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Discriminating among different types of verb-complement merge in Brazilian Portuguese: an ERP study of morpho-syntactic sub-processes

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Abstract

Taking into consideration differences in syntactic configurations underlying the verb-complement merge operation, this experiment investigates three series of sentences containing incongruous and congruous merges. The aim is to relate syntactic specificities to the resulting ERP morphologies. Conditions tested required three types of computations: local merge, local merge depending on inheritance of semantic properties from an antecedent and merge performed at distance (WH-displacement). A total of 240 experimental sentences (80 for each condition) and 240 distractor sentences were generated in Brazilian Portuguese. Using a kinetic presentation protocol, sentences were displayed to each of 25 subjects, while the raw EEG was acquired at 20 derivations. Signal processing techniques were used to estimate the individual ERP for each anatomic region. Series 1 involving strictly local computations resulted in classic parietal N400s, whereas the inheritance stimuli elicited two peaks in the parietal and central region ERPs. Series 3—WH-displacement—presented earlier and more salient cortical responses. The different ERP morphologies resulting from each condition are consistent with a model in which language processing results from task-specific computations involving different neurological subsystems.

Keywords: Verb-complement merges; Event-related brain potentials; N400; Cognitive sub-processes

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1. Introduction

Semantic violations coinciding with the merge operation between the verb and its complement have been related to enlarged negative-going event-related potentials (ERP), peaking at around 400 ms post-stimulus—the N400 (Kutas & Hillyard, 1980). This phenomenon has been widely described as a consequence of increased difficulty in morpho-syntactic integration due to the semantic anomaly (Kutas & Van Petten, 1990; Osterhout & Holcomb, 1995). In this paper, in order to assess the neurophysiology of different merge operations, we diversify the standard N400 experiment by testing less commonly explored contexts required by verb-complement integration.

A second contribution of this study concerns wave analysis. In the ERP literature, in order to characterize the N400 phenomenon, three parameters of the resulting averaged waveform (ERP) are usually analyzed: latency, amplitude and topographic (spatial) distribution (Kotz & Friederici, 2003). The latency of the cortical response is referenced to a specific instant in time (for example, the target stimuli presentation) and usually ranges from 300 to 500 ms. Amplitude is commonly related to the level of facility to perform morpho-syntactic integration (Fonteneau, Frauenfelder, & Rizzi, 1998; Kutas & Hillyard, 1984). Thus, it can also be seen as the inverse function of context: the least supporting context for semantic satisfaction: the larger amplitude of the waveform as a direct result of the integration challenge (Holcomb & Neville, 1991). Amplitude is also inversely correlated with recency and priming effects. Topography is usually reported as centro-parietally distributed in visually stimulated experiments and more diffuse in acoustic ones (Kutas & Kluender, 1994). We have here elected a fourth parameter—waveform—to see how it relates to the morpho-syntactic tasks underlying the three types of merge operations studied.

2. Theoretical framework

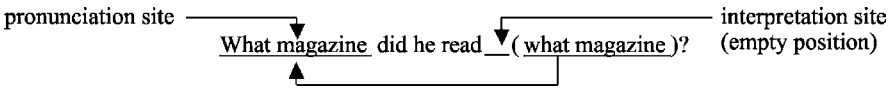
After over a decade of robust N400 findings chiefly related to the merge operation between a verb adjacent to a full noun phrase, it becomes of theoretical import to neurolinguistics to be able to characterize the neurophysiology of subtly different types of merge already formally and clearly described in the linguistics literature on verbal complementation: merge to a pronoun and merge to a slot emptied by WH-Movement.

Assuming that different types of syntactic contexts surrounding the merge operation trigger specific neuronal activation modes, this study compares the following three series of sentential stimuli that are derived by verb-complement merges embedded in different syntactic configurations.

Series 1 gathers sentences involving the most studied type of verb-argument combinations: the local one. The verb finds its argument right beside it. Incongruence is established by the local incompatibility between the selectional requirements of the verb and the semantic properties of the complement.

Series 2 encompasses stimuli that establish a local relationship between the verb and its pronominal complement, but, in this case, the semantic properties of the complement are inherited from the nominal antecedent.

In Series 3, instances of verb selection are performed at distance. These are syntactic structures known as WH-movement in the linguistics literature. In such constructions, the complement (WH-phrase) appears displaced from its interpretation site. As a complement, it is interpreted right beside the verb, but it is realized phonetically in a sentence initial position derived at a later merge, in spite of being pronounced first.



