UNVEILING ELECTROPHYSIOLOGICAL DIFFERENCES AMONG TYPES OF VERB-COMPLEMENT MERGES

Detectando diferenças eletrofisiológicas entre tipos de concatenações verbo-complemento no português do Brasil

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Introduction

Each and every cognitive task the human being performs – seeing an object, recognizing a sound, articulating a phoneme, sensing a smell – has an electrochemical basis. Cognition takes place through the flow of electrical cortical activity along neurons in the brain, a process that is triggered and maintained by biochemical reactions. The study of how this activity propagates within the brain has long been undertaken by physiology and neurology. But most of the crucial knowledge about the electrical patterns in the scalp has only surfaced through the disseminated use of the electroencephalogram (EEG): the record of the temporal and spatial summation of the excitatory and inhibitory post-synaptic potentials in the brain along the time (Lopes da Silva, 1998).

EEG signals are obtained through electrodes placed on the scalp over multiple areas of the brain. Due to each electrode's dimension and its location over the scalp, it detects the bioelectricity that stems from a neuronal population,

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which can reach millions of neurons, instead of just a single neuron. Since the bioelectricity is generated in the cortex, it propagates throughout non-neuronal tissues (such as meninges and bone) before reaching the scalp. So, at the scalp, the electrodes acquire an attenuated signal.

Throughout its history, the EEG has been more commonly used in the diagnosis of diseases such as seizure disorders, mental confusion, and in the evaluation of head injuries, tumors, infections, degenerative diseases, and metabolic disturbances that affect the brain. It is also used to evaluate sleep disorders and to investigate periods of unconsciousness or to confirm brain death in a comatose patient (Bear, Connors, Paradiso, 2001). In fact, conditions such as epilepsy, attention deficit disorder, dyslexia, sleep disorders and many others can be accurately characterized in terms of the electrical wave patterns displayed by the EEG (Gazzaniga, 2002).

Since the last decade, however, the field of neurolinguistics has also been making wide use of the EEG to assess the electrical cortical effects caused by different sorts of linguistic phenomena in normal people. Such studies apply a signal amplification and averaging technique to extract electrical brain components known as ERPs (Event Related Brain Potential). This technique is capable of relating a target linguistic stimulus to some specific characteristics of the ERP: a specific latency (the onset time of the peak), amplitude (how high the peak is) and topographic distribution (regions on the scalp where it is elicited). For instance, once a volunteer is stimulated with a sentence in written or oral form containing a semantic violation between the verb and its complement (for example, "eat shoes") a special electrical event takes place in her brain. This event is a wave of negative polarity which peaks at around 400 ms post-stimulus (Kutas; Hillyard, 1980; Kutas; van Petten, 1990). This electrical component, known in the literature as the N400 (N standing for negative polarity and 400 for the time it takes for the wave to raise since its stimulus onset), is widely described as a consequence of increased difficulty in morpho-syntactic integration due to the semantic anomaly (Osterhout; Holcomb, 1993; 1995).

In the N400 context, three aspects of the resulting ERP are usually analyzed: latency, amplitude and topographic 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 (Kutas; Hillyard, 1984; Fonteneau et al., 1998). Thus, it can also be seen as the inverse function of context, i.e., the least supporting context for semantic satisfaction results in the largest 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. Finally, topography is usually reported as centro-parietally distributed in visually stimulated experiments and more diffuse in acoustic ones (Kutas; Klunder, 1994).

Nevertheless, a formal analysis of verbal selection reveals that verb-noun merge is not a unified operation. There are a few types of processing underlying the merge operation, each one recruiting a number of distinct morpho-syntactic sub-processes. In order to discriminate among a few of these types, this study compares three series of sentential stimuli with similar verb-complement merges embedded in different syntactic structures. It aims at assessing the impact of the different contextual configurations onto the dependent variables of amplitude, latency and topographic distribution of the waveform, aside from the psycholinguistic variables of motor reaction time (time to press the button) and error rate.

The tested conditions were organized along a continuum requiring three types of cognitive computations: local verb + complement merge, local verb + pronoun merge depending on inheritance of semantic properties from an antecedent and verb + Wh-DP merge with an element that appears in a displaced position. An equal number of sentences were tested in each of three conditions. Half of the sentences were formatted to yield a congruous meaning and half to yield an incongruous one. Thus each series has two kinds of sentences: congruous and incongruous.

