Neurophysiological Analysis of Continuous Reading: the Choice of Text Segmentation Alternatives

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Abstract

Studies that analyse reading processing with neurophysiological techniques generally use isolated-word paradigms that do not consider processes related with continuous reading. This paper analyses different types of text segmentation as methods to support the study of continuous reading. Two types of segmentation were designed to provide more contextual information than a word-by-word segmentation paradigm, while requiring only one eye fixation per segment. Participants were asked to read texts in each segmentation type, as well as in the word by word paradigm. Participants were assessed with eye tracking (N=10), event related potentials (ERPs, N=16) and questionnaires were used to assess reading ease and comprehension (N=80). Although no significant differences were found with eye tracking and subjective responses, differences were found in the ERP data. These results suggest that studies that analyse continuous reading with ERP paradigms should consider the type of segmentation chosen, even if no behavioural differences are observed.

Keywords: Continuous reading, ERP, Parafoveal information, Reading, Text segmentation

Neurophysiological Analysis of Continuous Reading

Reading is a pervasive cognitive activity in many human activities. The neural mechanisms associated with reading have been studied intensively. However, most event-related-potential (ERP) studies focus on the detection and processing of single words, and do not analyse the activity of continuous reading. In particular, the integration of contextual information, essential for extraction of meaning in natural and continuous reading, is often neglected.

The study of reading with neurophysiological signals, namely electroencephalography (EEG), has been carried out with several methodologies. Many studies have used both frequency-based analysis (Bizas et al., 1999; Oliveira, 2010) and ERP analysis. The former have determined neural correlates of reading activity, which are generally coarser but allow an analysis of continuous reading. The latter, ERP-based analysis, provides a deeper insight into the underlying processes and the time course related to word processing, but generally disregard word integration in continuous reading and the naturally occurring processing of adjacent words.

Reading related ERPs have been extensively described in the literature. Word processing is initiated with a low level sensorial processing of the visual stimuli occurring around 100 ms after stimuli presentation (P100 component). The earliest components associated with word like strings in contrast to objects or faces has been found on occipital sites between 90 and 110 ms – N100 and P100 (Schendan, Ganis, & Kutas, 1998). In more ventral areas, the P150 has also been shown to diverge between words and other objects including faces (Schendan et al., 1998), possibly distinguishing well-known categories (as faces and words) from less known ones. The N170 component is sensitive to word shape, being specific for words when compared

to strings of symbols (Bentin, 1999). Semantic processing has been associated with the N400 potential, the most intensively studied potential in language, starting at around 200 ms and peaking at 400 ms (Barber & Kutas, 2007). Finally, grammaticality is associated with the P600, which has been shown to be sensitive to syntactic violations (Gouvea, Phillips, Kazanina, & Poeppel, 2010; Hagoort & Brown, 2000; Kaan, Harris, Gibson, & Holcomb, 2000).

The existence of well-studied potentials, such as the N400, that occur after the mean duration of word fixation (200 ms), suggests that in continuous reading there must be a significant overlap of word processing. This overlap, together with the noise inherent to eye movements, is a problem for the use of ERP techniques in the analysis of continuous reading. The interpretation of ERP waveforms becomes harder due to the overlapping of the different stages of word processing. Due to these constraints, among others (see Van Berkum, 2004 for a review), most ERP based studies focus on single words or short and complete sentences, avoiding the use of continuous text.

Besides this overlapping effect, the eyes perform fast jumps across the text, designated as saccades. During saccades the eyes frequently skip entire words (see Rayner, 1998 for an extensive review on eye movements in reading), a phenomenon that does not occur in typical word-by-word paradigms.

The specific goal of this work is the design and development of a paradigm based on delimited or discrete stimuli, with well-defined fixation points that mimic certain aspects of continuous reading. Segmentations were developed trying to sequence discrete segments of text presented in such a way that only one word is fixated per display.

