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HOW TO EXAMINE THE P600 USING LANGUAGE THEORY: WHAT ARE THE SYNTACTIC PROCESSES REFLECTED IN THIS COMPONENT?

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ABSTRACT

This article discusses an Event Related Potential known as the P600 with the aim of understanding the syntactic processes elicited by this component. The P600 is found in cases of syntactic violations, ambiguous sentences and in cases of long-distance dependencies. I show that a fine-grained understanding of the syntactic operations involved in the conditions in which the P600 appears can help determining the syntactic processes (and sub-processes) that modulate this component.

KEY WORDS: P600, EEG, Event Related Potentials, sentence processing, cognitive neuroscience of language

INTRODUCTION

This paper aims to discuss how the millisecond temporal resolution of the electroencephalogram (EEG) can be used to study the processes underlying sentence comprehension by discussing an experiment in which EEG was used to examine the processing of ungrammatical, ambiguous and long-distance dependency sentences (WH-movement) (Gouvêa, Phillips, Kazanina & Poeppel, 2010).

Researchers interested in studying cognition must deal with two key concepts regardless of the cognitive system of interest (attention, memory, vision, language). One of them relates to the fact that the processing of information depends on *internal mental representations*. The other is related to the fact that these mental representations undergo *transformations*. Cognitive psychology and cognitive neuroscience are interested in how we manipulate these representations, i.e., they are interested in our mental operations.

Therefore, researchers in these areas should design experiments to test hypotheses about mental operations. If a researcher is interested in studying the mind module responsible for language (and not, for instance, the mind module responsible for face recognition) he/she will, therefore, be interested in the *mental representations and transformations* related to language. For instance, he/she will be interested in how words combine to form phrases and sentences (syntax), or in how linguistic representations interact with the perceptual and motor systems involved in speech production, or in how the conceptual system determines the meaning of these representations.

Language theory is fundamental in this process, as it can offer a detailed description of the mental operations required to build the representation of a sentence. The basic question is how these mental representations are mapped in the brain. At the beginning of the discussions on how to use cognitive neuroscience advances in the study of language, Marantz et al. (2000, p.5) suggest that each mental operation proposed in language theory could correspond to a computation performed by the brain. Therefore, neurolinguistic experiments should take into account the descriptions of mental operations proposed by language theory, for these are the descriptions that will help researchers in the interpretation of experimental results and in determining the brain mechanisms involved in the representation of a sentence.

In this article, I exemplify an attempt to use language theory to explain the computations involved in the processing of particular sentences (ungrammatical, ambiguous and long-distance dependency sentences) using the electroencephalogram (EEG) technique to study an Event Related Potential (ERP) known as the P600. The P600 is a positive voltage variation, a positive peak in the EEG recording, which appears around 600ms after we hear/read an ungrammatical word in a sentence. Recently, the P600 was also found in ambiguous sentences and in cases of long-distance dependency. In the next section, I will discuss in greater detail the cases in which the P600 appears. Next, I will mention a study that examined all occurrences of the P600 in the same experiment using a 'within-subject' design with the purpose of understanding the linguistic computations elicited by the P600 (Gouvêa, Phillips, Kazanina & Poeppel, 2010) .

1. THE P600

The P600 is a positive-going deflection in the ERP response found in the posterior part of the scalp that starts about 500ms after the onset of a word, reaches its maximum amplitude around 600ms, and typically lasts from 500ms to 900ms. The P600 was first found in sentences that presented some syntactic and/or morphological violation (Hagoort, Brown, & Groothusen, 1993).

Several experiments showed that the P600 appears in several types of syntactic violations, including cases of phrase structure violation (Hagoort et al., 1993; Neville et al., 1991; Osterhout & Holcomb, 1992), subcategorization violations (Ainsworth-Darnell, Shulman & Boland, 1998; Osterhout & Holcomb, 1992; Osterhout et al., 1994) and violations of case, number or gender agreement (Coulson, King & Kutas, 1998a; Gunter, Stowe, & Mulder, 1997; Hagoort et al., 1993; Münte, Szentkui , Wieringa, Matzke & Johannes, 1997).

