THE AMPLE SEMANTIC SCOPE OF MINUTE LANGUAGE COMPUTATIONS: AN ERP STUDY OF WORDS IN PORTUGUESE

O AMPLO ESCOPO SEMÂNTICO DE COMPUTAÇÕES DIMINUTAS: UM ESTUDO DE ERP EM PALAVRAS DO PORTUGUÊS

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ABSTRACT: The semantic relationship between two separate words in the same semantic realm, e.g. vegetables, is often viewed as merely associative. Thus, if matched by frequency in a priming paradigm, a prime such as potato should help the activation of a target such as carrot, the same way that carrot may trigger the activation of potato. Direction is not expected to count here. Contrastingly, with words in a sentence there is hierarchical structure to which direction does count: Joan kissed Billy is different from Billy kissed Joan. This study aims at testing the hypothesis that the semantic relationship in a priming paradigm might be mediated by an unstated syntactic structure that pops up spontaneously during priming, making separate words behave very similarly to words in a phrase. Five conditions of word pairs were tested including two in which the words were identical, but prime and target were presented in opposite directions. If the hypothesis about syntactic mediation were right, there should be a difference between the N400 latencies of these two directionally

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opposite conditions. In fact, ERP analysis revealed that direction did play a role in latency here attributed to structural factors.
KEYWORDS: Priming. Directionality. Syntactic nesting. ERP.

RESUMO: A relação semântica entre duas palavras soltas de um mesmo campo semântico, por exemplo, legumes, é muitas vezes vista como meramente associativa. Assim, se a frequência for controlada, em um paradigma de priming, um prime como batata deve ajudar a ativação de um alvo como cenoura, da mesma forma que cenoura pode promover a ativação de batata. Não se espera achar efeitos de direcionalidade. Por outro lado, as palavras em uma frase estão sujeitas a uma estrutura sintática hierárquica para a qual a direção faz diferença: Joana beijou Beto é diferente de Beto beijou Joana. Este estudo tem como objetivo testar a hipótese de que a relação semântica entre certas palavras pode ser mediada por uma estrutura sintática que aparece espontaneamente durante o priming, fazendo com que as palavras soltas se comportem de forma muito semelhante às palavras em uma frase. Cinco condições de pares de palavras foram testados, incluindo duas em que as palavras do par eram idênticas, mas o prime e o alvo foram apresentados em direções opostas. Se a hipótese sobre a mediação sintática estivesse certa, deveria haver uma diferença entre as latências do N400 em relação a estas duas condições opostas direcionalmente. De fato, a análise dos ERPs revelou que a direção desempenhou um papel na latência, atribuído aqui a fatores estruturais.
PALAVRAS-CHAVE: Priming. Direcionalidade. Estrutura sintática subjacente, ERP.

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1. INTRODUCTION

Natural language users are hardly challenged when they understand and compute the meanings from words to sentences. In fact, except for a few contingencies, human beings are made to immediately understand an infinite set of complex expressions in their native language. Nevertheless, creating these meanings draws upon complex computation of various types of source information such as syntactic, semantic, pragmatic, as well as world knowledge. Exactly how we are able to construct an interpretation of the linguistic input and, when and what information is combined is an inquiry that has been extensively explored over many decades.

Part of the answer to this question is the fundamental notion that *the meaning of an expression is a function of the meaning of its parts and the way they are syntactically combined* (Frege's Principle of Compositionality of Meaning, from 1892, apud JANSSEN, 2001:115)

To go beyond this principle, over the past few decades, research in psycholinguists managed to unpack some of the mechanisms involved in the online lexical access and sentence processing. But still, there is a lot to be done resorting to multidisciplinary efforts.

The state-of-the-art language research achieving the right adequacy level should go beyond the formal knowledge of linguistics to involve the understanding of biological aspects of language cognition. This includes the electrical activity that carries linguistic information – electrical spikes – from the sense organs to the cortex where continuous time-dependent representations are encoded in a discrete sequence of waves (RIEKE et al., 1999). Elicited by experimental language stimulation, this electrical activity can be recorded at the scalp by an EEG (electroencephalograph). After the electrical signals time-locked to the linguistic stimuli are treated, so that they can be safely distinguished from noise, the resulting waves are the Event Related Brain Potentials (ERPs), that can be related to perception and processing of the language stimulus[1] (GESUALDI; FRANÇA, 2011).

These electrophysiological language experiments were first conducted in the 80's by several cognitive psychologists (KUTAS; HILLYARD, 1980; KUTAS; NEVILLE; HOLCOMB, 1987; KUTAS, 1987). They perceived that "semantically appropriate" words in a sentence or fragment – *first day at work* – were related to a small amplitude N400 wave. Nevertheless, whenever the stimulus was "semantically inappropriate" - *warm bread with socks* - they were related to a larger amplitude N400 ERP (Figure 1).

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[1] As much as behavioral studies greatly contribute to the understanding of the syntax and semantic interface measured during online sentence processing, such measurements reflect indirect information of the underlying neurocognitive processes. In order to acquire a more precise measurement of the brain responses during sentence processing, researchers have been using event-related brain potentials (ERPs) as a multidimensional measurement that can make explicit the qualitative and quantitative similarities and differences associated with different types of linguistic processes. The two most commonly cited ERP components are the so-called "N400" and the "P600". The N400 is a negative wave-form that occurs approximately 400ms after the onset of the target stimuli (KUTAS; HILLYARD, 1980, 1984). The P600 is a late positive-going wave form at approximately 600ms following the onset of a target word (HAGOORT, P.; BROWN; GROOTHUSEN, 1993). The N400 amplitude is mostly reported as being related to semantic incongruence while the P600 is reportedly related to ill-formed syntactic processing. Although they are highly correlated with semantic and syntactic parameters respectively, recently studies have shown that the dissociation between these two ERPs is not so clear cut.
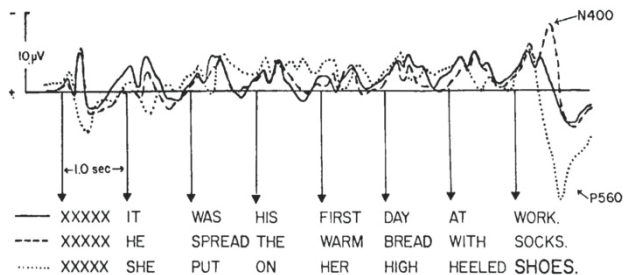
Figure 1: Extracted from the first published language ERP experiment (KUTAS; HILLYARD, 1980). Solid line is the congruous condition, resulting in a low amplitude N400. Dotted-line relates to the incongruous condition and it is indeed a large amplitude N400. The solid and dotted-line conditions are negative-going waves (peaks up). The micro-dotted line is the control condition. It shows a positive-going wave (peak down) that relates with the size of the font of the written stimulus and not with its semantic congruence. This condition was there to check the specificity of the response.

About two decades later, when linguists started studying the N400 effects, the experimental stimuli tested became more controlled in terms of their linguistic constituency. Most experiments tested stimuli formed by two words, either a preposition and its complement or a verb and its complement. Putting these two words together entails what is technically described as the syntactic integration or the merge computation, in Generative terms, between a thematic role assigner and its assignee. It was verified that, when manipulating with the plausibility of this merge operation, there was an N400 modulation: the harder to assign the thematic role to the complement, the higher amplitude of the N400. The way to explain this phenomenon was not an easy task, but most studies related it either to the semantic efforts to integrate the two words (a post-integration effect) or to the surprise created by the unfulfilled expectation of an ill-fitting complement (a pre-integration effect). (FRANCA et al., 2004; HICKOK; POEPPEL, 2000; LAU; PHILLIPS; POEPPEL, 2008; PHILLIPS; KAZANINA; ABADA, 2005).