In the different experiments performed during this study we created a (i) word-by-word sequential presentation of a text, (ii) a variation of this single-word style of presentation that includes adjacent words to evaluate the known effects of parafoveal information (Barber, Ben-Zvi, Bentin, & Kutas, 2011; Barber, Doñamayor, Kutas, & Münte, 2010), and (iii) a segmentation based on eye tracking data as an indexing device for analysis of continuous reading.

In the present study the alternative segmentation styles will be analysed using subjective measures, eye tracking and ERP analysis.

Experiment I – Subjective Perception of Alternative Segmentations

Subjects

Eighty-seven subjects (54 female), with mean age of 25.5±2.2 years participated in this experiment. The participants' mean education was 15.3±2.1 school years. All the participants were native speakers, with no known reading impairment.This study was submitted to and approved by the local ethical committee.

Stimuli

Three texts were designed and matched for number of words (73-76) and readability measured by a Flesch Reading Ease Score index (Aluisio, Specia, Gasperin, and Scarton, 2010). All texts were qualified as easy, ranging from 52 to 72 (the scale ranges from 0-100, with higher scores corresponding to easier texts). Word frequency was calculated using a multifunctional computational lexicon of the used language (Bacelar do Nascimento, 2001). Lemma was used instead of word form, and frequency norms were available for all words. Frequency per million was calculated from the absolute frequency value and inserted in one of five logarithmic classes

($\log_{10}$): 1 (1-10); 2 (11-100); 3 (101-1000); 4 (1001-10.000); 5 (10.001-max). Word frequency in words with semantic relevance ranged from 2 to 4.5 and word length from 3 to 7 letters.

Different segmentations were produced for each text, i) a word-by-word segmentation (WbW), ii) a parafoveal segmentation (PS), and iii) a fixation based segmentation (FBW).

In the WbW segmentation, each word of the text was presented sequentially with no further manipulation.

In the PS segmentation, each word appeared in the centre of the screen flanked bilaterally by the previous and next word in the sentence. First and final words of the text were respectively left- or right-flanked by ###. This segmentation was created since in continuous reading, words are inserted in the context of a larger text, allowing for a parafoveal pre-processing of the following word in the sentence.

The fixation-based segmentation (FBW) was created using eye tracking data collected from 16 participants, in a pilot study. Participants were asked to read all texts presented with an 18 point Times New Roman font, with triple spacing and in a grey background. Participants' gaze was monitored with a remote eye tracking device (RED, SMI). Fixations were considered with a minimum duration of 80 ms and maximum dispersion of 100 pixels. All words fixated by less than 50% of participants were presented next to the following fixated word. Exceptions to this rule occurred when either more than two consecutive words were fixated less than 50%, or when the fixation was a pause or the end of a sentence (a comma or a full stop), in which cases they were joined to the preceding fixated word. This segmentation considers

that words skipped during text reading do not require individual presentation and can be aggregated into reading segments.

Times New Roman point size 44 font was used in the three segmented texts.

Procedure

Texts were presented pseudo randomly in all three different segmentations across participants, with each segment shown for 200 ms, with an inter stimulus interval (ISI) of 800 ms (see fig.1). Participants read each text only once, in a given segmentation type, chosen pseudo randomly. Segmentation types where balanced through texts across participants. All participants were exposed to the three segmentation types.

After each text/segmentation type, participants had to judge the ease of reading in a scale from 1 to 5 segmentation's ease of reading (1 - '*very hard to read*', 5 - '*very easy to read*') and the level comprehension (1-'*did not understand it at all*', 5 - '*understood it completely*'). Participants also had to answer three questions regarding the specific stories of each text. Questions score was rated 0 for incorrect answers or 1 for correct.

Insert figure 1 here

Figure 1 – Presentation of the three segmentation styles: Word by word segmentation, (WbW), Parafoveal segmentation (PS), and Fixation based segmentation (FBW).