3. Materials and methods

A computerized grammaticality judgment test was presented to 25 right-handed volunteers (13 males). All volunteers were within the 18–36-age bracket (mean age, 26.2 years), had a college education (complete or partial) and were previously screened for systemic diseases and for the current use of antidepressants.

Volunteers were visually stimulated by 240 experimental sentences (80 for each series: 40 congruous and 40 incongruous) and 240 distractor sentences (80 for each series: 40 congruous and 40 incongruous), all in Brazilian Portuguese, displayed in a pseudo-random manner within each series. The distractors in each series were mixed with the experimental stimuli and were formulated not to present the same types of selection as those in the target stimuli. For instance, some distractors included intransitive verbs or subordinate clauses, despite having the same number of words as the experimental sentences in the series they were inserted in.

3.1. Examples of experimental sentences in Series 1

3.1.1. Congruous: Minha professora leu um livro
my teacher read a book

3.1.2. Incongruous: Meu primo rasgou a geladeira.
my cousin tore the fridge

The selection sub-processes involved in this series include the syntactic-categorial structuring of a phrase marker and the assignment of conceptually felicitous or infelicitous local thematic role.

3.2. Examples of experimental sentences in Series 2

3.2.1. Congruous: Ele lavou a maçã e secou-a.
he washed the apple and dried it

3.2.2. Incongruous: Ela abriu as janelas e comeu-as.
she opened the windows and ate them

The selection sub-processes involved in this series include first the syntactic-categorial structuring of a phrase marker. Then, since the pronoun is devoid of conceptual content, there is a search for an antecedent with which to establish a co-reference. As the referential binding is established, the semantic properties already activated in the preceding sentence can be transferred to the pronoun. Finally, there is the assignment of conceptually felicitous or infelicitous local thematic role.

3.3. Examples of experimental sentences in Series 3

3.3.1. Congruous: Que quadro ela pintou?
what picture she painted

3.3.2. Incongruous: Que cor ela bebeu?
what color she drank

The first sub-process involved in verb-selection in Series 3 is the extraction of semantic properties of the WH-phrase. These properties have to be stored in initial sentence position to be checked later with the verb. Then, there is the structuring of a phrase marker, including the operation of matching verb event requirements with those of the complement, which is an empty category. Then, since the empty category is devoid of conceptual content, the stored WH-antecedent gets activated. As the connection is established, the semantic properties already stored in the WH-phrase can be transferred to the empty category. Finally, there is the assignment of conceptually felicitous or infelicitous local thematic role to the empty complement position.

3.4. The stimulation protocol

Stimulus sentences were presented kinetically, word-by-word, on the computer screen, commanded by a script written in Presentation 0.5 (*Neurobehavioral Systems*, Albany, USA). Subjects read test instructions on the screen followed by a warm-up drill that checked their comprehension of the protocol. After the warm-up, subjects could receive additional coaching from the experimenter, in case doubts about the protocol still lingered. When ready, subjects would start the grammaticality judgment test.

Each word was centrally displayed on the monitor for 200 ms, formatted with white, 14-point, *Times New Roman* font over a black screen ($17'$ monitor with a 1024×768 resolution). After the presentation of the last word of each sentence, subjects were to judge the stimulus by pressing either the red or green key on the keyboard, respectively for incongruence or congruence. Response wait would time-out after 1000 ms. Following the event of judgment or time-out, a white fixation cross was displayed for 2000 ms before the first word of the next sentence was presented.

3.5. Electroencephalogram recording and processing

Brain bioelectric signal (EEG, electroencephalogram) was recorded continuously during the whole experimental session from 20 unipolar derivations. Silver-tip

electrodes were attached to subjects' scalp according to the International 10–20 System, with linked-mastoid reference and ground at FPz.

Electrode impedance was controlled to normal values (for EEG, lower than 10 kΩ). Signal was amplified (gain = 18,000) and treated with low-pass (cutoff frequency of 32 Hz) and high-pass filtering (1.6 Hz). All EEG derivations were digitized with a sampling frequency of 200 Hz (12-bit analog-to-digital resolution) and were stored for off-line processing.