At the same time, other considerations about the N400 started being taken into account. For instance, some studies pointed out that accessing long-term memory representations, such as lexical access to words or morphemes also yielded in small amplitude N400, when it is a regular and

frequent word in the language (EMBICK, 2003; EMBICK et al., 2001). And it could be modulated to take on even smaller amplitudes if it is elicited by stimulus repetition (VAN PETTEN; KUTAS, 1991). Yet, larger N400 amplitudes are robustly related to: (i) infrequent words (SMITH; HALGREN, 1987; VAN PETTEN; KUTAS, 1990) (ii) irregularly formed words (MÜNTE et al., 1999); (iii) non-words (KIM; LAI, 2012), and (iv) unpredicted words in a priming paradigm (GOMES; FRANÇA, 2008).

This paper is about a lexical access priming experiment, monitored neurophysiologically, that was specifically designed to contribute to the current discussions in sentence processing. We take on the hypothesis that sentence processing is so syntax-driven that granted the right lexical features, even at the absence of theme and case assigners, two nouns presented in a priming paradigm may obtain a phrasal reading, that is, an underlying reading hierarchically construed. So, two words, for instance rod / fish might be getting the phrasal, hierarchically nested reading of rod *to catch fish or rod for fish, while rod / reel* will inhibit such reading and activate a coordination reading: rod and reel.

Because this is not the most canonical design for a lexical access experiment, and once we aim at tapping into a deeper sentential level, we must first present an overview of the three major linguistic processing models, their theoretical underpinnings and the related neurobiology findings that may support them. Then, we present the lexical access experiment and discuss its findings in view of the models revised.

2. SENTENCE PROCESSING MODELS

The first is the bottom-up, syntax-first Model, derived from generative linguistic theories (CHOMSKY; LASNIK, 1993; HALLE; MARANTZ, 1993). The idea is that on the surface, every sentence is a sequence of words with an underlying hierarchy. The hierarchy determines meaning to a considerable extent. Understanding the overall meaning in spoken or written language entails deducing the nested hierarchy from the linear surface sequence.

To explore the online aspects of syntax-semantics processes under this view, a great number of studies started monitoring the neurophysiology of simple linguistic distinctions in view of their electrical counterpart component. After over a decade of research reporting robust N400 findings related to the semantic fit of complements in their argument structure, an ERP experiment in Brazilian Portuguese diversified the classic N400 stimuli by testing three different syntactic contexts for the verb-object merge computation: (i) local merge of verb to nominal direct object (*The man eats sandals*); (ii) local merge of verb to pronoun with referential inheritance from an antecedent (*He is holding the pizza and wants to read it*); and (iii) wh-phrase dependency (*What stories did Denise wash___?*) (FRANCA et al., 2004).

The distinction among the computations in the presented stimuli had been clearly defined linguistically: in (i) – simple verb-Determiner Phrase merge (hence, [v DP] merge); in (ii), [v DP] merge + Principle B of Binding Theory to license the correference between *it* and its anaphoric antecedent; and in (iii) merge of [v DP] + attraction of the DP, with its Wh feature, into the Specifier position of the Complementizer Phrase where it remerges. Such computational distinctions had been less-commonly investigated in neurophysiological terms by the field of ERP research. The study was an attempt to introduce formal linguistic hypotheses into the emerging neuroscience of language field.

With the trigger at the verb, the ERP findings revealed that the computational contrasts indeed diversified the integration efforts between verb and complement. This yielded in distinct neurophysiological counterparts visible in the many bioelectrical differences among the waves (ERPs) related through the time processing f the three types of sentences studied.

In (i) – *The man eats sandals* vs *The man eats sandwich* – involving strictly local computations, the findings were classic parietal N400s. The inheritance stimuli in (ii) – *He is holding the pizza and wants to read it* Vs *He is holding the pizza and wants to heat it* – elicited parietally and centrally distributed N400 ERPs, whose amplitudes were lower than those from stimuli in (i). Since context is inversely related with amplitude, the fact that the target

merge was dependent on semantic material already elicited in the previous merge seems to have narrowed the options for the second verb. Thus, the perception of the congruous or incongruous material was facilitated and the amplitude was lower. As for latency, these stimuli elicited a very wide peak ERP that was interpreted as being related to the processing burden of this task. In fact, the average motor reaction time was higher (1.84 ms) than that in (i). More recently, another experiment tested similar dependencies in Portuguese and a plateau was also present in the related ERPs (FRANÇA; GESUALDI; SOTO, 2012). In (iii), the WH-displacement stimuli – *What stories did Denise wash___?* Vs *What* stories did Denise tell ___? – presented earlier and the most salient cortical responses, with a marked large amplitude N400. The results of the incongruous stimuli show much more activity centrally and parietally distributed than in the prior conditions. The amplitude was the highest of the three sets of stimuli and so was the amplitude difference between congruous and incongruous conditions.

Since, syntax-first Model is bottom-up, subject computation should follows the verb + complement computation. Thus, incongruous subject integration would have to come after that of the object. This prediction was tested neurophysiologically also in Portuguese (LAGE et al., 2008).

Using the extraction of event-related brain potentials (ERPs), in 29 healthy subjects, this work studied different conditions in Brazilian Portuguese among which was the subject merge with the vP (A cadeira chutou a bola Vs The chair kicked the ball). With the trigger also at the verb, findings included the well-known N400, downplayed for the felicitous verb-object merge, but also revealed aspects and morphology of a later wave - the P600 - that seemed to have been modulated by the fit of the subject to the integrated vP: high amplitude for the incongruous subject and low amplitude for the congruous one.

Unsurprisingly, this formal linguistic theory view resonates well with findings from neurobiology that assert that no matter how complex a natural behavior might seem, one can always be confident that there is a modular neural circuit with a dedicated algorithm designed to mediate it. So, the more one knows about one specific circuit, the clearer will the behavior that springs from it be (SHEPHERD, 1994)

In fact, back in the early 80s, Croatian Pasko Rakic, Director of the Kavli Institute for Neuroscience at Yale, published the results of experiments supporting the view that the cerebral cortex is comprised of distinct, orderly regions or modules that subserve very particular cognitive functions of vision, hearing, movement, language and others. The function of every neuronal cell depends on its position and pattern of connectivity. How this complex neuronal map arises from a single fertilized cell during development is a mesmerizing puzzle in science. Rakic's most interesting research projects focus in a Condition of *in vitro* and *in vivo* studies, that unveiled evidence that there are several genes specific for signaling and making regulatory molecules, involved in neuronal migration. Such receptors coordinate the Condition of events that will give rise to neuronal proliferation, phenotype determination, and proper neuronal migration.

A second way of explaining the syntax-semantic interface comes from Dual- stream and Multi-stream models. As default, these models are also bottom up, syntax driven, but purport at least one independent semantic analyzer that runs a top-down stream to take care of difficulties in sentence interpretation. Multi-stream models offer highly dynamic strategies to allow combinatory decision to be influenced by semantic or syntactic factors that are believed to be the strongest during the processing of a given sentence. Authors report the existence of a game of weights between semantics and syntax.

For instance, take the stimuli in (iv) through (vi):

(iv)   The hearty meal was devoured
(v) *The hearty meal was devouring
(vi) *The dusty tabletops were devouring

Using these three different conditions, Kim & Osterhout (2005) advance the idea that in (i) syntax comes first as the default path, because this is the way to go when the sentence offers no illness of any sort. The verb assigns the right thematic role to the subject of the passive and syntax authorizes felicitous semantics interpretation. While (iv) is considered acceptable regarding to syntax and semantic factors, (v) and (vi) are anomalous. However, they are anomalous in different ways. According to the authors,

the surface attraction between *hearty meal* and the verb root devour_ in (v) preserves the healthy semantics of the sentence.