Results

The results on easiness and comprehension, where compared across participants using ANOVA. There was no significant difference between segmentations in the subjective assessment of comprehension (WbW, M=4.0; FBW, M=4.3; PS, M=4.3; $F(2, 258)=2.7$; $p=0.07$). Furthermore, no differences were found for the subjective judgement of ease of reading (WbW, M=4.0; FBW, M=4.0; PS, M=3.9; $F(2, 258)=8.3$; $p=0.50$).

The total scores for comprehension were assessed by the sum of the scores on the three questions related with details of each text. There were also no differences regarding the total comprehension score (WbW, M=2.7; FBW, M=2.7; PS, M=2.8; $F(2, 258)=0.25$; $p=0.80$).

From this experience we can conclude that the subjective experience of the readers was not significantly affected by the segmentation style.

Experiment II – Reading activity in Alternative Segmentations

Subjects

Ten subjects (8 female) aged between 20 and 30 years (M=24.8 years) participated in the experiment. All participants were university undergraduates and native speakers with normal or corrected to normal vision. All participants gave written informed consent.

Stimuli and Procedure

The segmented texts described above were presented in a 22 inch monitor using E-Prime software (Psychology Software Tools). Eye movements and fixations were

recorded with the iView system with an eye tracking device (RED, SMI) with a sampling rate of 120 Hz and gaze position accuracy inferior to 0.4º. Participants were seated at 70 cm from the screen. All participants started the task with a 9-point calibration procedure, which was repeated between segmentations. Fixations were considered with a minimum duration of 80 ms and maximum dispersion of 100 pixels. A Times New Roman point size 24 font was used in the three segmented texts.

Results

Average number of fixations per image was not significantly different for each type of segmented text, with an average of 1.39 ± 0.364 fixations in the fixation based segmentation (FBW), 1.35 ± 0.441 in the parafoveal segmentation (PS) and 1.28 ± 0.243 in the word by word segmentation (WbW).

The deviation on the x–axis (horizontal axis) in pixels also did not differ between segmentation. The values obtained for the FBW segmentation were M = 18.50 ± 4.32 pixels, for the WbW segmentation M = 13.53 ± 6.69 pixels and for the PS segmentation M = 21.62 ± 11.25 pixels.

The results show that the number and patterns of fixations per segment of a given text is not significantly affected by the segmentation style.

Experiment III – ERP analysis of Reading of Segmented Texts

Subjects

Sixteen participants (6 female) with ages ranged between 23 and 35 years (M = 27.75 years) participated in this experiment. All participants were native speakers with no known language disorders nor vision impairments, and gave written informed consent.

Stimuli and Procedure

All participants were seated comfortably in an electrically shielded room and fitted with an electrode cap for the ERP recordings. Participants were asked to read the previous texts in each of the three segmentation types and to try to follow each story. Stimuli were shown using E-Prime software on a 19 inch computer screen, with a refresh rate of 74 Hz, located 60 cm apart from the participant. Words were displayed for 200 ms followed by an ISI of 800 ms. Order of segmentation types was random between subjects.

At the end of each text participants were asked three questions regarding the details of each story.

EEG recording and analysis

The EEG was recorded with a 71 channels electrode cap (Nihon Kohden) placed accordingly to the 10-10 system. Electrode impedances were kept under 5 kΩ and online recording was referenced to C3 and C4, with a sampling frequency of 1000 Hz.

Data was offline re-referenced to electrodes average, re-sampled to 256 Hz and filtered with a basic Finite Impulse Response (FIR) filter with a low and high frequency pass band of 30 Hz and 0.3 Hz, respectively. Trials were excluded from averaging if they contained eye movements, blinks or excessive muscle potentials artefacts (based on visual analysis of the EEG signals).

The average ERPs were computed for each participant over a 1000 ms epoch with baseline correction from the 200 ms previous to each trial. A grand average of all

subjects was obtained at PO7, PO8, AF3 and AF4 electrodes, corresponding to bilateral occipital and frontal areas respectively.