The multi-channel EEG digital processing of all experimental sentences was performed within Matlab® version 5.2 environment (*The MathWorks, Inc.*, MA). First, the original signal of each subject was segmented into epochs with 800 ms duration triggered by the onset of the target words. Then, an algorithm for artifact rejection was applied to each signal epoch. This algorithm consisted of a simple comparison to a threshold, defined as 1.35 times the root mean squared (RMS) value of an artifact-free individual EEG raw signal. The epochs which presented any sample with module above this threshold were eliminated.

The ERP was then estimated by coherently averaging the epochs relative to congruous (or incongruous) EEG response for each electrode site of a subject. Hence, ERPs were time-locked to the onset of the stimulus-trigger for each of the two conditions (congruous and incongruous). A 200 ms pre-stimulus interval was set as a baseline. Individual ERPs were then low-pass filtered (cutoff frequency of 7 Hz, fourth order Butterworth, applied bi-directionally for obtaining null phase frequency-response, i.e. no phase distortion).

Finally, individual ERPs of all subjects for each condition were grand-averaged and plotted. Reaction time and error rate were treated statistically with ANOVA ($p < 0.05$ error threshold).

4. Results

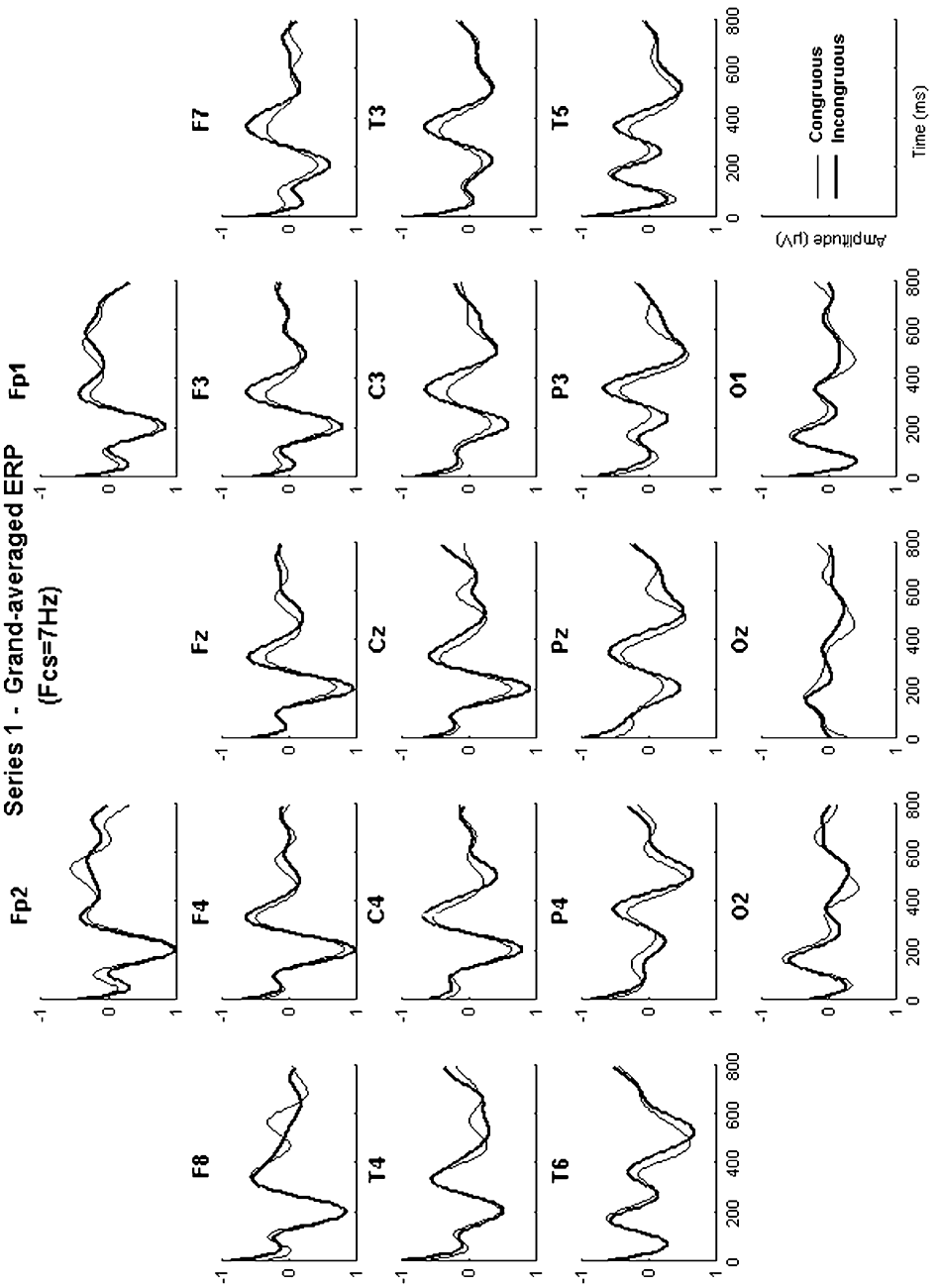
4.1. Series 1

In Series 1, a slightly early N400 can be noticed parietally and centrally both for congruous and incongruous stimuli. More activity on the left hemisphere derivations and an accentuated peak in C3 can be noticed, as described in other studies (Friederici, Hahne, & Saddy, 2002). Incongruous sentences were marked by larger wave amplitude (Fig. 1).

In comparison with the two other series, Series 1 presented an N400 with the longest and steepest valley to peak line which started noticeably deeper for the incongruous stimuli. The judgment error rate (when subjects failed to distinguish between congruous and incongruous sentences) was 21%. The average reaction time was 170 ms post display of last word.