> (…), the semantic cues in the sentence suggest a different interpretation. While *meal* is an anomalous Agent for *devouring*, it is a highly plausible Theme. The 'semantic attraction' to the Theme interpretation might be so compelling that it is pursued even though it contradicts the syntactic structure of the sentence. (KIM; OSTERHOUT, 2005:207)

Thus, according to the authors,

(v) *The hearty meal was devouring

will be reprocessed as

(v)' The hearty meal was devoured

and this mobilizes changing closed class morphemes, which amounts to syntactic efforts, and not semantic ones.

Contrastingly, in

(vi) The dusty tabletops were devouring

there is no semantic attraction and "so the syntactic cues in the string unambiguously signal the agent assignment, and this assignment is expected to be pursued" (KIM; OSTERHOUT, 2005: 211)[2] So in this case there are no syntactic efforts but just semantic ones. The authors believe that fact that in one case only semantic efforts will be mobilized and in the other, syntactic efforts, will define different types of electrophysiology.

Taking (iv) as the default sentence processing here used as the control group,   the results of (v) with a trigger at verb show a P600. In (vi), there is no semantic attraction, so the most economical transformation would take a semantic path. The related electrical counterpart was an N400 (trigger

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[2] We believe that the effect they report could also be explained in these terms: In (v), since the verb root could assign the right thematic role to the subject of the passive, the ill-formedness will be detected and corrected in terms of a formal morpheme change: from the active *ing* to the passive *ed*. In (vi), however, there is no correct thematic assignment and the only possible repair would incur in root change (a change in open class words) +and this is not believed by the authors to be a possible operation. So no repair is previewed in this case.

at the verb) explained as the frustrated attempt to merge the noun phrase with the verb.

As to the neurophysiological correlates of these Multi-stream models, the literature cites the activation patterns of "streams of processing" or parallel streams and discusses at least two pathways in order to connect the language-relevant cortical regions (FRIEDERICI, 2011). For instance, the Dual-stream models assume ventral and dorsal pathways, which are relevant respectively to speech perception and language processing. Despite the fact that there is great cross-talking data among them, the ventral stream is supposed to connect different areas of the temporal cortex, supporting sound-meaning mapping, whereas the dorsal pathway connects the posterior-dorsal temporal lobe to the pre-motor and motor areas supporting auditory-motor integration (FRIEDERICI, 2011; HICKOK; POEPPEL, 2000)we suggest, stems from the fact that the neural systems supporting 'speech perception' vary as a function of the task. Specifically, the set of cognitive and neural systems involved in performing traditional laboratory speech perception tasks, such as syllable discrimination or identification, only partially overlap those involved in speech perception as it occurs during natural language comprehension. In this review, we argue that cortical fields in the posterior-superior temporal lobe, bilaterally, constitute the primary substrate for constructing sound-based representations of speech, and that these sound-based representations interface with different supramodal systems in a task-dependent manner. Tasks that require access to the mental lexicon (i.e. accessing meaning-based representations.

A stronger version of the Streams of processing view will assert that world knowledge about events and their participants might undermine even the strongest syntactic dependencies that are held between the verb and its complement (ALTMANN; KAMIDE, 1999; KAMIDE; ALTMANN; HAYWOOD, 2003)a cake, and various distractor objects. Whilst viewing this scene, they heard sentences such as 'the boy will move the cake' or 'the boy will eat the cake'. The cake was the only edible object portrayed in the scene. In each of two experiments, the onset of saccadic eye movements to the target object (the cake. Consequently, this strong version could

be understood as weakly Multi-stream and is thus quite similar to the semantics-first-stream models that will follow next.

Finally, a semantics-first account: The Retrieval Integration Account (BROUWER; FITZ; HOEKS, 2012). It denies the very existence of a syntax-semantics interface in the sense that it does not attempt to pair two aspects of processing simultaneously: form and meaning. It assumes a simple single-stream, pragmatic-first account that will start by looking at internally stored world knowledge representations, to match a certain input and interpret it, and then turn this into lexical information that will be integrated in a sentence. So, it is a top-down approach that starts its first phase – memory retrieval phase - by pragmatics and continues into computational operations in a second phase – the integration phase, determined by how much the current mental representation needs to be adapted to incorporate the current input.

> (…) we propose to interpret the N400 amplitude as reflecting a memory retrieval phase in which all the information linked to an incoming word (ie. The syntactic, semantic and pragmatic information associated with that word) is retrieved from long-term memory. We also propose that the Integration of this activated lexical information into the existing current mental representation of an unfolding sentence is reflected in the P600 amplitude, so we combine this retrieval view and the integration view into a single stream account of language processing.
> (BROUWER; FITZ; HOEKS, 2012: 7)

This electrically biphasic language processing system, advances two successive progressing stages, starting with the N400 and continuing with the P600, in which "the output of the retrieval phase serves as input for the integration one" (BROUWER; FITZ; HOEKS, 2012: 1). In the first stage of language processing, bottom-up memory-based activation processes are occurring, but top-down information from the mental representation

can add to the activation patterns in memory without constraining them (BROUWER; FITZ; HOEKS, 2012).

Using a set of stimuli created following the *Moses illusion paradigm*[3] (ERICKSON; MATTSON, 1981; SANFORD, A.J. et al. 2011), experimenters compared the waveforms of participants that detected the anomaly to those who didn't detect it in sentences such as (viii):

(viii) Child abuse cases are being reported much more frequently these days. In a recent trial, a 10-year **<u>sentence</u>** was given to the victim…' ('sentence' = anomalous)

The authors compared the ERPs yielded with the trigger at the subject of the passive, and reported two findings: (a) no marked N400 was found in neither groups; (b) a P600-effect was detected for the participants who detected the anomaly.

Based on these findings the authors conclude that, the N400 and P600 responses reflect successive processing stages, which means that all cognitive sentence processing entails negative-positive cycles and so there is a biphasic sequence response (N400/P600) for every word during the interpretation of a sentence. The P600 "is the brain's natural electro-physiological reflection of updating a mental representation with new information (…). There is a single representation of what is communication and the ease of managing this representation (…) is reflected in the P600 amplitude" (BROUWER; FITZ; HOEKS, 2012; KOTCHOUBEY, 2006).

This bare-bones account of the three theoretical paradigms still leaves out many lingering questions and many hybrid models that could fit partly into more than one division that was drawn here for the sake of theoretical simplification.

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[3] In the *Moses Illusion Paradigm* when asked "How many animals of each kind did Moses take on the Ark?," most people have the tendency to respond "two,". Nevertheless, while caught in the task to answer the question, participants most usually fail to notice that, obviously it was Noah, not Moses, who took the animals on the Ark (Erickson, Mattson, 1981). This is a very robust effect and tends to happen even when the participant is warned that something wrong, a distortion, might be included in the question and even when participants are asked to reply with full answers in oral or written form. They usually come up with "*Moses took two animals of each kind on the ark*".

3. BETWEEN LEXICAL ACCESS AND SENTENCE PROCESSING

With the aim to design an experiment that could test the predictions of the three Sentence Processing Models just sketched in 2, we decided to work with the simplest possible data: two nouns in a priming paradigm.

Under the scope of the Syntax-first model, this work is about the relation between two words; two nouns such as those presented in sequence in a priming paradigm: for example, the prime *lice* followed by the target *hair.*[4] This is of course an experimental approach to the inquiry because two isolated words out of a structure do not usually come together in a sequence in natural languages. But depriving the words from the sentence structure would probably give us a chance to see what will come in first in this intricate syntax-semantic interface. Will *hair* be accessed faster if it is preceded by *lice*? Or will *lice* hinder access to *hair*?