Series 1 gathers sentences involving local and simple verb-argument combinations. 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.

Examples:

1.1 Incongruous version

Meu	tio	rasgou	a	pia
my	uncle	tore	the	sink

1.2 Congruous version

A	garota	lavou	as	mãos.
the	girl	washed	the	hands

The sub-processes involved in verb selection in Series 1 are the following:

a. Matching verb event requirements with semantic properties of complement.

b. Felicitous or infelicitous local thematic role assignment.

Series 2 encompasses stimuli that establish a local relationship between the verb and its pronominal complement, but the semantic properties of the complement are dependent upon inheritance of semantic properties from an antecedent.

Examples:

2.1 Incongruous version

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

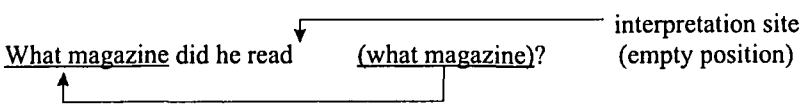
2.2 Congruous version

Eu	peguei	o	dinheiro	e	contei-o.
I	got	the	money	and	counted it

The sub-processes involved in verb-selections in Series 2 are the following:

a. Matching verb event requirements with semantic properties of complement.
b. Searching for co-reference. The pronominal nature of complement requires establishment of co-reference chain, connecting pronoun to antecedent.
c. Retrieving semantic properties already activated in the preceding sentence.
d. Transferring semantic properties of antecedent to pronoun.
e. Felicitous or infelicitous thematic role assignment to pronoun.

Series 3 presented instances of verb selection is performed at distance. These are syntactic structures named WH-movement. In such constructions, the complement (WH-phrase) is displaced from its interpretation site. As a complement, it should be interpreted right beside the verb, but it is realized phonetically in sentence initial position.



Examples:

3.1 Incongruous version

Que livro ela vestiu?
what book she wore

3.2 Congruous version

Que canção ele cantou?
what song he sang

The sub-processes involved in verb-selection in Series 3 are the following:

a. Extracting semantic properties of the WH-phrase and storing them to be matched later.
b. Matching verb event requirements with semantic properties of a local complement, which is an empty category.
c. Searching for co-reference. The nature of the empty category requires a search for semantic properties in an antecedent.
d. Retrieving semantic properties of the WH-phrase previously stored.
e. Reconstructing the properties of the empty category.
f. Felicitous or infelicitous local thematic role assignment.

Materials and methods

Participants

A computerized grammaticality judgment test was presented to 25 right-handed subjects (13 males). All subjects 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.

The stimulation material

A total of 240 experimental sentences (80 for each series: 40 congruent and 40 incongruent) and 120 distractor sentences were generated in Brazilian Portuguese and presented to subjects in a pseudo-random manner.

The stimulation protocol

It comprised of the word-by-word kinetic presentation of stimulus sentences, commanded by a script written in Presentation 0.5 (*Neurobehavioral Systems*, Albany, USA). Presentation, like Psyscope and RSVP (Rapid Serial Visual Presentation), is one of the several stimulus presentation software that compile written our audio stimuli scripts designed for cognitive experiments. Experimenters plan the sequence of events with time precision that are to happen during the experiment and program these events sequentially in a master script. Then this master script pulls the stimuli from stimulus lists that are indexed to it. Volunteers' reaction times and answers are recorded. Most of these programs can also be connected with the EEG, allowing the correlation between a specific stimulus and the electrical brain activity.

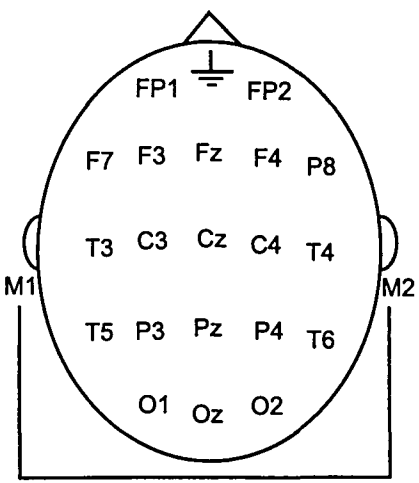
In this test, volunteers read test instructions on the screen followed by a warm-up drill that checked their comprehension of the protocol. After the warm-up, subjects could receive additional coaching from the experimenter, in case doubts about the protocol still lingered. When ready, subjects would start the grammaticality judgment test.