The time windows for the analyses where selected upon visual inspection of both the individual participants' data and the grand averages. The P150 potential was considered between 90-160 ms, N170 between 150-210 ms and P2 [12] between 210-350 ms. The mean amplitude was used as measure in each time window.

The data for each time window was subjected to repeated-measures three-ways ANOVA, considering (i) electrode laterality (left *vs*. right hemisphere), (ii) frontality (occipital *vs*. frontal sites) and (iii) condition (three segmentation types) as within-subject factors.

Results

No statistically significant difference was found between conditions during 90-160 ms (P150) and 150-210 ms (N170), nor any interaction between condition, laterality or frontality. Differences were found for the P2 potential between conditions ($F(2,30)=4.53$, $p=.02$), as well as an interaction between condition and frontality ($F(2,30)=16.8$, $p=.01$). No other significant differences were found.

Since there was no effect of laterality, data from both hemispheres was averaged together. One-way ANOVAs where conducted for the occipital and frontal electrodes comparing the three conditions. A difference between condition was found in occipital electrodes ($F(2,30)=6.07$, $p=.006$). Post-hoc analysis with Bonferroni correction indicated that the fixation based segmentation ($M=1.7\pm5.2$) differed from the parafoveal segmentation ($M=.55\pm.59$; $p=0.005$) with no other differences.

Differences were also found in frontal electrodes ($F(2,30)=4.1, p=.02$). As before, fixation based segmentation values ($M=-.53\pm1.2$) differed from the parafoveal ($M=.28\pm1.2$; $p=0.02$) with no other differences being observed.

The results indicate a difference between segmentations in the P2 component, which was shown in occipital channels with more positive amplitude for fixation based than parafoveal words and at frontal electrodes with the corresponding difference of inversed polarity (fig.2)

Insert figure 2 here

Figure 2 - ERP waves for a) PO7, PO8 and b) AF3 and AF4.

Discussion

The results suggest that even in the absence of a behavioural difference between segmentations as assessed by the subjective evaluation, comprehension scores and eye tracking measures, differences can be found in ERP components. Differences were found in the P2 potential between fixation based and parafoveal presentation.

Although, the different segmentation types used did not differ in terms of eye movements, assessed both by number of fixation per screen and fixation dispersion, the different amount of information available on each segmentation type might have an effect on ERP components.

Nonetheless, although WbW segmentation provided the least information about the immediately following context, this did not seem to be associated with differences in processing and perception relatively to the other two segmentation types. This lack of differences might be related with the integration of each word displayed in the larger

context of the story which was kept for this segmentation, and is unusual in this type of paradigm. The integration of local and global information processed for text comprehension might have masked effects of next word integration that could be present on the fixation based and parafoveal segmentations. Furthermore pre-processing of the following word might be essential for speed in normal reading, but its effects might be unnoticeable in a slow paradigm with 800 ms between word presentations, particularly for subjective questions such as ease of reading.

Differences between fixation-based (FBW) and parafoveal (PS) segmentations in the ERP paradigm might reflect a difference in word processing latent to these types of segmentation. Differences in the mentioned component (P2) have already been shown by Barber et al. (2011) in relation with parafoveal presentation. In their experiment they showed that this component was less positive for contextually incongruent than congruent flanker words suggesting the relevance of this component on parafoveal word processing. The results of the fixation-based segmentation (FBW) may suggest a higher integration of information.

This study suggests that the different types of segmentation might be appropriate to study word processing of continuous reading. Different segmentations styles show a similar pattern of eye movements with comparable subjective perception in comprehension and ease of reading. Nonetheless, the selection of segmentation method must take into account that different segmentations show differences in ERP patterns even in the absence of behavioural differences.

Future studies should assess how the presentation of any type of segmentation is affected by the presence of context and continuous integration in a larger body of text.