4.2. Series 2

Series 2 yielded very different waveforms from those in Series 1. Two components may be seen within the 800 ms window. First, at 100 ms a low amplitude peak can be noticed in



which congruous and incongruous lines completely overlap. Then, the N400 ERP for the target merge happens at about 300 ms post-trigger word, but here the line relative to the incongruous stimuli ascends to a higher amplitude than that of the congruous. These negative-going waves show a parietal and central distribution, are more expressive on the left hemisphere, and present a lower amplitude than in Series 1 (Fig. 2).

In most derivations, the N400 culminates in accentuated plateaus which were present in the individual ERPs, and therefore could not have resulted from a grand-averaging bias. After the plateau, the slope related to the incongruous sentences tended to deepen into the next valley in a slower fashion than that of the congruous sentences.

4.3. Series 3

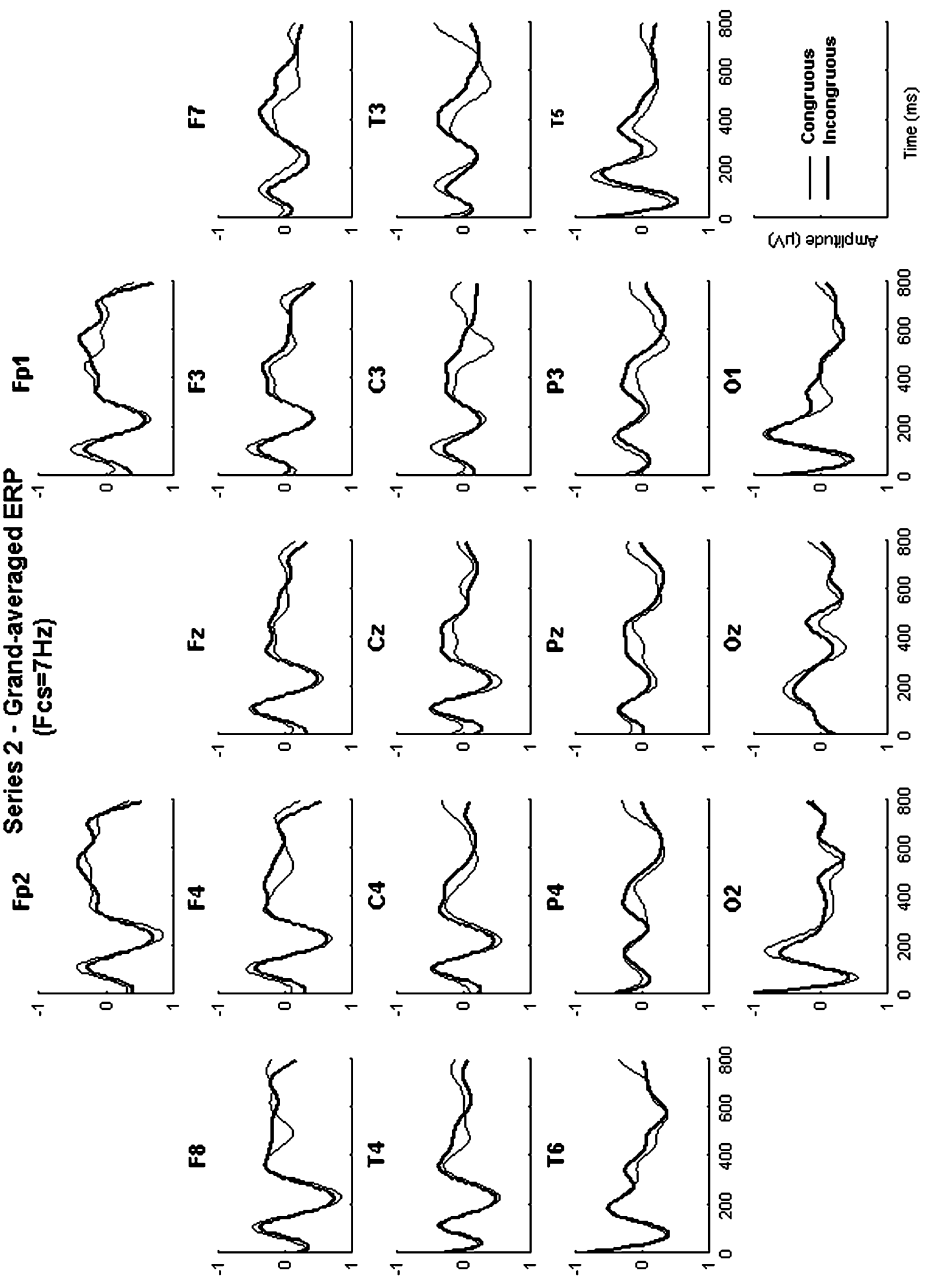
The results of the selection in Series 3 show more centrally and parietally distributed activity than in prior series. There are two negative components and a positive one within the 800 ms window. The first negative component can be seen at around 100 ms and is more lateralized to the right; then there are the N400 and the P600. In these two last components, there is a slight lateralization effect to the left. Amplitude of the N400 is the highest in the three series and so is the amplitude difference between congruous and incongruous. The latency of the P600 is accountably larger for the incongruous line than for the congruous. Motor reaction time was the lowest among the three (151 ms) and the judgment error rate was the smallest (10.3%) (Fig. 3).

