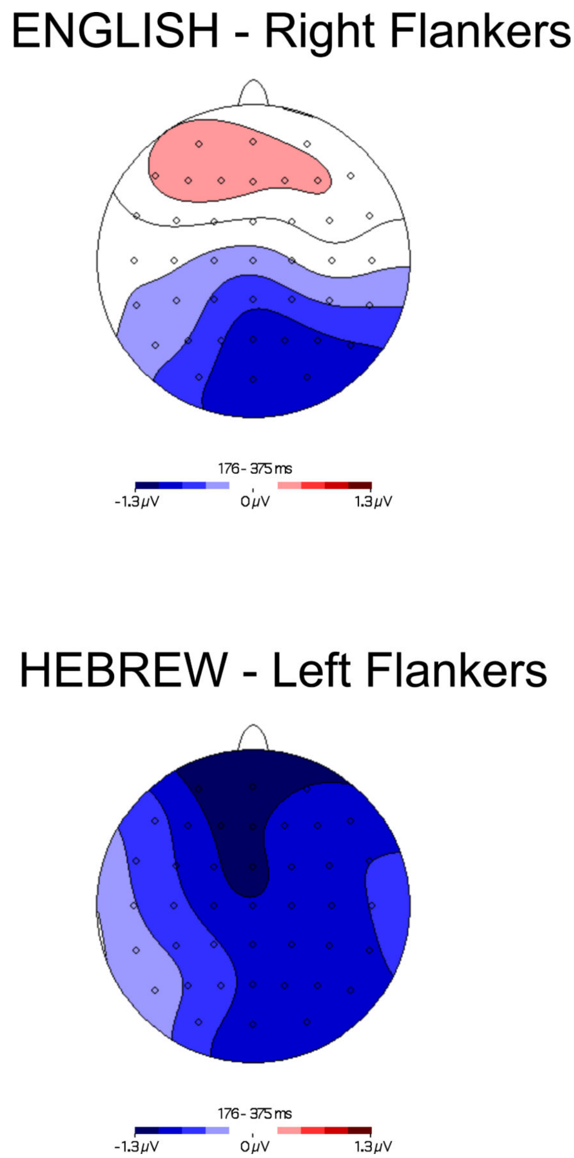

Figure 6.

Topographical maps of the P2 differences over the scalp (Incongruent minus Congruent conditions).

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Table 1

Example stimuli (words at critical position underlined for illustration).

English sentences	Congruent flankers	Incongruent flankers
My cousin eats cereal for breakfast.	cereal	rhymes
Jolly clowns toss pies in the circus.	pies	surf
Excited puppies wag tails and bark.	tails	veins

Hebrew sentences and English translation	Congruent flanker	Incongruent flankers
הצינור המחוספס מרוקן בריכה עגולה.	בריכה	מחברת
The rough pipe empties a round pool.	pool	notebook
המדען החרוץ ניתח ארנב מורדם.	ארנב	מחדד
The industrious scientist operated an anesthetized rabbit.	rabbit	pencil sharpener
השירה היפה נסכה תקווה בליבי.	תקווה	שרשרת
The beautiful singing gave me hope.	hope	chain