CURRENT ADVANCES IN NEUROLINGUISTICS: THE USE OF ELECTROENCEPHALOGRAPHY (EEG) TO STUDY LANGUAGE

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ABSTRACT

This article discusses how cognitive neuroscience techniques are used to study language with the aim of showing its advantages to neurolinguistics. It focuses on Electroencephalography (EEG) because of the great temporal resolution of this technique. The concept of Event Related Potentials (ERPs) is explained and some ERPs found in sentence processing experiments are discussed in order to show how the understanding of the linguistic operations elicited by these ERPs can be useful to explain how these operations are implemented on-line and to validate psycholinguistics models.

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

Over the past 30 years cognitive neuroscience techniques have become widely used in language studies with the aim of answering questions related to the mapping of language in the brain. In addition to being non- invasive, these techniques can aid in the understanding of the regions responsible for language processing in the brain, as well as in the understanding of which operations are performed on-line by the brain in certain time intervals. In this article, I discuss recent advances in the cognitive neuroscience of language. In the first section, I briefly describe how neurolinguistics has benefited from these advances, and I introduce the techniques used in cognitive neuroscience, emphasizing their advantages and disadvantages in the study of language. In the second section, I more specifically discuss the use of Electroencephalography (EEG) in language experiments, the concept of Event Related Potentials (ERPs) and I mention the most common Event Related Potentials found in language studies. The aim is to show how the understanding of the linguistic processes elicited by Event Related Potentials may reveal information about on-line language processing and be useful to psycholinguistic models that attempt to elucidate the processes involved in language comprehension.

1. RECENT ADVANCES IN COGNITIVE NEUROSCIENCE

Until recently the examination of how mental operations related to language are mapped in the brain was restricted to the study of language deficits resulting from brain damage (aphasias), and to electrical stimulation.

Aphasias are deficits in speech production and/or language comprehension that result usually from strokes or cerebrovascular accidents (CVAs). The first scholars to diagnose cases of aphasia were Paul Broca, in 1861, and Carl Wernicke, in 1876. Broca discovered that injuries in the front part of the brain, more specifically on the back of the left inferior frontal gyrus, now known as Broca's area, caused speech production problems in patients. Thus, roughly speaking, patients with Broca's aphasia have no trouble understanding what they are told, but they have trouble expressing themselves. Wernicke discovered that damages in the posterior region of the superior temporal gyrus, caused problems opposite to those of Broca's aphasia. These patients had no problems expressing themselves, being even verbose, but had serious problems understanding what they were told. However, more recent studies (for a review of these studies see Caplan, 1992, and Grodzinsky, 1990) show that Broca's aphasics have problems comprehending certain types of structures, such as passive sentences and object relative clauses, among others. The study of aphasic patients, however, has severe limitations. One of them concerns the fact that brain lesions usually do not uniformly affect the same brain area, and therefore make it difficult to determine in detail the role of each area in language processing. At the same time, lesions in a specific area of the brain do not ensure the presence of a particular type of deficit. For instance, lesions in Broca's area do not ensure the presence of speech production deficits (Broca's aphasia) (Dronkers, 2000).

Electrical stimulation studies are normally done in epileptic patients, where surgery intervention is indicated in order to remove the epileptic tissue and relieve the effects of seizures. During surgery, in order to avoid future speech problems, there is an attempt to locate brain areas responsible for language in the patient. This is done through electrical stimulation, where electrodes placed on the patient's scalp are used to send a small electrical current that momentarily interrupts the activity in this area. The purpose of this type of intervention is to access the role played by this group of neurons in speech. When a group of neurons is stimulated, the patient is asked, for instance, to name an object that is shown to him/her in a picture. If the patient fails to name the object or makes mistakes in naming it, one deduces that the stimulated region is related to language processing in this patient (for further details see Calvin & Ojemann, 1994). This type of assessment clearly presents deep limitations, as it reduces language processing to the simple task of naming a word, and does not evaluate the complexity of language processing.