5. Discussion

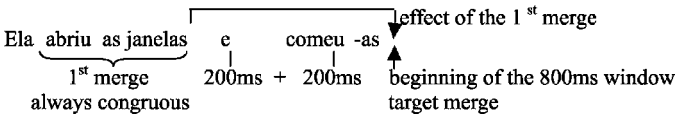
Series 1 results were similar to those robustly defined in the N400 literature: semantic anomaly increases wave amplitude (Osterhout & Holcomb, 1993, 1995). In our study, however, we noticed that this effect can be observed not only with respect to the high peaks, but also concerning the depth of the preceding valleys related with incongruous sentences. This parameter—the length and angle from valley to peak—is possibly related to the urgency of the integration. Series 1 presents the greatest urgency of the three series, since integration has to be performed ‘on the spot’. So, it might trigger a more vigorous neuronal firing pattern that results in the long and steep slope before the peak.

As to Series 2 stimuli, the target verb-noun merge placed in the second sentence of the coordinate pair is dependent on context set by the prior verb-noun-phrase merge of the first sentence. Despite the fact that this prior merge was not time-locked in this study, we believe that its effect was still caught right at the beginning of the 800 ms window,

Fig. 1. Grand-average ERP of 25 right-handed subjects submitted to Series 1: 40 congruous and 40 incongruous sentences generated in Brazilian Portuguese and presented to subjects in a pseudo-random manner. Equal number of distractor sentences was also used. ERP in 20 different cortical regions, in accordance with the International 10–20 System and with linked-mastoid reference (medial line: Fz, Cz, Pz and Oz; FP2, F4, F8, C4, T4, P4, T6, O2 and their homologous). The thick line refers to ERPs resulting from congruous sentences and the thin line to those of the incongruous ones.



initiating after the target merge. We interpreted this initial negative-going ERP as the N400 response to the verb-complement merge of the preceding sentence of the coordination:



Since the initial ERPs corresponding to the congruous and incongruous stimuli are low-amplitude overlapping lines (cf. the central and parietal derivations), they should stem from congruous stimuli. In fact, the merge in the first coordinated sentence is always congruous—anomaly only happens at the second merge.