Is retrieval information of the target modulated by the semantic relatedness it holds with the prime? Will these two words ever get a phrasal reading and if yes, what characteristics should the two words have to elicit this phrasal reading? And what counts more for a phrasal reading: world knowledge or syntactic hierarchy.

Playing with the distinctions of the three processing models, is theme assignment a fundamental computation (Syntax Driven Model) or is semantic attraction stronger (Multi Stream)? Does the order of prime and target interfere in the priming effects or priming still holds even if the positions of the words are swapped (Retrieval Integration Model)?

Our hypothesis is that if two nouns in a priming paradigm[5] are carefully

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[4] The original examples in Portuguese are for the prime *lice* ('piolho') and for the target *hair* ('cabelo').

[5]   The experimental protocol of priming consists in the presentation of linguistic units in sequence, for example, two words. The first of these units is called the prime and the second the target. The aim of this test is to study the influence of the prime on the activation of the target. To exemplify the implementation of a test such as this one, we might think of the influence of a prime *lemon* on target *lemonade*. Would *lemon* favor or hinder access to *lemonade*? It is assumed that when we are exposed in a short period of time to pairs that share some kind of feature (semantic, phonologic, or morphologic), in other words, that share informational units, there would be some kind of priming effect on the target. There may be a facilitator or inhibitory effect on the recognition of the target. In order to

picked, there might be an automatic insertion of an understated theme assigner between them, and so a phrasal reading would be naturally deployed. This is an intuitive hypothesis since grammar integration does facilitate processing and memory.

Notice that this hypothesis would only make sense for the Syntax-first model. It would not be right for the Multi-Stream models that assume that the connection between words is a matter of semantic attraction. As it will be discriminated in our experimental design, two words may hold different sorts of semantic relatedness and semantic attraction is more inclusive than the semantic relationship between a theme assigner and the assignee. Beyond this, if the Syntax-first model is right, the phrasal reading must depend on directionality, since it is hierarchically nested. Thus, by assuming that world knowledge comes first, the Retrieval Integration Account would expect priming effects not to be altered by the direction of the priming.

Believing that a full understanding of language comprehension requires a detailed understanding of the set of composition operations and how these operations interface with the rest of the language process system, once we assume that we can automatically relate two separate words in a syntactic structure, this explanation would have to account not only for the easy and immediate relationship between *lice* and *hair*, but also for the not so straightforward relationship between *lice* and *comb*. With *lice* and *comb*, it is not possible to be economical and establish an immediate syntactic relation. Notice that the prediction is that, as there is no *comb* in the basic definition of *lice*, and no *lice* in the basic definition of *comb*, despite the fact that there is semantic attraction between the two. So in order to construct a phrasal

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know if this in fact occurs, a control group is always included in the priming protocol. In this control group, there are primes and target between which there is no type of relation whatsoever. The test target is compared to the control target. For example, *lemonade* from the test pair *lemon-lemonade* is compared to *telephone* of the control pair *lemon – telephone*. Besides these pairs, the design of this kind of experiment includes pairs with prime/non-word (*chair/phrepple*) seeing that lexical decision is the task given to the volunteer. That is, we asked him/her to press a certain button if the target is a word and another button if it is a non-word. By analyzing the answers to this kind of protocol, both the psycholinguistic variables (reaction time and error rate) and the neurolinguistic variables (cortical wave latencies), we can assess the influence of prime representations on the target according to morphological, phonological and syntactic similarities.

reading here we would need to suppose more derivational cycles. Maybe, *lice in the hair, hair on the comb.*

We believe that with an experimental design that makes these distinctions, if there is a gradation in the strength of the semantic relation between two words, it should be possible to verify the psychological and neurophysiological reality of this gradation experimentally.

4. MATERIALS AND METHODS

4.1 The neuronal systems from which the n400 is extracted

> The distributed nature of the cortical processing is underscored when you consider that the output of a *million* ganglion cells can recruit the activity of well over a *billion* cortical neurons throughout the occipital, parietal, and temporal lobes! Somehow, this widespread cortical activity is combined to form a single, seamless perception of the world.
> (BEAR; CONNERS; PARADISO, 2006: 269)

The main task of neuronal systems is to construct in the brain a reliable representation of the world, captured by the senses, so that this representation can be manipulated by cognitive processes.

The first stage of this task consists in translating the physical phenomena into "the language of neurons". The great diversity of physical stimuli must be reduced to a unique code, which is the variation in electric potential of the membrane of receptor neuronal cells. The sensory translation is the process of transforming the electricity that is present in the plasma membrane of the sensory receptors. Thus, physical stimuli will be re-codified in terms of synaptic effects (LENT, 2008: 12).

Synapses hold the mechanism that is responsible for the transmission of impulses between one nervous cell and the other, that is, between one

neuron[6] and the other, or between a neuron and a motor end plate. Most of the synapses of the human nervous system are chemical, and the impulse causes the release of a neurotransmitter in one of its presynaptic terminals. In some synapses, the transmission is purely electric and in others it is mixed, or rather, electrochemical. These impulses are like digital codes to be deciphered by cortical processing. From a micro-perspective, this process is responsible for the functioning of the brain (BEAR; CONNERS; PARADISO, 2006).

The electroencephalograph (EEG) allows for the acquisition and storage of bioelectric signals, executing the continuous registration of electrocortical activity by means of electrodes fixed to the scalp.

During an EEG exam, each of the electrodes is placed at a specific point which is directly related to an area of the cerebral cortex. These points on the scalp are called *derivations*. The tip of the electrode captures the electric activity of millions of neurons. Any voltage fluctuation (μV) captured between pairs of electrodes, or rather, between two derivations, is registered by the EEG, enabling the measurement of electric activity at the derivations, which is a reflection of the electric activity in the brain (BEAR; CONNERS; PARADISO, 2006).

Therefore, the electric signal of the EEG captured on the scalp is an oscillatory signal, stemming from the spatial-temporal sum of inter-neuronal synaptic potentials with two major components: the background or continuous or base signal[7]; and the set of discontinuous (or transient) signals.

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6   The neuron can be considered the basic structural unit of the brain and the nervous system. It is the cell in the nervous system that is responsible for transmitting the nervous impulse. There are approximately 100 billion neurons in the human nervous system. Neurons consist of the following parts: (i) cell body – where the cell nucleus is; (ii) dendrites – extensive branches that come from the exterior membrane of the neuron and receive electric signals from other neurons; (iii) axon – an extension of the neuron; (iv) telodendrion – a terminal branch of the axon where the impulse goes from one neuron to the other or to another organ.

7   In the visual analysis, the background signal is usually described by characteristics of amplitude and frequency. In the temporal domain, the EEG signal is a function of time in which the amplitude may be described numerically (5, 10, 60 microvolt, for example) or nominally (small, medium, large, for example), the same occurs for frequency (1, 4, 12 Hz, for example; or slow, fast, for example). The EEG background signal is not a stationary signal. Quite the contrary, it is rather complex, undergoing synchronization/desynchronization processes over time, ran-

The EEG measures the electric current that flows during the synaptic neuronal excitation, that occurs invariably in subcortical areas[8]. Capturing the electric current in these subcortical areas implies in a loss of electric conduction as the electricity must go through many layers of non-neuronal tissue on its way to the surface of the cortex. That is why the electric signals that are captured during the exam or experiment must be amplified and digitalized technically by way of signal processing in order to suppress noise and enhance electric potentials (ERPs). Thus, ERPs consist of a chronometric measurement of the electrocortical effects related to the processing of linguistic information with a high temporal resolution. This chronometric measurement was carried out in this experiment by means of a priming test monitored by EEG. ERPs related to the reading of target words were extracted from the obtained bioelectric signals.