One of the first discussions generated by the P600 'discovery' was related to the specificity of this component. Would the P600 be reflecting processes related only to language processing or more general processes that are normally reflected in the P300? The P300 is a component with a positive peak around 300ms which is related to the probability of occurrence of a stimulus. The more likely the stimulus, the lower the amplitude and latency of the P300. The P300 seems to be related to adaptive systems of the brain that anticipate and react to the discrepancy of events in general (Kutas & Dale, 1997). The P300 is found in visual, auditory and tactile stimuli. More specific proposals relate the P300 to working memory update processes (Donchi & Coles, 1988) and to the transfer of information to consciousness (Picton, 1992). As the P600 is related to violations of the probability of occurrence of a stimulus in the area of syntax, it has been proposed that the P600 is a component of the P300 family (Coulson et al., 1993). However, Osterhout, McKinnon, Bersick, & Corey (1996) showed that syntactic violation effects and probability of stimulus occurrence effects are additive, suggesting that the generators of the syntactic violation effects are different from the generators of the standard P300. Further evidence of the dissociation of the P300 and the P600 comes from patients with lesions in the basal ganglia (Frisch, Kotz, von Crammon, & Friederici, 2003).

Another discussion related to the P600 concerns the fact that the P600 has also been found in cases of anomalies in areas beyond syntax, such as music (Patel, Gibson, Ratner, Besson, & Holcomb, 1998) and mathematical sequences (Martin-Loeches, Casado, Gonzalo de Heras, & Fernandez-Frías, 2004), among others. Thus, the P600 seems to reflect processes that are not specific to language. Patel et al. (1998), for instance, suggest that the P600 reflects general processes of structural integration in the fields of music and language and propose a theory based on psycholinguistics and on the theory of musical cognition to explain the similarity of the P600 found in music and in language. It is not within the scope of this article to discuss the specificity of the P600. In this article, I discuss how different linguistic manipulations may affect the P600 and how language theory can help in understanding the linguistic computations involved in the P600.

Although the P600 has been found primarily in cases of syntactic violations, further studies showed that the P600 is also found in cases of syntactic ambiguity (syntactic garden-path), such as (1a) below (Osterhout et al. 1994). In English, unlike Portuguese, the verb 'charge' may be followed by a direct-object type complement or by a clausal complement. Thus, in (1a) the complement 'the defendant' may be initially analyzed by the parser as a direct-object (*the lawyer charged the defendant...*) or as a complementizer structure (t*he lawyer charged that the defendant...*). In such cases, the parser's preferred reading is the direct object reading (Frazier & Rayner, 1982; Trueswell, Tanenhaus, & Kello, 1993). When processing the auxiliary verb 'was', the parser is forced to reconsider the direct object structure and replace it with a clausal complementizer structure. Osterhout and colleagues observed that when (1a)-type structures are compared to (1b)-type structures, which offer no ambiguity, a P600 appears when processing the auxiliary verb 'was'.

(1a) The lawyer charged the defendant <u>was</u> lying.
(1b) The lawyer charged that the defendant <u>was</u> lying.

Osterhout et al. (1994) also observed that the amplitude of the P600 varies according to the probability of the main verb's lexical bias. The greater the discrepancy found in the main verb, the greater the amplitude of the P600.

Recently, the P600 was also found in sentences that do not exhibit any kind of syntactic anomaly (Kaan, Gibson, & Holcomb, 2000). These sentences contain long-distance dependencies, as they involve a WH- direct object complement ('who' and 'which pop-star') (2a and 2b). In such cases, the WH- complement appears distant from the verb, the position where it receives thematic role and case. These complements can only be interpreted when the verb is processed, hence these structures are known as cases of long-distance dependency. These sentences are considered syntactically complex as they involve working memory resources since the WH- complement must be kept in working memory until it can be interpreted at the point in which the verb is processed.

(2a) Emily wondered who the performer in the concert had imitated for the audience's amusement.

(2b) Emily wondered which pop-star the performer in the concert had imitated for the audience's amusement.

(2c) Emily wondered whether the performer in the concert had imitated a pop star for the audience's amusement.

When sentences (2a) and (2b) were compared to sentences (2c) where the direct object complement appears in its canonical position, a P600 was found in the verb ('imitated') by Kaan and colleagues. In a second experiment, Kaan and colleagues compared the P600 in cases of long-distance dependencies to the P600 in cases of syntactic violations, and found similar responses.