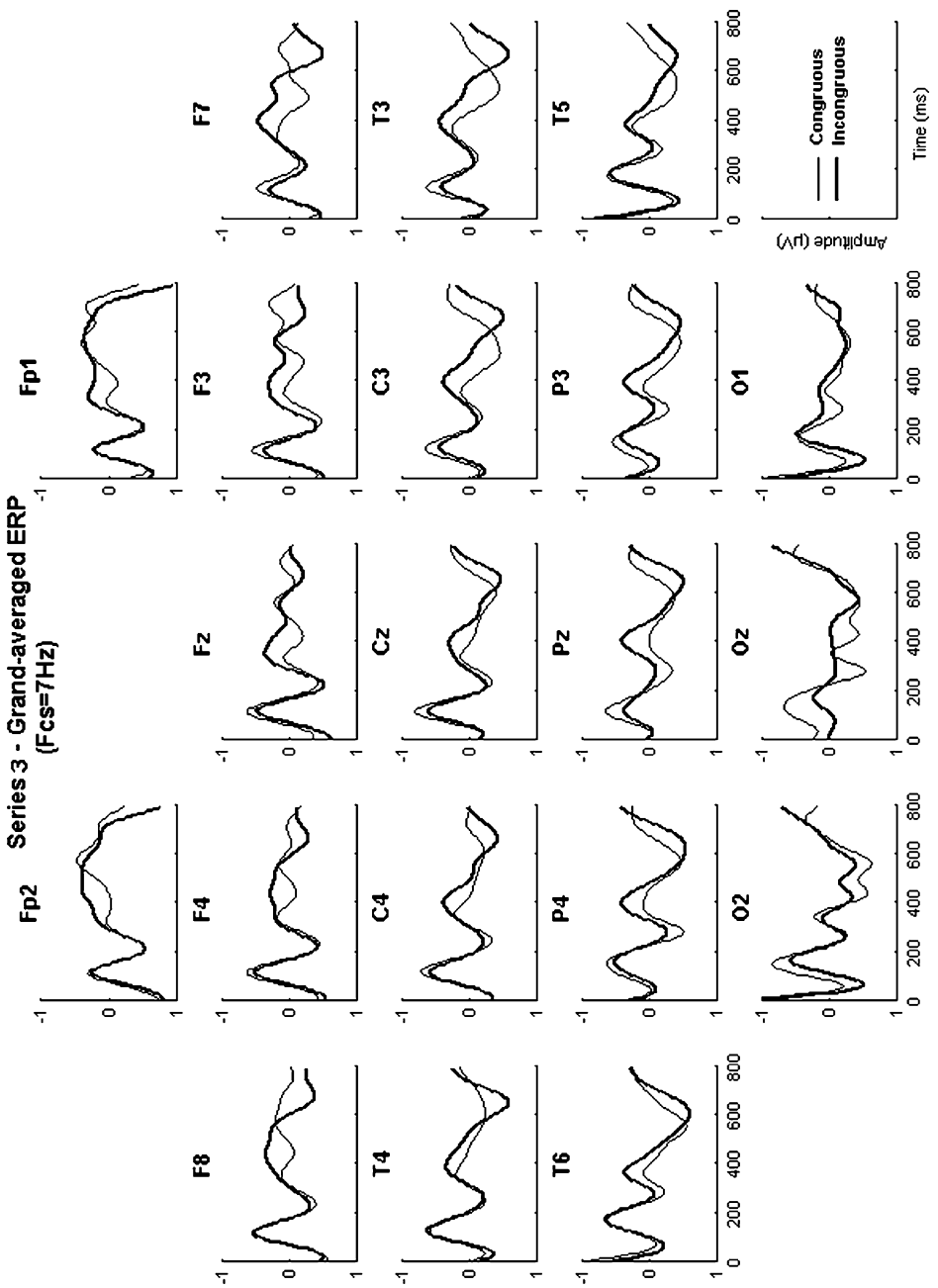
Concerning the target merge, we already know that semantic context is inversely related with amplitude. Since this second merge was dependent on semantic material already negotiated in the previous verb selection, its range of conceptual options was possibly narrowed. Thus, the perception of the congruous or incongruous material was facilitated, accounting for the lower amplitude of the N400.