ERPs, responses of the nervous system to motor or sensory stimulation, are composed by a sequence of waves characterized by latency, amplitude, and polarity. In order for us to visualize the ERP, it is necessary to average various epochs[9] and filter all the noise mixed with the interest signal in the raw EEG. This way, the effect of averaging is to increase the signal/noise ratio (SNR), which allows for the visualization of the related linguistic stimulus that was time-locked to it. Thus, random noise is eliminated by filtering the noise resulting from muscular movement, blinking of the eyes or even from an electric interference caused by some pieces of equipment competing with the event related signal under study. The noise being random, the result of the averaging converges to zero. That is why, at the end of this operation, only the event-related signal stands out.

4.2 Participants

A total of 30 subjects (15 male) undergraduates from the Federal University of Rio de Janeiro (UFRJ) participated in the experiment for cash.

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domly or due to a specific event. The reactivity of the alpha rhythm is a classic example of this, in that it desynchronizes with stimuli provoking alertness and synchronizes in a state of rest.

[8] Subcortical areas are those localized below the cortical level. They are deeper regions in which there is a higher cell density.

[9] Epochs are functional time windows in the EEG continuum marked out for further study.

Participants aged 18-26 (mean: 22.7). All participants were right-handed. Selection criteria required all participants to have normal or corrected-to-normal vision and to be native speakers of Portuguese. A written consent was obtained from all subjects before participation.

4.3 Stimuli

We created a total of 180 pairs of prime-target words and 180 pairs of prime-target word-nonwords in five experimental conditions: (1) the target is contained in the definition of the prime; (2) the target is not contained in the definition of the prime, but in the definition of a word that is related to the prime; (3) prime and target are unrelated; (4) condition 1 inverted; and (5) the target is a non-word. Three stimulus lists were created using these conditions. Each stimulus item occurred only once in each list. Each participant saw just one of the lists.

The following table has a sample of the tested pairs translated into English. Word size, frequency and phonotactic control were performed for the real experimental word sets in Brazilian Portuguese.

Table 1: Experimental Conditions and Stimuli: The prime is always the same for 5 different targets, except in condition 4 in which prime and target are reversed in relation to

Condition 1

SUBJECTS	STIMULI (total: 360 stims)				
		Condition 1	**Condition 2**	**Condition 3**	**Condition 4**	**Condition 5**
		Target within the definition of the prime – direct semantic connection	Target within the definition of a word that is within the definition of the prime– indirect semantic connection	Semantically unrelated prime and target – no semantic connection	Condition 1 inverted	Target as nonword
	PRIME	TARGETS 1	2	3	4	5

LIST 1 (10 subjects)	LICE	hair	comb	tennis	HAIR-lice	taffel
		15 stims	15 stims	15 stims	15 stims	60 stims
LIST 2 (10 subjects)	PETAL	flower	garden	cup	FLOWER-petal	tauth
		15 stims	15 stims	15 stims	15 stims	60 stims
LIST 3 (10 subjects)	CLOUD	rain	puddle	team	RAIN-cloud	paton
TOTAL		15 stims	15 stims	15 stims	15 stims	60 stims
30 subjects		**45 stims**	**45 stims**	**45 stims**	**45 stims**	**180 stims**

4.4 Stimulus presentation and procedures

This test followed a within-subject experimental design. Participants were randomly assigned to one of the three lists used, so as not to repeat trials across participants and to counterbalance participants across lists.

Participants sat in a comfortable chair, in a dimly lit room separate from experimenter and computers. Words were presented, prime-target, on a computer screen. Each trial (one-pair of words or word-non-word) followed the events in Figure 2. The presentation began with a fixation cross at the center of the screen for 1500ms, followed by a 500ms mask of 4 stars. Then came the prime word that was on for 38ms, followed by another mask of stars for 50ms. The target word was presented for 200ms. A 1500ms blank-screen followed each trial and remained on the screen until the subject made his/her judgment (Figure 2).
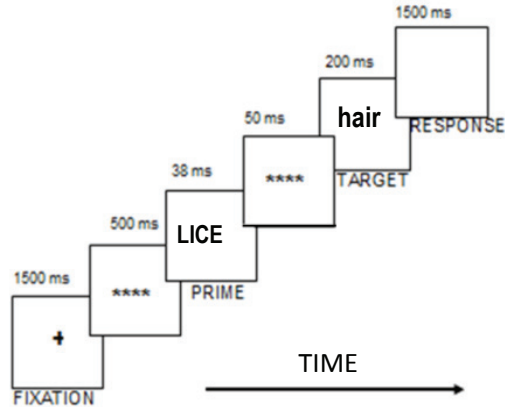
Figure 2: Presentation timeline

The subject's task was to decide whether or not each target was a word or a non-word in Brazilian Portuguese by pressing one of two buttons on a response box. As training, each subject was given 10 trials at the start of the experiment.

5. RESULTS

5.1 Behavioral data

When subjects make explicit judgments about whether or not the target is a word or a non-word, the behavioral data showed that compared to condition 1, in which the definition of the target is within the definition, conditions 2 and 3 generated progressively longer response times and this difference was statistically significant. Thus, compared to condition 1 (LICE-hair) Condition 2 (LICE-comb) and Condition 3 (LICE-tennis) took longer. Among the 5 conditions, subjects took the longest time judging the prime in Condition 5 (LICE- taffel). This can be explained since the non-word had a good phonotactic of Portuguese so participants took longer to realize it was a nonword. Most importantly, Condition 4, which has Condition 1 prime-

target pair reversed, took the longer than Condition 1, in spite of having the same two words. This is a hint that semantic attraction is not the only factor at play since directionality is a strong measure of underlying hierarchy.
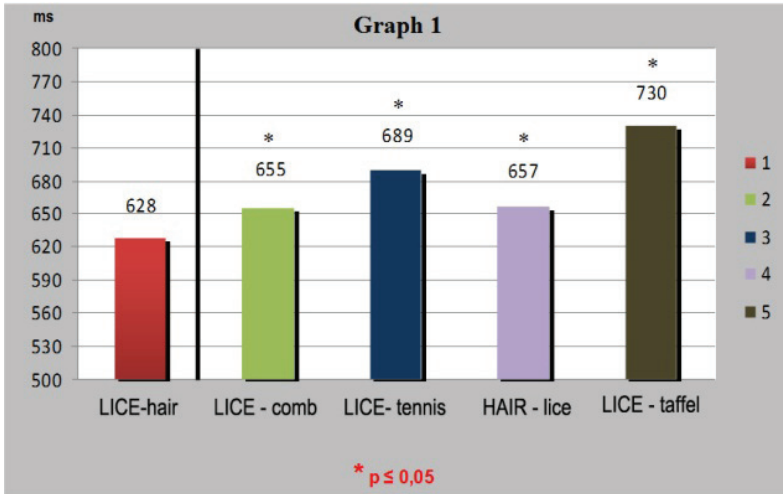
Graph 1: Behavioral response times – RTs in milisseconds.

5.2 Electrophysiological data

A total of 21 electrodes were held in place on the scalp with an EMSA gel (*Elefix*, *Nihon Kohden.* All of them were placed in standard International 10-20 System locations. Other two electrodes were placed on left and right mastoids.

The EEG signal was amplified and was continuously sampled at 200 Hz. The stimuli presented to participants and their behavioral responses were simultaneously monitored.

5.3 ERPS: statistical analysis

Continuous analog-to-digital conversion of the EEG and stimulus *trigger* codes were performed at a sampling frequency of 200 Hz. ERPs, time-

locked to the onset of the target stimulus, were averaged off-line within each condition type (Condition 1 to 5) for each subject at each electrode site. Grand averages were formed by averaging over participants.

Trials characterized by eye blinks, excessive muscle artifact, or amplifier blocking were not included in the average.

ERP components of interest were quantified by computer as mean voltage within a window of activity. After visual inspection of the data, the following windows were employed: 50–150ms (N1), 150–300ms (P2), 400–600ms (N400), relative to a 100ms pre-stimulus window.