Each sentence word was centrally displayed on the monitor for 200 ms. Words were formatted with white, 14-point, "Times New Roman" font over a black screen. After the presentation of the last word of each sentence, subjects were to judge the stimulus by pressing either the red or green key in front of them, respectively for incongruence or congruence. Response wait would time-out after 1000 ms. After 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.

Electroencephalogram recording and processing

The brain bioelectric signal on the scalp (EEG - electroencephalogram) was recorded continuously during the whole experimental session from 20 silver-tip electrodes, attached to subjects' scalp according to the International 10-20 System, with linked-mastoid reference. While the volunteer performed the task of deciding if the sentence she was reading was congruous or incongruous, the activity taking place in her brain was monitored by the electrodes distributed among the following cortical areas: pre-frontal (PF), frontal (F), temporal (T), central (C), parietal (P) e occipital (O) (cf. Fig. 1).

FIGURE 1 - THE 10-20 INTERNATIONAL SYSTEM OF ELECTRODE PLACEMENT



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

The multi-channel EEG digital processing of all experimental sentences was performed within Matlab® version 5.2 (*The MathWorks, Inc.*, MA). This is an adequate programming environment for numerical computation, particularly with matrices and vectors. When applied to the EEG record processing it allows

filtering, normalization, and graphical visualization of these records and also the ERP.

First, the original signal of each subject was segmented into epochs of 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 that presented any sample with module above this threshold were discarded.

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 stimuli-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, 4^{th} order Butterworth, applied bi-directionally for obtaining null phase frequency-response).

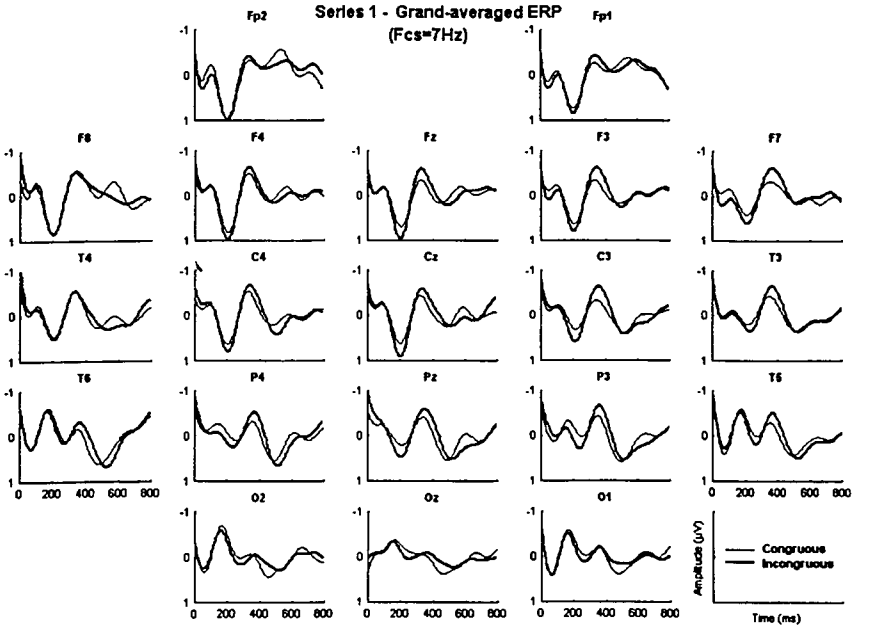
Finally, individual ERPs of all subjects for each condition were grand-averaged and then plotted. Reaction time and error rate were treated statistically with ANOVA ($p < 0.05$ error threshold).

Results and discussion

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. 2). 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.

FIGURE 2



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 (central line: Fz, Cz, Pz and Oz; FP2, F4, F8, C4, T4, P4, T6, O2 and their homologous). The thin line refers to ERPs resulting from congruous sentences and the thick line to those of the incongruous ones.