Further work also found a P600 in cases of long-distance dependencies (Fiebach, Schlesewsky & Friederici, 2002; Phillips, Kazanina & Abada, 2005). These works, however, do not directly compare the similarities and differences between the P600 found in cases of syntactic violations, and the P600 found in cases of long-distance dependencies.

Based on the conditions in which the P600 is found, several hypotheses have been suggested to explain which syntactic processes the P600 would be reflecting. Friederici et al. (1995), for instance, suggest that the P600 reflects sentence repair processes, since it is found in ungrammatical sentences. In such cases, the parser would try to repair the sentence to obtain a grammatical sentence. These sentence repair processes would be reflected in the P600. As the P600 is also found in cases of syntactic ambiguity, Friderici et al. (1995) also suggest that the P600 reflects reanalysis processes in which the parser seeks the correct structure for the sentence. It has also been proposed that the P600 reflects more general processes of syntactic integration, since it has been found in sentences that have no ungrammaticality or ambiguity, as in cases of long-distance dependency, where a WH-word must be integrated into the structure in the position where it receives case and thematic role from the verb (Kaan et al. 2000). In this last proposal, the P600 would be reflecting different types of syntactic integration processes under all the conditions in which it is found - ungrammatical, ambiguous and WH- sentences. The difference among these cases would be in terms of syntactic integration difficulty. For instance, in cases involving long-distance dependency, syntactic integration does not pose major problems.

None of these proposals, however, clearly determine which syntactic processes the P600 would be reflecting. It is also unclear which specific syntactic processes would be involved in notions such as repair, reanalysis or syntactic integration.

An attempt to examine the P600 in greater detail is found in Gouvêa, Phillips, Kazanina & Poeppel (2010). In this work, the various conditions where the P600 is found are examined in the same experiment, using the same lexical material, and the results are analyzed taking into account a detailed description of the syntactic processes that would be involved in each condition, in order to more accurately determine the processes that the P600 would be reflecting. This work is examined in the next section.

2. EXEMPLE OF AN EXPERIMENT EXAMINING THE P600

In this experiment for the first time all the conditions that elicit the P600 are examined using the same lexical material. Thus, ungrammatical and ambiguous sentences, as well as sentences involving syntactic integration (WH- dependencies) were presented to the same participants (within-subject design) and variations in the sentence's regions of interest were minimized in order to prevent lexical and contextual differences from compromising variations of the P600. An example of a set of stimulus sentences is shown below.

(3a) Control sentence: The patient met the doctor *while* the nurse with the white dress *showed* the chart during the meeting.

(3b) Ungrammatical sentence: The patient met the doctor *while* the nurse with the white dress *show* the chart during the meeting.

(3c) Sentence with WH-dependency: The patient met the doctor *to whom* the nurse with the white dress *showed* the chart during the meeting.

(3d) Ungrammatical sentence with WH-dependency: The patient met the doctor *to whom* the nurse with the white dress *show* the chart during the meeting.

(3e) Ambiguous sentence: The patient met the doctor *and* the nurse with the white dress *showed* the chart during the meeting.

As can be seen in the above examples, the critical word is always the same verb (*showed* in 3a-e), and the six words preceding the verb and the five words following the verb are identical so as to prevent variations in the P600 due to lexical differences.

In the control sentence (3a) the verb in the region of interest appears in the past tense and in the ungrammatical sentences (3b, d) the verb appears in the present tense, not agreeing in tense with the first verb of the sentence, and therefore causing an ungrammatical verb agreement. In the WH-dependency sentence (3c), upon processing the verb in the region of interest, the WH-word can be integrated into the structure and the dependency between the WH- and the verb can be completed. In the ambiguous sentence (3e), before processing the verb in the region of interest, the sentence's preferred reading is one in which the noun phrases are part of a coordinated noun phrase (the patient met the doctor and the nurse with the white dress). Previous studies show that this is the preferred reading for these constructions (Frazier, 1985; Frazier & Clifton, 1996). At the point of processing the verb, however, the structure's initial analysis must be reviewed in favor of an analysis with coordinated sentences.