References

Aluisio, S., Specia, L., Gasperin, C., & Scarton, C. (2010). Readability assessment for text simplification. In Proceeding of NAACL-HLT 2010, the 5th Workshop on Innovative Use of NLP for Building Educational Applications, June 2010, Los Angeles, CA, USA

Bacelar do Nascimento, M. F. (2001). Um novo léxico de frequências do português Homenagem ao Professor Herculano de Carvalho (pp. prelo).

Barber, H. A., Ben-Zvi, S., Bentin, S., & Kutas, M. (2011). Parafoveal perception during sentence reading? An ERP paradigm using rapid serial visual presentation (RSVP) with flankers. *Psychophysiology, 48*(4), 523-531. doi: 10.1111/j.1469-8986.2010.01082.x

Barber, H. a., Doñamayor, N., Kutas, M., & Münte, T. (2010). Parafoveal N400 effect during sentence reading. *Neuroscience letters, 479*, 152-156. doi: 10.1016/j.neulet.2010.05.053

Barber, H. a., & Kutas, M. (2007). Interplay between computational models and cognitive electrophysiology in visual word recognition. *Brain research reviews, 53,* 98-123. doi: 10.1016/j.brainresrev.2006.07.002

Bentin, S. (1999). ERP Manifestations of Processing Printed Words at Different Psycholinguistic Levels : Time Course and Scalp Distribution. *Journal of Cognitive Neuroscience*, 235-260.

Bizas, E., Simos, P. G., A, C. J. S., Arvanitis, S., Terzakis, D., & Micheloyannis, S. (1999). EEG Correlates of Cerebral Engagement in Reading Tasks. B*rain, 12*, 99-105.

Dien, J. (2009). The neurocognitive basis of reading single words as seen through early latency ERPs: a model of converging pathways. *Biological psychology, 80*, 10-22. doi: 10.1016/j.biopsycho.2008.04.013

Gouvea, A. C., Phillips, C., Kazanina, N., & Poeppel, D. (2010). The linguistic processes underlying the P600. *Language and Cognitive Processes, 25*(2), 149-188. doi: 10.1080/01690960902965951

Hagoort, P., & Brown, C. M. (2000). ERP effects of listening to speech compared to reading : the P600 / SPS to syntactic violations in spoken sentences and rapid serial visual presentation. *Neuropsychologia, 38*, 1531-1549.

Kaan, E., Harris, A., Gibson, E., & Holcomb, P. (2000). The P600 as an index of syntactic integration dificulty. *Language and Cognitive Processes, 15*, 159-201.

Oliveira, I. (2010). Relevance of EEG Input Signals in the Augmented Human Reader. Read, 0-8.

Rayner, K. (1998). Eye movements in reading and information processing: 20 years of research. *Psychological bulletin, 124,* 372-422.

Schendan, H. E., Ganis, G., & Kutas, M. (1998). Neurophysiological evidence for visual perceptual categorization of words and faces within 150 ms. *Psychophysiology, 35*(3), 240-251.

Van Berkum, J. (2004). Sentence comprehension in a wider discourse: Can we use ERPs to keep track of things The on-line study of sentence comprehension: Eye tracking, ERPs and beyond (pp. 229-270): New York NY: Psychology Press.