FIGURE 3

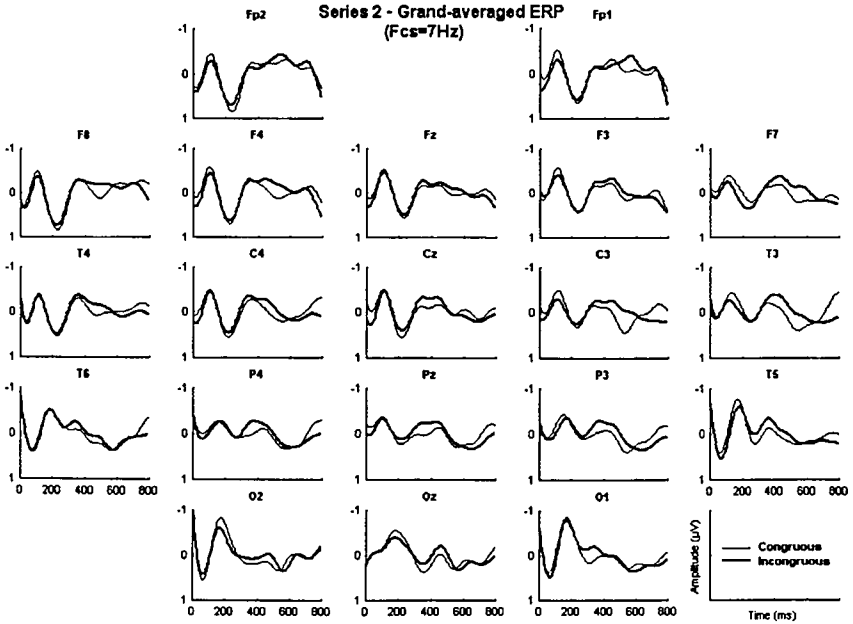


Figure 3 - Grand-average ERP of 25 right-handed subjects submitted to Series 2: 40 congruous and 40 incongruous sentences generated in Brazilian Portuguese and presented to subjects in a pseudo-random manner. Equal number of distractor sentences was also used. ERP in 20 different cortical regions in accordance with the International 10-20 System and with linked-mastoid reference (central line: Fz, Cz, Pz and Oz; FP2, F4, F8, C4, T4, P4, T6, O2 and their homologous). The thin line refers to ERPs resulting from congruous sentences and the thick line to those of the incongruous ones.

Series 2

Series 2 has a more complex processing in which the target verb-noun merge is dependent on context set by a prior verb-noun-phrase merge in a coordinate sentence. It thus yielded a very different waveform from that in Series 1 (Fig. 3). At 100 ms a peak can be noticed. This ERP is the N400 response to the verb-complement merge of the preceding sentence, which was always congruous. Since there is no extra activity that would be connected to an

incongruous reading of such sentences, all waveforms overlapped at this portion of the ERP.

Then, the N400 ERP for the target merge happens at about 300 ms post-trigger word. There is a negative-going wave parietally and centrally (C4, Cz, C3) distributed whose amplitude is lower than that from Series 1. Since context is inversely related with amplitude, the fact that the target merge was dependent on semantic material already elicited in the first previous merge seems to have narrowed the options for the second verb. Thus, the perception of the congruous or incongruous material was facilitated, and amplitude was lower.

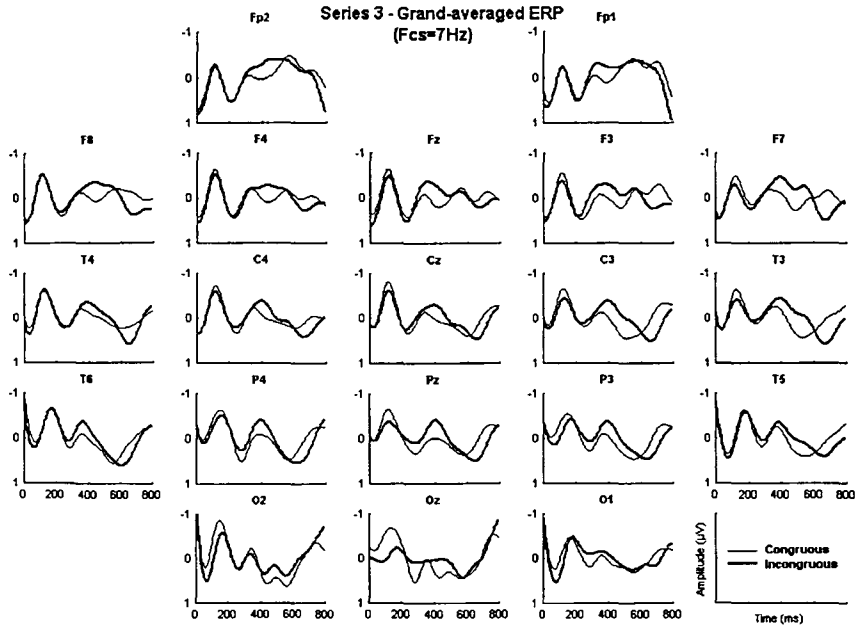
As for latency, the very wide basis of the wave stands for the processing burden of this task. In fact, the average motor reaction time was higher (1.84 ms) than that in Series 1. On the other hand, the judgment error rate was lower (15.6%), probably for the same reasons that prompted the lower amplitude.