The plateau-shaped peak may be depicting the complexity of transferring semantic properties from the noun to the pronoun. Additionally, the slower slope to form the next valley, especially present in the incongruous sentences, may reveal an attempt of repair (cf. P3 and C3). In fact, the average motor reaction time was higher (1.84 ms) than that in Series 1. The judgment error rate was lower (15.6%), presumably for the same reasons that prompted the lower amplitude.

Series 3 tested stimuli with syntactic dependencies caused by the displacement of the WH-phrase. The appearance of the WH-phrase right at the beginning of the sentence, opening the dependency, has been amply described by the behavioral sentence processing literature as triggering an immediate 'search mode' for feature matching (DeVilliers, Roeper, & Vainikka, 1990; DeVilliers & Roeper, 1995). We relate this event to the first negative component peaking at around 100 ms, a finding which is in accordance with the neurolinguistics literature as well (Holcomb & Neville, 1991; Kaan, Harris, Gibson, & Holcomb, 2000).

Then, processing has to deal with storing, retrieval and reconstruction of properties, which are time-costly tasks. But differently from Series 2, in which the semantic feature transference is required without prior warning, Series 3 has a warning flag for property reconstruction—the WH-morphology—and that probably accounts for the lower cortical

Fig. 2. Grand-average ERP of 25 right-handed subjects submitted to Series 2: 40 congruous and 40 incongruous sentences generated in Brazilian Portuguese and presented to subjects in a pseudo-random manner. Equal number of distractor sentences was also used. ERP in 20 different cortical regions in accordance with the International 10–20 System and with linked-mastoid reference (medial line: Fz, Cz, Pz and Oz; FP2, F4, F8, C4, T4, P4, T6, O2 and their homologous). The thick line refers to ERPs resulting from congruous sentences and the thin line to those of the incongruous ones.



activation of the N400, faster motor reaction times and also for the lower judgment error rate.

If at the beginning of this dependency, the retrieval mechanism may probably have been facilitated by the salience of the WH-phrase in initial position, then the closure of this dependency carries the burden of syntactic integration. Thus, the slowly deepening P600 might be reflecting this complex processing, specially for the incongruous stimuli, whose ERPs are accountably slower (cf. Cz, C3, Pz, P3) than those related to the congruous sentences.

The very different waveforms related to the three series will be summarized in Table 1.

6. Conclusion

The data extracted from this experiment indicate that there are different N400 morphologies related to the different types of merge and their associated morpho-syntactic components. This finding is consistent with premises from current neurophysiology of language models that view language processing as resulting from the interaction of task-specific computations (Chomsky, 2001; Hauser, Chomsky, & Fitch, 2002), plausibly involving different neurological subsystems and neuronal firing modes (Hickok, 2001; Hickok & Poeppel, 2000, 2004; Poeppel & Marantz, 2000).

One can also conclude that the experimental protocol was successful to reveal electrophysiological data that mapped linguistic specificities onto different wave morphologies derived at different cortical regions.

Furthermore, in this paper we have launched the possibility that the length of the slope prior to the peak, the amplitude of the peak, its latency, its shape and the slope after it are important parameters related to the urgency of the merge, integration facility, the activation time, the complexity of the cognitive tasks and the readiness to move on to other tasks, respectively.

The three series studied in this paper have explored merge conditions that involve strictly linguistic tasks. Now, in order to take a further step in the neurophysiological characterization of the ERP components, other types of merge should be exploited including those that recruit cognitive tasks beyond those used in the narrow linguistic realm.

Fig. 3. Grand-average ERP of 25 right-handed subjects submitted to Series 3: 40 congruous and 40 incongruous sentences generated in Brazilian Portuguese and presented to subjects in a pseudo-random manner. Equal number of distractor sentences was also used. ERP in 20 different cortical regions in accordance with the International 10–20 System and with linked-mastoid reference (medial line: Fz, Cz, Pz and Oz; FP2, F4, F8, C4, T4, P4, T6, O2 and their homologous). The thick line refers to ERPs resulting from congruous sentences and the thin line to those of the incongruous ones.