In the 80's and 90's, new techniques such as positron emission tomography (PET), functional magnetic resonance imaging (fMRI), electroencephalography (EEG) and magnetic encephalography (MEG) appear as new tools for the study of human brain activity in healthy individuals .

PET and fMRI are hemodynamic methods, as they relate neuronal activity to the increase of blood volume in the brain. Differences in activity for a population of neurons would be related to differences in blood supply, i.e., the increase in neuronal activity would result in increased blood volume and vice versa. In a typical experiment using PET or fMRI, images are acquired from at least two experimental conditions that in theory are different with respect to a cognitive operation. For instance, passively

seeing a word and naming it out loud. Regions activated under one condition are subtracted from regions activated under another condition (subtraction method) and the region(s) that remain(s) activated following this subtraction would correspond to the regions responsible for the cognitive operation in question.

Hemodynamic methods are very efficient in terms of spatial resolution, i.e., they are very good for telling where the activity takes place in the brain, generating images whose spatial resolution is around 3mm. Nevertheless, they have the disadvantage of the hemodynamic gap. This gap concerns the time difference, in seconds, between the neuronal activity and the increase in blood volume. In other words, although the neuronal activity results in an increase of blood flow in the region where the activity takes place, this increase only occurs a few seconds after the brain activity took place. This "delay" in the arrival of blood creates difficulties in establishing which effects are specifically related to the stimulus.

Electrophysiological methods such as EEG and MEG, are also common in cognitive neuroscience . These devices directly measure the electrical activity produced by a population of neurons. In the case of EEG, an electric field is measured, and in the case of MEG, a magnetic field is measured. Both EEG and MEG have an excellent temporal resolution (milliseconds). EEG, however, does not present a good spatial resolution due to a problem that scientists call the "inverse problem". The "inverse problem" refers to the fact that it is impossible to determine the distribution of an electric charge when measured at the surface of a sphere (the brain, for instance). This problem occurs because an infinite number of possible options for the distribution of the electric charge inside the sphere may generate the same pattern on the surface of the sphere. To solve this problem, scientists have tried to use sophisticated modeling techniques based on brain structure and brain tissue, as well as on neurons electrical structure. MEG has better spatial resolution than EEG, because unlike electric fields, magnetic fields are not distorted as they pass through the brain and scalp. In spite of presenting a good spatial and temporal resolution, MEG also presents disadvantages, such as the fact that it only detects magnetic fields oriented in parallel to the surface of the skull (neurons in cerebral sulcus). Another disadvantage of MEG is the price of the equipment, which costs between 2 and 3 million dollars.

As we have seen, PET and fMRI are good techniques for studying where certain processes take place, and can therefore help in locating the brain activity related to a particular mental event (spatial dimension of the brain activity). However, the observation that a mental activity is associated with a particular area does not solve the problem of how the brain works or how computations are carried out. To understand how computations are carried out by the brain, it is necessary to study the representations and transformations of information on-line. EEG and MEG are appropriate techniques for this type of study, as they reflect the temporal dimension of brain activity. Thus, these techniques may be useful in determining which linguistic operations (computations) take place at which time intervals during, for instance, the processing of a sentence.

In the next section, I will explain the EEG technique in greater detail, and illustrate how this technique may be used to study sentence processing.

2. THE USE OF ELECTROENCEPHALOGRAPHY IN COGNITIVE STUDIES

In an experiment using electroencephalography (EEG), several electrodes are placed on the scalp of a person in order to measure the electrical activity of a population of neurons. Since the electrical signals sent by the brain are very small, they are amplified through an amplifier. The EEG recordings show voltage variations on the time axis. These voltage variations correspond to the difference of potential between the signal of a particular electrode in comparison with the signal of an electrode used as reference.