Repeated measures analysis, Running T-test (HAGOORT et al., 2004), were performed on the above dependent measures. In such cases, the corrected p value is reported.

This parametric test was applied sample to sample, taking into account all subjects. T-test evaluates whether the average for each condition is different from one another. Besides the T-test, two one-way tests were applied, of 2.5% each (α = 2.5%), with the aim of testing the null hypothesis – checking if there was no difference between the amplitudes of the ERPs at each time interval (25ms). Also Wilcoxon test was performed, with a significance level $p \leq 0.05$ (CAGY; INFANTOSI, 2004; CAGY et al., 2006)the objective of the present study was to study the N400 statistically in 24 volunteers. Stimulation consisted of 80 experimental sentences (40 congruous and 40 incongruous. The Wilcoxon test does not incorporate the restrictive assumptions, used in some parametric tests. Within Wilcoxon, it's not necessary the data to be normally distributed (Free Distribution). It is only necessary that they are orderable. The Wilcoxon test is less sensitive to measurement errors and is a good test for small samples.

This methodology, which consists of several tests, was able to check whether there was a difference between the two amplitude EEG tracking comparisons, considering the entire length of the window (up to 800ms. after trigger). Thus, it is possible to test for which time intervals the null hypothesis is accepted or rejected.

After plotting the set of graphs with the ERPs resulting from each comparison, it was possible to test the relevant statistical results (Table 2). In these graphs, we can identify each derivation and the time interval in which

no difference in amplitude between statistically attested EEG tracings (with significance of α = 5%). Thus, the time intervals which are not included in the table correspond to portions of the graphs that are effectively overlapped, that is, do not show statistically relevant amplitude differences – when the null hypothesis was rejected.

5.4 Activation time: latency (ms) and amplitude (μv)

The morphology of the wave reflects different cognitive processes. Higher amplitudes are generally associated to a greater integration effort. Also, the sharper angle the wave peak, the faster the merging task has been completed. Besides, as can be foreseen, longer latencies reflect that more time was needed to execute the task, while shorter latencies indicate facilitation in task completion.

The derivations P (parietal), C (central) and T (temporal) are more important for the cognition of language than the F (frontal) and O (occipital) derivations although the supposed location of the electric response is just a rebounding of potentials within the brain.

Based on a derivation that is quite active when it comes to language cognition, the Pz derivation, it was possible to create a graph focusing on latencies, measured in milliseconds, related to the targets of Condition 1 in comparison with the targets of other Condition. The asterisk above the columns (Graph 2) indicates statistically significant comparisons.
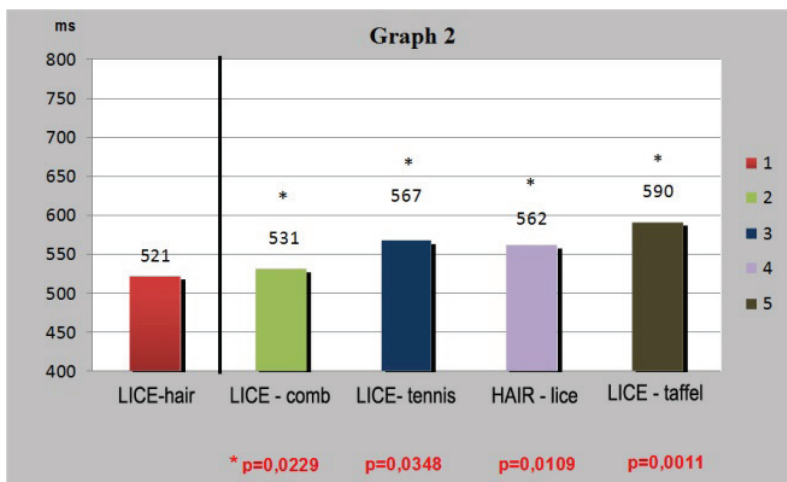
Graph 2 – Latency (in milliseconds) of the parietal derivation Pz related to the targets of Series 1 in comparison to the targets of the other series – the asterisk above the columns indicates the statistically relevant comparisons.
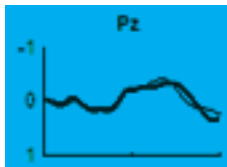
In Graph 2 above, we can see that Condition 1 (LICE-hair) presented a latency of 521ms, which is the shortest latency obtained for the Pz (parietal) derivation among the 5 conditions in relation to the task of target word recognition between 300ms and 550ms (N400 time-windows).

Thus, closely semantic related words, like the ones in Condition 1 (LICE-hair) resulted in a smaller N400 latency, comparing to latencies resulted from the unrelated pairs, Condition 3 (LICE-tennis), $t(29) = 2.34$, $p = .0348$.

With regards to the recognition of non-word targets, the longest latency detected for the Pz derivation was 590ms, which was found for Condition 5 (LICE- taffel) comparing to Condition 1 (LICE-hair), $t(29) = 6.87$, $p = .0011$. We can also see that Condition 2 (LICE-comb) and 3 (LICE-tennis) reached, respectively, latencies of around 531ms and 567ms, $t(29) = 11.8$, $p = .2797$, being not significantly different from each other.

Besides, we can observe that for Condition 4 (HAIR-lice), the inverse of Condition 1, ERPs resulted in an intermediate latency of 526ms comparing to Condition 1(LICE-hair) in the N400 time windows, $t(29) = 4.49$, $p = .0109$, which lies between the latencies of Conditions 2 and 3.

The following graph (Graph 3) shows the amplitudes (measured in microvolts) obtained at the Pz derivation related to the lexical access of the targets in each Condition.
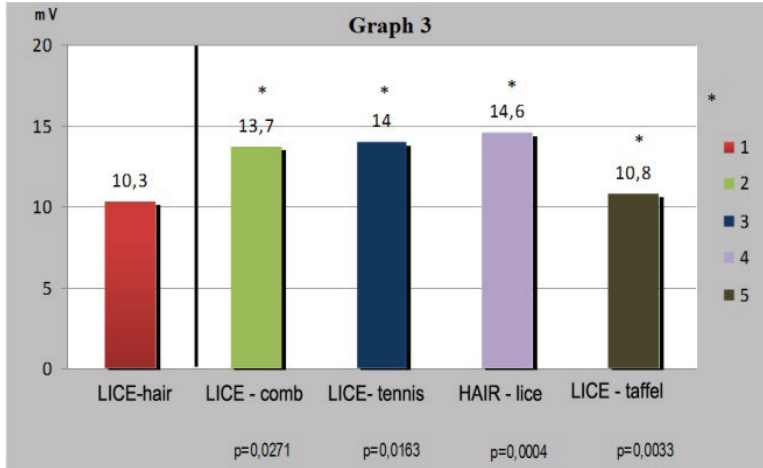
Graph 3 – Amplitude (in microvolts) of the parietal derivation Pz related to the targets of Series 1 in comparison to the targets of the other series – the asterisk above the columns indicates the statistically relevant comparisons.
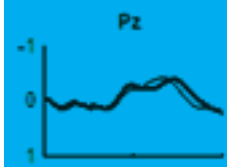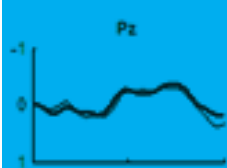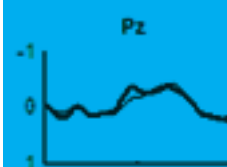
Analyzing the graph above (Graph 3), we can observe that at the parietal derivation Pz in the task of distinguishing between target words and non-words the lowest amplitude detected (10,3 µV) was for Condition 1 (LICE-hair). We can also see that Condition 2, 3, and 4 obtained equivalent amplitude values of 13,7 µV, 14,0 µV and 14,6 µV, respectively, comparing to Condition 1 (LICE-hair), $t(29) = 3.4$, $p = .0271$, $t(29) = 3.7$, $p = .0163$ and $t(29) = 4.3$, $p = .0004$, respectively.
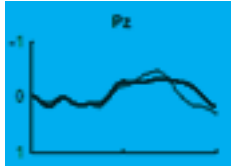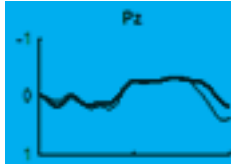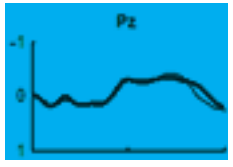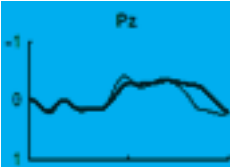
Condition 5 (LICE-taffel) in turn, achieved a 10,8 µV amplitude, compared to that of Condition 1, $t(29) = 0.5$, $p = .0033$. In Graph 4 the asterisk above the columns indicates the statistically relevant comparisons also.