Series 3

The results of the incongruous selection in Series 3 show much more activity centrally and parietally distributed than in prior series (Fig. 4). The latency is at 400 ms. Amplitude is the highest in the three series, and so is the amplitude difference between congruous and incongruous. Motor reaction time was the lowest among the three (151 ms), and the judgment error rate was the smallest 10.3%. These findings are in accordance with the sentence processing literature concerning the prominence of the WH-phrase. The appearance of the phrase right at the beginning of the sentence immediately sets out a "search mode" for feature matching since the beginning of processing (De Villiers et al., 1990; De Villiers; Roeper, 1995).

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, and that probably accounts for the lower cortical and motor reaction times and also for the lower judgment error rate. The retrieval mechanism may probably be enhanced by the supporting attention mechanisms triggered by the salience of the WH-phrase in initial position. The very different waveforms related to the three series might be more accurately depicted in the following comparison chart.

FIGURE 4



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 (central line: Fz, Cz, Pz and Oz; FP2, F4, F8, C4, T4, P4, T6, O2 and their homologous). The thin line refers to ERPs resulting from congruous sentences and the thick line to those of the incongruous ones.

TABLE 1

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) How salient is the incongruence?	••	•	•••
Topographic distribution (the activated electrode sites) How diffuse was the activity?	•	••	•••
Error rate of response (mistakes in motor response) How high was the error rate?	•••	••	•

• the least •• the middle ••• the most

Conclusion

The data extracted from this experiment indicate that there are different N400 morphologies related to the different types of merge and their underlying morpho-syntactic sub-processes. This finding is also consistent with premises from current neurophysiology of language models that view language processing as resulting from the interaction of task-specific computations, plausibly involving different neurological subsystems.(Hickok & Poeppel, 2000; Hickok, 2001; Chomsky, 2001; Hauser *et al.*, 2002)

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

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ABSTRACT

This is a neurolinguistic experiment in Brazilian Portuguese, investigating aspects of the merge between verb and complement, in three experimental conditions: Series 1 - simple and local verb-complement merge; Series 2 - verb-complement merge involving inheritance of noun features from a previous sentence; Series 3 - verb and complement merge involving **Wh-questions**. A total of 240 experimental sentences (80 for each condition) and 240 distractor sentences were generated. Using a kinetic presentation protocol, sentences were displayed to each of 25 subjects, while 20 EEG derivations were adequately acquired. 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 (series 2) elicited two peaks in the parietal and central region ERPs. In 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, perhaps involving different neurological subsystems.

Key-words: Event-Related Brain Potentials (ERPs), N400, verb-complement merges.

RESUMO

Trata-se de um experimento neurolingüístico em português do Brasil, investigando aspectos da concatenação entre verbo e complemento, em três condições experimentais: Série 1 - concatenação verbo-complemento simples e local; Série 2 - concatenação verbo-complemento envolvendo herança de traços de nome pertencente a uma sentença anterior; Série 3 - concatenação do verbo e complemento envolvendo perguntas com **sintagmas QU-**. Foram geradas 240 sentenças experimentais (80 para cada condição) e 240 distratores. A partir de um protocolo de apresentação cinética, as sentenças eram exibidas para cada um dos 25 sujeitos enquanto se fazia a aquisição de 20 derivações de EEG. Empregaram-se técnicas de processamento de sinais a fim de estimar-se a ERP individual para cada região anatômica. A série 1, envolvendo computações estritamente locais, resultou em N400s parietais clássicos, enquanto os estímulos relativos à herança nominal (Série 2) geraram dois picos nos ERPs da região central e parietal. Na Série 3, o **deslocamento de QU-** apresentou respostas corticais mais precoces e marcantes. As diferentes morfologias de ERP, resultantes de cada condição, são compatíveis com um modelo no qual o processamento lingüístico resulta de computações tarefa-específicas, talvez envolvendo diferentes subsistemas neurológicos.

Palavras-chave: Potenciais Relacionados a Evento (ERPs), N400, concatenações verbo-complemento.

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