As researchers of a particular cognitive module (e.g., language), we are interested in how the brain activity is modulated in a particular task (e.g., reading a word, hearing a syllable). In this sense, the continuous EEG recording of brain activity is not sufficient to clarify the processes related to a specific task. In order for the EEG recording to reflect the brain activity related to a specific task, it is necessary that this recording be "time-locked" to a stimulus so that it reflects the exact moment the brain receives the stimulus. This allows the recording to reveal voltage variations that are specifically related to the brain's response to this stimulus. These voltage variations related to a specific stimulus are called Event-Related Potentials (or ERPs).

However, an Event-Related Potential (ERP) is an extremely small signal "within" the continuous EEG recording. In order to obtain an Event-Related Potential, it is necessary to present a series of stimuli to the experiment's participant (30 to 100 for each condition) and examine these stimuli in several participants. Next, the average signal is calculated in order to obtain an Event-Related Potential related to the event. The Event-Related Potential is a wave with a certain amplitude and latency related to a particular stimulus. For instance, 100ms after hearing a word, we obtain a negative potential called N1, followed by a positive potential, around 200ms, known as P2. Event-Related Potentials are, therefore, positive or negative peaks in the EEG recordings with specific features in terms of scalp distribution and latency that can be related to specific experimental manipulations.

Event-Related Potentials provide an accurate time recording of the neuronal activity, and may, therefore, be useful in the study of language processing. Thus, the differences between Event-Related Potentials derived from different conditions (e.g., grammatical sentence versus ungrammatical sentence) represent differences in neuronal activity related to these conditions.

2.1. Event-Related Potentials in language

In linguistic experiments using EEG, three Event-Related Potentials have been widely studied. One of them relates to semantic violations, and is known as the N400 since it is a negative potential that occurs 400ms after we hear or read a word in a sentence that presents a semantic incongruity, as in example (1a) below, where the word socks does not make sense in the semantic context of the sentence (Kutas & Hillyard, 1980). The expectation in the sentence below is to find a word that designates something edible and that can be spread on bread, like "butter" in (1b) .

(1a) *He spread <u>socks</u> on the warm bread.
(1b) He spread <u>butter</u> on the warm bread.

When sentences that present a semantic violation, such as (1a) are compared to sentences that present no semantic violations as (1b), the N400 appears. Later studies showed that the N400's amplitude is inversely proportional to the semantic fit of the word that is processed (Hagoort & Brown, 1994; Kutas & Hillyard, 1984; Kutas & Van Petten, 1994). In other words, the more "weird" the word is for the semantic context of the sentence, the greater the amplitude of the N400 will be. Currently, the N400 is interpreted as a component associated with processes of semantic integration of a word into a sentence or discourse (Chwilla, Brown, & Hagoort, 1995; for a review of the N400: Kutas & Federmeier, 2000; Lau, Phillips and Poeppel, 2008; Osterhout & Holcomb, 1995). Recently, the N400 has also been studied in Brazilian Portuguese sentences with different types of semantic and discourse anomaly (França et al . 2004).

Other Event-Related Potentials commonly found in language experiments are the LAN, ELAN and the P600. The LAN, or left anterior negativity, is a negative potential located in the left anterior region of the scalp. This ERP occurs around 300-500ms after we hear an ungrammatical stimulus that presents a violation of syntactic subcategorization information (Osterhout & Holcomb, 1993) or agreement violations (Coulson , King, & Kutas, 1998; Friederici et al., 1993; Gunter , Friederici, & Schriefers, 2000; Hagoort, Wassenaar, & Brown, 2003), as shown below:

    (2) *Every week they <u>cuts</u> grass.

In cases of phrase structure violations, an ERP with a similar location, but with an early latency (between 125-250ms), has been elicited in some studies (Friederici et al., 1993; Hahne & Friederici, 1999; Lau, Stroud, Plesch, & Phillips, 2006; Neville et al., 1991). Because of its latency, this ERP is known as ELAN (Early Left Anterior Negativity).

The P600 is a positive potential which starts around 500 ms after the onset of a word, has its maximum amplitude around 600ms, and typically lasts from 500ms to 900ms. The P600 was first found in sentences that presented some ungrammaticality, such as in (3a), where the subject does not agree in number with the verb (Hagoort et al. 1993). When ungrammatical sentences, such as (3a) are compared to grammatical sentences, such as (3b), the P600 appears.