6. ERPS: COMPARATIVE ANALYSES OF THE CONDITION

A summary of the eight comparisons that were carried out in the tests can be found in Table 2 below. For the sake of illustration, once again we have chosen results from the Pz (parietal) derivation, following the pattern established in Graphs 2 and 3 (Section 4.4.1), as it is generally the most important derivation for electrophysiological experiments involving the language cognition.

Table 2 – Tested condition and comparisons between latencies

Comparisons between latencies:	N400	Pz (parietal) ERPs
*1. Condition 1 vs. Condition 2 Thin line: *hair* (*LICE-hair*) Thick line: *comb* (*LICE-comb*)	Pz [521,5 – 530,9] p=0,0229	
*2. Condition 1 vs. Condition 3 Thin line: *hair* (*LICE-hair*) Thick line: *tennis* (*LICE-tennis*)	Pz [521,9 – 546,2] p=0,0348	
3. Condition 2 vs. Condition 3 Thin line: *comb* (*LICE-comb*) Thick line: *tennis* (*LICE-tennis*)	Pz [555,6 – 567,4] p= 0,2797	
*4. Condition 1 vs. Condition 4 Thin line: *hair* (*LICE-hair*) Thick line: *lice* (*HAIR-lice*)	Pz [521,5 – 566,4] p=0,0109	

*5. Condition 1 vs. Condition 5 Thin line: *hair* (*LICE-hair*) Thick line: *taffel* (*LICE-taffel*)	Pz [521,5 – 590,2] p=0,0011	
*6. Condition 2 vs. Condition 5 Thin line: *comb* (*LICE-comb*) Thick line: *taffel* (*LICE-taffel*)	Pz [530,9 – 590,2] p=0,0006	
*7. Condition 3 vs. Condition 5 Thin line: *comb* (*LICE-comb*) Thick line: *taffel* (*LICE-taffel*)	Pz [567,4 – 590,2] p=0,0274	
*8. Condition 4 vs. Condition 5 Thin line: *lice* (*HAIR-lice*) Thick line: *taffel* (*LICE-taffel*)	Pz [562,5 – 590,2] p= 0,0451	

In the first column (Table 2), we have the description of the comparisons that were carried out between the conditions, more precisely between their latencies, besides examples of the experimental stimuli involved in each Condition. In the second column (Table 2), we can find for one of the analyzed derivations, Pz (parietal), the latencies for the compared Condition and the value of the statistical coefficient "p". For the statistical analysis to be statistically significant, we need $p \leq 0,05$.

7. DISCUSSION AND CONCLUSION

To make the analysis easier to understand, we will point out the electrophysiological results for all the comparisons made.

In the behavioral study, the comparisons between the reaction times indicated a gradual effect in the prime-to-target facilitation. Conditions 1, 2 and 3 provoked gradually increasing reaction times.

In the electrophysiological test the measured data are negative waves at approximately 400ms. The N400 has been robustly related to the merge of syntactic units as well as to lexical access (LAU; PHILLIPS; POEPPEL, 2008).

Similarly to the behavioral findings, we could also observe a gradual priming dismay operating in the activation latencies of waves related to the targets of Conditions 1, 2 and 3. In almost all of the analyzed derivations progressively longer latencies were detected in the three first comparisons between the targets of Conditions 1, 2 and 3. With regards to the amplitudes, the lowest was verified for Condition 1. Given that the amplitude is generally associated to cognitive effort, we may relate the low amplitude of the ERPs for Condition 1 to the facilitated integration of these stimuli into a phrase. The other conditions, 2, 3, and 4, revealed higher amplitudes, and, therefore, characterize increased cognitive effort. Condition 5, which presented non-words, also resulted in low amplitude. This is a frequently observed result which is commonly related to the fact that persistence in integration efforts are ceased as soon as the non-word status of the stimulus is confirmed (KUTAS; HILLYARD, 1984; PYLKKÄNEN; LLINÁS; MURPHY, 2006; PYLKKÄNEN et al., 2004).

Such results for latency and amplitude seem to indicate that the semantic proximity between two words can be manipulated. We found a parameter that maybe can be advanced as a measure of the possibility of the two words to form an abstract prepositional phrase which can relate two nouns by means of theta role assignment. Based on these comparisons, it was possible to test the hypothesis that the relationship between prime and target might be mediated by a syntactic relationship whenever possible. Words will tend to be more strongly related to each other if their semantic features allow for an underlying hierarchical structure. Then targets semantically related to the definition of the prime, as in Condition 1, would present facilitated lexical access via syntax. On the other hand, unrelated targets, as expressed in the stimulus condition of Condition 3, would have slower access because the indirect semantic relationship between prime and target make it harder for an underlying structure to be assigned to them.

Our results seem to confirm, with statistical significance, the expectation of shorter latencies for Condition 1 (521ms), followed by Condition 2 (531ms), and Condition 3 (567ms). Going back to the predictions, in Condition 1 two operations seem to have been at work in an immediate manner: arbitrary form-meaning mapping and after that, syntactic merge. We believe that this occurred by means of semantic licensing, in other words, theta role assignment mediated by an underspecified assigner which was not openly expressed in the experimental stimuli.

But the crucial finding of this experiment is related to the comparison between Conditions 1 (LICE-hair) and 4 (HAIR-lice) that present the same pair of words in reverse order. This comparison proved to be statistically significant, which means that Condition 1 and 4 are different from each other, with Condition 1 presenting faster access to the target, t(29) = 4.49, p = .0109. Therefore, directionality seems to influence the semantic relationship established between prime and target, We here advance an explanation that our carefully picked words for the pairs in Conditions 1 and 4 favored the natural mediation of an unstated theta role assigner that organized their relationship hierarchically. The difference in the activation times between targets in 1 and 4 stems from the fact that the hierarchical structure in each direction has its own peculiarities and our stimuli were organized in a way to favor syntax and their semantic readings in Condition 1 more than in Condition 4. For instance, in Condition 1, *lice* [in the] *hair* is easier to process than *hair* [with] *lice*. Fundamentally, the notion of semantic attraction without hierarchy could not explain our findings.

At this point, we may reflect on the predictions posed by the Retrieval Integration Models. Pragmatic- based models are top down and would therefore skip the lexical access part in favor of a frame reading. On its turn, frame reading would compute the number of times that those words were used together and activation would result from this proximity. This would cancel differences between Conditions 1 and 4 because they would be virtually identical. Yet, according to our findings, they were not. The primes in the direction organized for Condition 1 provoked a faster activation of the corresponding targets then those organized for Condition 4. Thus, it seems that the Syntax-first model is the best to explain the results in this experiment.