A total of 180 sets of five sentences were created from 90 different verbs. All verbs allowed a direct object complement (3a,b,e) and an optional indirect object complement (3 c, d) so that all sentences were grammatical from the verb's semantic point of view. Five lists of stimuli were created and only one list was presented to the participants. Thus, each participant saw only one sentence from each of the 180 sets; i.e., 36 samples per condition (latin-square design). The stimulus sentences were randomly introduced with 360 distractor sentences. The experiment involved two sessions and half the stimuli were introduced in each session.

The EEG was recorded with 30 Ag/Cl (silver chloride) electrodes mounted on an elastic cap (Electro CAP International). Movements, such as eye blinkings were monitored by two electrodes placed in the corner of the eyes (horizontal movements) and by two electrodes placed above and below the left eye (vertical movements). The left mastoid electrode was used as reference and impedances were kept below 5 KΩ.

Sentences were presented visually word by word in the middle of a computer screen. Each word remained on the screen for 500ms (300ms per word, 200ms blank screen) (for more details on the experiment's methodology and procedures, see Gouvêa et al. (2010)) .

For the analysis six pairs of electrodes were chosen: left anterior (FT7, F3, FC3), midline anterior (FZ, FCZ, CZ), right anterior (F4, FC4, FT8), left posterior (TP7, P3, CP3) midline posterior (PZ, CPZ, OZ) and right posterior (P4, CP4, TP8). This choice enables the comparison of the P600's scalp distribution or, in other words, it enables determining whether the signal originates from the same region of the scalp. If the signal has the same spatial distribution under different conditions, there is indication that the linguistic processes that the P600 reflects are similar. If scalp distribution is different, there is evidence that the P600 is reflecting different linguistic processes.

Different time intervals were examined: 0-300ms, 300-500ms, 500-700ms, 700-900ms, 900-1100ms, in order to determine the similarities and differences in the component's latency. If the P600 shows the same latency under different conditions, there is indication that the processes that took place within that time interval are similar; if the latency is different, there is indication that the processes are different.

These comparisons, in terms of scalp distribution and latency enable us to examine the P600 in detail and to determine whether this component is the same under the various conditions in which it appears, or whether the P600 reflects different syntactic (sub-) processes.

The results of this experiment showed that all conditions presented a P600 when compared to the control condition. Thus, ungrammatical sentences, WH- dependency sentences and ambiguous sentences elicited a P600 when compared to the control sentence. However, variations in the scalp distribution and latency of the component have also been found. In the 300-500ms inteval, ungrammatical conditions presented an anterior negativity, the WH-dependency condition presented an anterior positivity, and the ambiguous condition presented a posterior positivity. In the 500-700ms interval, all conditions presented a posterior positivity characteristic of the P600. The main difference among the conditions concerns the duration of the posterior positivity. In the WH-dependency condition the posterior positivity appeared only in the 500-700ms interval, in the syntactic ambiguous conditions, and in the ungrammatical sentences the posterior positivity remained until the 1100-1300ms interval. The table below summarizes these results. For further details regarding the statistical analysis of this experiment, see Gouvêa et al. (2010).

Condition	0-300ms	300-500ms	500-700ms	700-900ms	900-1100ms	1100-1300ms
WH-dependencies	_	Anterior positivity	Posterior positivity	_	_	_
Ungrammatical sentences	_	Anterior negativity	Posterior positivity	Posterior positivity	Posterior positivity	Posterior positivity
Ambiguous Sentences	_	Posterior positivity	Posterior positivity	Posterior positivity	Posterior positivity	Posterior positivity

Under controlled conditions that minimized lexical and contextual differences that could bias the distribution of the P600, we noticed that all three conditions (ungrammatical, ambiguous, and WH-dependency sentences) presented a P600. With regards to the differences in the component's latency, Gouvêa et al. (2010) suggest that when the P600 occurs in different latencies, it could be reflecting differences in time required to complete the different syntactic processes elicited by the P600.

For instance, the differences in the P600 latency in the ungrammatical (onset 500-700ms) and garden-path (onset 300-500ms) conditions can be explained by examining the syntactic recovery processes involved in these sentences. In garden-path sentences, the introduction of the verb triggers the search for a subject Noun Phrase (NP) that agrees with the verb. When the proper subject NP is found, the syntactic structure can be build and a P600 is elicited. In ungrammatical sentences, in contrast, the incorrect verb agreement may have delayed the recovery of the subject NP, since the parser may have first looked for a NP that would agree with the verb agreement features.