    (3a) *The stubborn child <u>are</u> throwing the toy on the floor.
    (3b) The stubborn child <u>is</u> throwing the toy on the floor.

In such cases, a LAN followed by a P600 is elicited. Various types of ungrammaticality may elicit the P600, such as, for instance, 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 et al., 1998a; Gunter, Stowe, & Mulder, 1997, Hagoort et al., 1993; Münte, Szentkui , Wieringa , Matzke & Johannes, 1997).

Further work showed that the P600 is also found in cases where there is no syntactic ungrammaticality, such as in cases of syntactic ambiguity (Gouvêa, Phillips, Kazanina & Poeppel, 2010; Osterhout et al. 1994), or in cases of long-distance dependency (Gouvêa et al., 2010; Kaan et al., 2000). Thus, the P600 has been interpreted as an ERP related to repair processes and sentence reanalysis, as well as to processes of syntactic integration (for a review, see Gouvêa et al., 2010).

Examination of these ERPs reveals important temporal information related to language processing. Semantic violations take place 400ms after we hear a deviant word, and syntactic violations may occur much earlier, around 300ms or even 125ms, depending upon the type of violation. This type of temporal information led Friederici (1995) to propose a three stages sentence comprehension model based on psycholinguistic models (Frazier 1987, Frazier & Rayner 1982). In the first stage, the parser incrementally determines the structure of the sentence by only taking phrase structure information into account. This stage is reflected in the ELAN that was found in cases of phrase structure violation. In the second stage, the processing of lexical-semantic information reflected in the N400 and the processing of syntactic information, such as subcategorization and agreement morphology reflected in the LAN occur. In the third stage, lexical and syntactic information are mapped together, and in cases where such information cannot be mapped, reanalysis and repair processes occur, reflected in the P600.

Other models have also been proposed to explain the processes reflected in these language related ERPs (Friederici & Weissenborn, 2007; Hagoort, 2003). Vos, Gunter, Kolk, & Mulder (2001), for instance, noticed that some experiments containing sentences with no morphological abnormalities do not elicit LANs. To account for these differences, Friederici & Weissenborn, (2007) propose an explanation based on the functional importance of agreement morphology for the grammatical relations of some languages. However, this explanation does not account, for instance, for data from an experiment in Hindi, a language with a very rich subject, number and gender agreement morphology that has not presented a LAN in cases of agreement violation (Nevins et al., 2007). Gouvêa et al. (2010) suggests that the LAN does not reflect morphosyntactic violations in general, but cases in which a specific morphological feature is expected because of a particular context, or because of a marked feature in subject position (e.g. feature [+ plural].) Thus, the LAN would not be linked to processes of creating new syntactic relations, but would be reflecting the selective use of structural predictions in parsing.

Thus, the temporal resolution of EEG may be very useful to evaluate psycholinguistic models. The detailed examination of ERPs may lead to a better understanding of which linguistic operations occur at certain time intervals. Gouvêa et al. (2010), for instance, examine the P600 and suggest that concepts, such as repair, reanalysis or syntactic integration are very general concepts for explaining the processes reflected in the P600. A more detailed examination of the operations reflected in the P600 may generate a better understanding of these syntactic operations on-line.

3. CONCLUSIONS

The use of EEG in language studies presents some advantages when compared to other techniques generally used in psycholinguistics (e.g., self-paced reading, eye- tracker), which are based on reading time and performance data. EEG provides on-line data on language processing using non-invasive recordings with a temporal resolution of milliseconds. This temporal resolution may be very useful in determining which processes are performed at certain time intervals. Thus, EEG may also contribute towards the empirical assessment of different psycholinguistic models and cooperate in developing more accurate models that take linguistic processes into account on the time axis, allowing more precise observations about the operations involved in language processing.

Thus, the millisecond temporal resolution of EEG is an important tool to help explain the processes underlying syntactic processing and in the assessment of psycholinguistic models.