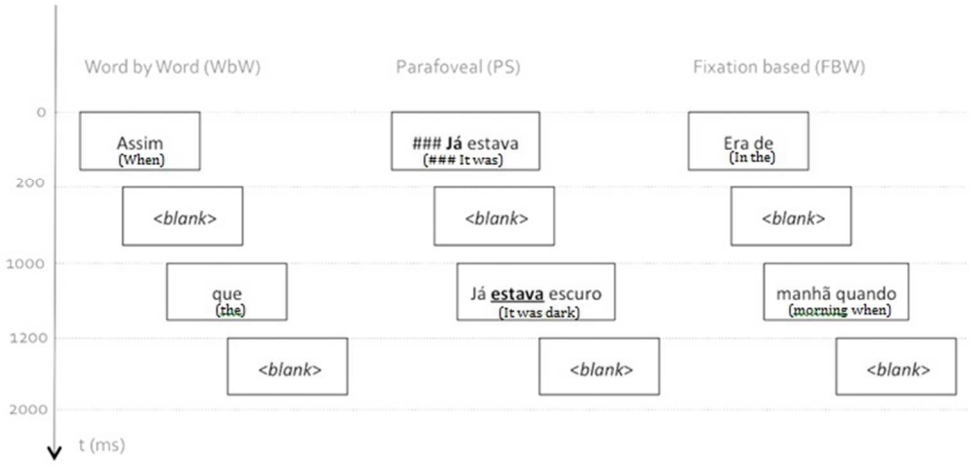

Figure 1. Presentation of the three segmentation styles: Word by word segmentation, (WbW), Parafoveal segmentation (PS), and Fixation based segmentation (FBW)
157x78mm (120 x 120 DPI)

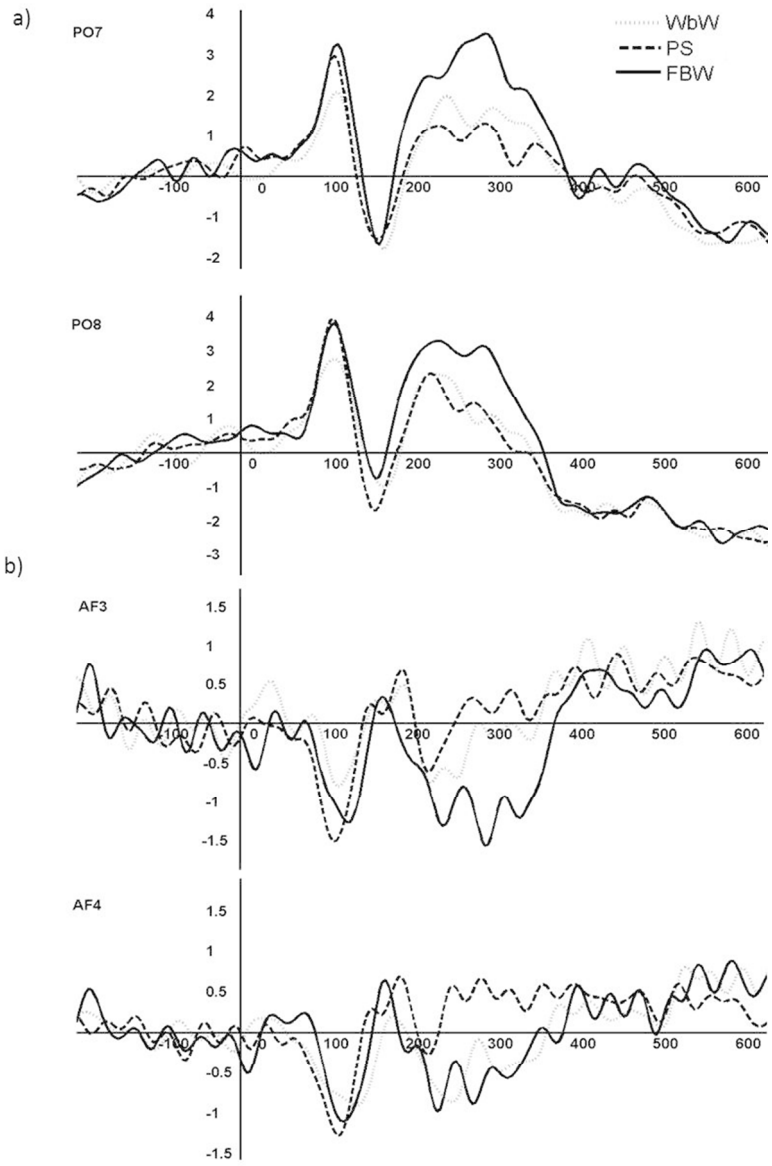

Figure 2 - ERP waves for a) PO7, PO8 and b) AF3 and AF4
135x208mm (150 x 150 DPI)