In the WH-dependency sentences a shorter positivity (500-700ms) was found when compared to ungrammatical and garden-path sentences, as well as with regards to the positivity found in Kaan et al. (2000). This difference can be explained on the basis of the information the WH-phrase carries. In this study, participants read dative WH-phrases (to whom); thus, WH-phrases preceded by a preposition. This preposition assigns case and thematic role to the WH-word at the moment the WH-word is read. Thus, when the verb is processed the WH-phrase must be integrated into the verb as its complement, but case and thematic role have already been checked. In other studies in which a P600 was found in WH-phrases, in addition to the integration of the WH-word as a complement of the verb, case and thematic role had also to be checked when the verb was processed. Thus, the use of dative WH-phrases reduced the number of structural relations to be build at the moment of processing the verb, which led to a shorter duration of the P600 in relation to other studies.

WH-dependency sentences also showed an anterior positivity in the 300-500ms interval that had not been found in previous studies (Kaan et al., 2000 , Phillips et al., 2005). This difference can be explained taking into account the different operations required in the processing of relative clauses. In the study under discussion, the PP argument (to whom) forms a semantic relationship with the previous argument of the relative clause (the doctor to whom the nurse showed...) while in other studies this semantic relationship is formed at the verb (the patient asked to which doctor the nurse showed...) . Thus, in the relative clauses used by Gouvêa et al. (2010), WH-phrases form a syntactic dependency with the PP argument, but a semantic dependency with the previous argument (the doctor), while in other studies both syntactic and semantic dependencies are established at the verb. Gouvêa et al. (2010) suggest that this is just one of the possibilities related to the different properties of relative clauses used in different studies that may explain this anterior positivity.

With regards to the anterior negativity found in ungrammatical sentences, this negativity was also found in other studies that presented morphosyntactic violations. Gouvêa et al. (2010) suggest that an anterior negativity (AN) is found when a specific morphological feature is expected because of a particular context or because of a marked feature in subject position (e.g., the feature [+ plural]) and, therefore, reflects recovery processes of a morphological mismatch.

Thus, the P600 reflects the attempt to create or repair syntactic relations, both in grammatical sentences (WH-dependency) and in ungrammatical and ambiguous sentences, and the onset of the P600 would be related to the time required to begin structure building. The amplitude and duration of the P600 would be related to the number of syntactic operations to be build. In the case of subject and verb agreement violations, the onset of the P600 reflects the time required to recognize and analyze the verb, access the morphological features of the subject NP, and detect the mismatch. Thus, the P600 reflects unsuccessful review processes that start after the morphological mismatch was detected.

Since the P600 may have its onset, duration and scalp distribution affected by the different conditions presented, we may conclude that the P600 is affected by different syntactic sub-processes. Thus, the P600 should be understood in terms of which operations are required in the retrieval and construction (or 'deconstruction') of the syntactic structure. The latency of the P600 would be reflecting the time required to retrieve the elements that participate in a structural relation and the component's amplitude and duration would be related to the construction (and 'deconstruction') of syntactic relations.

Thus, one can conclude that a detailed analysis of the syntactic operations involved in the conditions where the P600 appears may help the understanding of the processes that modulate this component. As suggested in this article's introduction, the descriptions of the mental operations proposed in language theory can assist in the interpretation of experimental results and in determining the mechanisms involved in sentence representation. It is the detailed understanding of these operations that will help the identification of the computations reflected in the electrophysiology of syntactic processing.

COMO EXAMINAR O P600 USANDO A TEORIA LINGUÍSTICA: QUAIS OS PROCESSOS SINTÁTICOS REFLETIDOS NESSE COMPONENTE?

RESUMO

Nesse artigo discuto o Potential Evocado conhecido como P600 com o objetivo de entender quais os processos sintáticos que estão representados nesse componente. O P600 foi encontrado em casos de violações sintáticas, sentenças ambíguas e de dependência de longa distância. Mostro que uma observação pormenorizada das operações sintáticas envolvidas nas condições aonde o P600 aparece pode ajudar no entendimento dos processos (e sub-processos) sintáticos que modulam esse componente.

PALAVRAS-CHAVE:

P600, EEG, Potenciais Evocados, processamento de sentença, neurociência cognitiva da linguagem

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