The impact that the use of cognitive neuroscience techniques has had in the studies of different cognitive modules is undeniable. The use of these techniques in language studies can only contribute to linguistic theory. Hornstein (2009), in agreement with Poeppel &Monahan (2008), argues that the operations proposed by the grammar need to be implementable in terms of brain circuits. Although techniques such as EEG may not precisely answer which neurons are implementing which syntactic operations, these techniques can be of great help in understanding the syntactic operations on the time axis and are a hope for improving our understanding of how the brain decodes computations related to language.

AVANÇOS RECENTES DA NEUROLINGUÍSTICA: O USO DO ELECTROENCEFALOGRAMA (EEG) NO ESTUDO DA LINGUAGEM

ABSTRACT
Neste artigo discuto como técnicas da neurociência cognitiva tem sido usadas nos estudos da linguagem com o objetivo de mostrar suas vantagens para a neurolinguística. Atenção particular é dada ao Electroencefalograma (EEG) devido a qualidade da resolução temporal de seus registros. Também explico o conceito de Potencial Evocado (PE/ERPs) e discuto alguns dos PEs encontrados em experimentos de processamento de sentenças com o objetivo de mostrar como o entendimento das operações linguísticas elicitadas pelos Potenciais Evocados pode ser útil para explicar como essas operações são implementadas on-line e para a validação de modelos psicolinguísticos.

PALAVRAS-CHAVE: EEG, Potenciais Evocados, processamento de sentença, neurociência cognitiva da linguagem

REFERENCES:

Ainsworth-Darnell, K., Shulman, H., & Boland, J. (1998). Dissociating brain responses to syntactic and semantic anomalies: evidence from event-related potentials. *Journal of Memory and Language*, 38, 112_130.

Calvin e Ojemann (1994). *Conversations with Neil's brain*. Addison-Wesley Publisher.

Caplan (1992). *Language: structure, processing and disorders*. MIT Press, Cambridge, MA.

Chwilla, D.J., Brown, C.M. & Hagoort, P. (1995). The N400 as a function of the level of processing. *Psychophysiology*, 32, 274-285.

Coulson, S., King, J. W. & Kutas, M. (1998). Expect the unexpected: Event-related brain response to morphosyntactic violations. *Language and Cognitive Processes*, 13, 21-58.

Dronkers, N.F. (2000). The pursuit of brain-language relationships. *Brain and Language*, 71(1):59-61.

Frazier, L. (1978). On comprehending sentences: Syntactic parsing strategies. Doctoral Dissertation, University of Connecticut.

Frazier, L. & Rayner, K. (1982). Making and correcting errors during sentence comprehension: Eye movements in the analysis of structurally ambiguous sentences. *Cognitive Psychology*, 14, 178-210.

Friederici, A.D. (1995). The time course of syntactic activation during language processing: a model based on neurological and neurophysiological data. *Brain and Language*, 50, 259-281.

Friederici, A.D., Pfeifer, E. & Hahne, A. (1993). Event-related brain potentials during natural speech processing: Effects of semantic, morphological and syntactic violations. *Cognitive Brain Research*, 1, 183-192.

Friederici, A. D., & Weissenborn, J. (2007). Mapping sentence form onto meaning: The syntaxsemantic interface. *Brain Research*, 1146, 50_58.

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

Grodzinsky, Y. (1990). Theoretical Perspectives on Language Deficits. Cambridge, MA: MIT Press.

Gunter, T.C., Friederici, A.D. & Schriefers, H. (2000). Syntactic gender and semantic expectancy: ERPs reveal early autonomy and late interaction. *Journal of Cognitive Neuroscience*, 12, 556-568.

Gunter, T.C., Stowe, L.A. & Mulder, G. (1997). When syntax meets semantics. *Psychophysiology*, 34, 660-676

Hagoort, P., Brown, C.M. & Groothusen, J. (1993). The syntactic positive shift as an ERP measure of syntactic processing. *Language and Cognitive Processes*, 8, 439-483.