Table 1
Summary of parameters affecting electrophysiology of different types of verb-complement merge

series → / parameters ↓	**Series 1** Local merge	**Series 2** Local merge requiring co-reference mechanism	**Series 3** Reconstruction of a syntactically displaced item
Cortical response (latency) How fast?	••	•	•••
Motor response (finger pressing) How fast?	•	••	•••
Integration facility (amplitude: peak height) How salient is the incongruence?	••	•	•••
Integration urgency slope before peak (length and steepness from valley to peak) How long and steep is the slope?	•••	••	•
Topographic distribution (the activated electrode sites) How diffuse is the activity?	•	••	•••
Complexity of cognitive tasks peak angle (degree: from plateau to acute angle) How flat?	•	•••	••
Readiness to move on to other tasks slope after peak (from peak to next valley) How fast?	•••	•	••
Error rate of response (mistakes in motor response) How high was the error rate?	•••	••	•

•, The least; ••, The middle; •••, The most.

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References

Chomsky, N. (2001). MIT Occaisional Papers in Linguistics, MIT Working Papers in Linguistics. *Beyond explanatory adequacy*. Cambridge, MA: MIT Press, *20*, 1–28.

De Villiers, J., & Roeper, T. (1995). Relative clause are barriers to WH-movement in young children. *Journal of Child Language*, *22*(2), 389–404.

De Villiers, J., Roeper, T., & Vainikka, A. (1990). The acquisition of long-distance rules. In L. Frazier, & J. De Villiers (Eds.), *Language processing and language acquisition* (pp. 257–297). Dordrecht: Kluwer.

Fonteneau, E., Frauenfelder, U., & Rizzi, L. (1998). On the contribution of ERPs to study of language comprehension. *Bulletin Suisse de linguistique appliquée: Etudes en neurolinguistique*, *68*, 111–124.

Friederici, A. D., Hahne, A., & Saddy, D. (2002). Distinct neurophysiological patterns reflecting aspects of syntactic complexity and syntactic repair. *Journal of Psycholinguistic Research*, *31*(1), 45–63.

Hauser, M. D., Chomsky, N., & Fitch, W. T. (2002). The faculty of language: what is it, who has it, and how did it evolve? *Science*, *298*, 1569–1579.

Hickok, G. (2001). Functional anatomy of speech perception and speech production: psycholinguistic implications. *Journal of Psycholinguistic Research*, *30*(3), 225–235.

Hickok, G., & Poeppel, D. (2000). Towards a functional neuroanatomy of speech perception. *Trends in Cognitive Sciences*, *4*(4), 131–138.

Hickok, G., & Poeppel, D. (2004). Dorsal and ventral streams: a framework for understanding aspects of the functional anatomy of language. *Cognition*, *92*(1–2), 67–99.

Holcomb, P. J., & Neville, H. J. (1991). Natural speech processing: an analysis using event-related brain potentials. *Psychobiology*, *19*, 286–300.

Kaan, E., Harris, A., Gibson, E., & Holcomb, P. (2000). The P600 as an index of syntactic integration difficulty. *Language and Cognitive Processes*, *15*(2), 159–201.

Kotz, S. A., & Friederici, A. D. (2003). Electrophysiology of normal and pathological language processing. *Journal of Neurolinguistics*, *16*(1), 43–58.

Kutas, M., & Hillyard, S. A. (1980). Reading senseless: brain potentials reflect semantic incongruity. *Science*, *207*, 203–205.

Kutas, M., & Hillyard, S. A. (1984). Brain potentials during reading reflect word expectancy and semantic association. *Nature*, *307*(5947), 161–163.

Kutas, M., & Kluender, R. (1994). What is who violating? A reconsideration of linguistic violations in light of event-related brain potentials. In H. T. Heinze, G. R. Mangun, & T. Muente (Eds.), *Cognitive electrophysiology* (pp. 183–210). Boston: Birkhaeuser.

Kutas, M., & Van Petten, C. (1990). Interactions between sentence context and word frequency in event-related brain potentials. *Memory and Cognition*, *18*(4), 380–393.

Osterhout, L., & Holcomb, P. J. (1993). Event-related potentials and syntactic anomaly: evidence of anomaly detection during the perception of continuous speech. *Language and Cognitive Processes*, *8*(4), 413–437.

Osterhout, L., & Holcomb, P. J. (1995). Event-related potentials and language comprehension. In M. D. Rugg, & M. G. H. Coles (Eds.), *Electrophysiology of mind: event-related brain potentials and cognition* (pp. 171–215). New York: Oxford University Press.

Poeppel, D., & Marantz, A. (2000). Cognitive neuroscience of speech processing. In A. Marantz, Y. Miyashita, & W. O'Neil (Eds.), *Image, language, brain* (pp. 29–50). Cambridge, MA: MIT Press.