Hagoort, P., & Brown, C. M. (1994). Brain responses to lexical ambiguity resolution and parsing. In C. Clifton Jr., L. Frazier, & K. Rayner (Eds.), *Perspectives on sentence processing* (pp. 45_80). Mahwah, NJ: Lawrence Erlbaum Associates, Inc.

Hagoort, P., Wassenaar, M. & Brown, C. (2003). Syntax-related ERP-effects in Dutch. *Cognitive Brain Research*, 16, 38-50.

Hahne, A., & Friederici, A. D. (1999). Electrophysiological evidence for two steps in syntactic analysis: Early automatic and late controlled processes. *Journal of Cognitive Neuroscience*, 11, 193_204.

Hornstein (2009). *A Theory of syntax*. Minimal operations and Universal Grammar. Cambridge University Press.

França, A. I. ; Cagy, M.; Lemle, M.; Constant, P.; Infantosi, A.F.C. (2004). Discriminating among different types of verb-complement merge in Brazilian Portuguese: an ERP study of morpho-syntactic sub-processes. *Journal of Neurolinguistics*, v. 17, n. 6, p. 425-437.

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

Kutas, M. & Federmeier, K.D. (2000). Electrophysiology reveals semantic memory use in language comprehension. *Trends in Cognitive Sciences*, vol. 4 (12), 463-470.

Kutas, M. & Hillyard, S.A. (1980). Reading senseless sentences: Brain potentials reflect semantic anomaly. *Science*, 207, 203-205.

Kutas, M., & Hillyard, S. A. (1984). Brain potentials during reading reflect word expectancy and semantic association. *Nature*, 307, 161_163.

Kutas, M., & van Petten, C. (1994). Psycholinguistics electrified: Event-related brain potential investigations. In M. A. Gernsbacher (Ed.), *Handbook of psycholinguistics* (pp. 88_143). New York: Academic Press.

Lau, E., Phillips, C., & Poeppel, D. (2008). A cortical network for semantics: (de)constructing the N400. *Nature Reviews Neuroscience*, 9, 920_933.

Lau, E., Stroud, C., Plesch, S., & Phillips, C. (2006). The role of structural prediction in rapid syntactic analysis. *Brain and Language*, 98, 74_88.

Münte, T.F., Szentkui, A., Wieringa, B.M., Matzke, M. & Johannes, S. (1997). Human brain potentials to reading syntactic errors in sentences of different complexity. *Neuroscience Letters*, 235, 105-108.

Neville, H.J., Nicol, J.L., Barss, A., Forster, K.I. & Garrett, M.F. (1991). Syntactically based sentence processing classes: Evidence from event-related brain potentials. *Journal of cognitive Neuroscience*, 3, 151-165.

Nevins, A. I., Dillon, B. W., Malhotra, S., & Phillips, C. (2007). The role of feature-number and feature-type in processing Hindi verb agreement violations. *Brain Research*, 1164, 81_94.

Osterhout, L. & Holcomb, P.J. (1992). Event-related brain potentials elicited by syntactic anomaly. *Journal of Memory and Language*, 31, 785-806.

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, 413-438.

Osterhout, L. & Holcomb, P.J. (1995). Event-related potentials and language comprehension. In *Electrophysiology of mind* (eds. M.D. Rugg and M.G.H. Coles), 171-215. Oxford University press.

Osterhout, L. Holcomb, P. J. & Swinney, D.A. (1994) Brain potentials elicited by garden-path sentences: Evidence of the application of verb information during parsing. *Journal of Experimental Psychology: Learning, Memory and Cognition*, 20, 786-803.

Poeppel, D., & Monahan, P.J. (2008). Speech perception: Cognitive foundations and cortical implementation. *Current Directions in Psychological Science, 17*, 80-85.

Vos, S. H., Gunter, T. C., Kolk, H. H. J., & Mulder, G. (2001). Working memory constraints on syntactic processing: An electrophysiological investigation. *Psychophysiology*, 38 41-63.