Referring to results presented below, in Graph 4, latencies for both hemispheres from the central, parietal and temporal derivations can be observed. A statistically significant difference can be seen with regard to latencies in odd and even derivation pairs in the central and parietal regions: we have shorter latencies in the right hemisphere. These findings are compatible with those presented by Pylkkänen and colleges (2006), who found slower waves in the right hemisphere when sensory components of the same word competed. Contrastingly in our study, words were matched so that they activated the same aspect of a semantic feature for example, the telic qualis of lice and the telic qualis of hair. Our stimuli do not compete and have virtually the same latency at the right hemisphere derivations. Therefore, our results complete those of Pylkkänen, Llinás and Murphy's (2006), as they relate faster latencies to identity and slower latencies to competing forms. These results seem to indicate that manifestations of sensory or qualia-related characteristics associated to roots occur faster than arbitrary form-meaning mapping and they would be visible in the right hemisphere (in the even derivations).
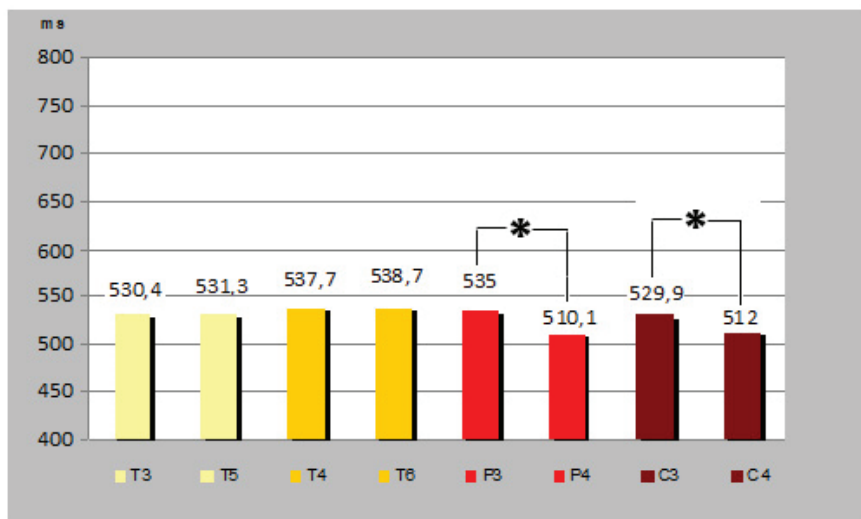
Graph 4 – Latency distribution of most important derivations for both hemispheres for Series 1: yellow columns for the right hemisphere; red, for left.

Another important distributional criterion which can be observed here is the fact that the fastest latencies found in the right hemisphere derivations are not found in the temporal derivations. ERPs that surface in the temporal lobe (T3, T5, T4 and T6) are slower and evenly distributed on both hemispheres. We can verify that this distributional pattern and its time course are similar to the parietal and central derivations on the left hemisphere. These bilateral temporal and left hemisphere parietal and central characteristics are in turn related specifically to the operation of arbitrary sound-meaning mapping which has already been extensively described (HICKOK; POEPPEL, 2007; POEPPEL; HICKOK, 2004; PYLKKÄNEN; LLINÁS; MURPHY, 2006).

We have come, then, to a result that seems to support the hypothesis that there is micromodularity in the lexical access computations; moreover, it reveals minimal differences between such computations involved in the semantic relationship between two words.

With these findings, we contributed to the current discussions in sentence processing by showing experimental conditions with the right lexical features that revealed that sentence processing is syntax-driven. In a priming situation, two separate stimuli, prime and target - produced neurophysiological data compatible with a phrasal reading, that is, one that has an underlying reading hierarchically construed: processing seems to be syntax-first unavoidably even if several semantic readings intersperse syntax computations.

REFERENCES

ALTMANN, G. T.; KAMIDE, Y. Incremental interpretation at verbs: restricting the domain of subsequent reference. In: *Cognition,* v. 73, n. 3, p. 247-64, 17 dez. 1999.

BEAR, M.; CONNERS, B.; PARADISO, M. *Neuroscience: Exploring the Brain*. 3rd. ed. Philadelphia: Lippincott, Williams and Wikins, 2006. p. 858

BROUWER, H.; FITZ, H.; HOEKS, J. Getting real about semantic illusions: rethinking the functional role of the P600 in language comprehension. In: *Brain research,* v. 1446, p. 127-43, 29 mar. 2012.

CAGY, M. et al. Statistical analysis of event-related potential elicited by verb-complement merge in Brazilian Portuguese. In: *Brazilian Journal of Medical and Biological Research*, v. 39, n. 11, p. 1465-74, nov. 2006.

CAGY, M.; INFANTOSI, A. F. C. Statistical Frequency-Domain Technique to Reflect Changes on MLAEP during Anaesthesia. In: IFMBE. *Proceedings…* v. 6, p. 95-99, 2004.

CHOMSKY, N.; LASNIK, H. The theory of principles and parameters. In: *Syntax:* An international handbook of contemporary research. Jacobs. Ar ed. Berlin: Walter de Gruyter, 1993. v.1, p. 546-569.

EMBICK, D. et al. Short communication. In: *A magnetoencephalographic component whose latency reflects lexical frequency*, v. 10, p. 345-348, 2001.

EMBICK, D. Locality, Listedness, and Morphological Identity. In: *Studia Linguistica,* v. 57, n. 3, p. 143-169, dez. 2003.

ERICKSON, T. D.; MATTSON, M. E. From Words to Meaning a Semantic Illusion. In: *Jornal of Verbal Learning and Verbal Behavior,* v. 20, n. 4, p. 540-551, 1981.

FRANCA, A. I. et al. Discriminating among different types of verb-complement merge in Brazilian Portuguese: an ERP study of morpho-syntactic sub-processes. In: *Journal of Neurolinguistics*, v. 17, n. 6, p. 425-437, nov. 2004.

FRANÇA, A. I.; GESUALDI, A. DA R.; SOTO, M. Modulando o n400 através da incongruência semântica estabelecida pela relação antecedente-pronome. In: *Revista LinguiStica,* v. 8, n. 2, p. 221-238, 2012.

FRIEDERICI, A. D. The brain basis of language processing: from structure to function. In: *Physiological reviews*, v. 91, n. 4, p. 1357-92, out. 2011.

FRIEDERICI, A. D. The brain basis of language processing: from structure to function. In: *Physiological reviews*, v. 91, n. 4, p. 1357-92, out. 2011.

GESUALDI, A. DA R.; FRANÇA, A. I. Event-related brain potentials (ERP): an overview. In: *Revista LinguíStica,* v. 7, n. 2, p. 24-42, 2011.

GOMES, J. N.; FRANÇA, A. I. A direcionalidade no relacionamento semântico. In: *Revista Veredas*, v. 2, p. 167-170, 2008.

HAGOORT, P. et al. Integration of word meaning and world knowledge in language comprehension. In: *Science* (New York, N.Y.), v. 304, n. 5669, p. 438-41, 16 abr. 2004.

HAGOORT, P.; BROWN, C. M.; GROOTHUSEN, J. The syntactic positive shift (SPS) as an ERP-measure of syntactic processing. In: *Language and Cognitive Processes*, v. 8, p. 439-483, 1993.

HALLE, M.; MARANTZ, A. Distributed Morphology and the Pieces of Inflection. In: *The view from building 20:* Essays in Linguistics in Honor of Sylvian Bromberger**.** HALE, K (Ed). Cambridge (MA): MIT Press, 1993. p. 111-176.

HICKOK, G.; POEPPEL, D. Towards a functional neuroanatomy of speech perception. In: *Trends in cognitive sciences*, v. 4, n. 4, p. 131-138, abr. 2000.

HICKOK, G.; POEPPEL, D. In: *Processing.* v. 8, n. May, p. 393-402, 2007.

JANSSEN, T. M. V. Frege, Contextuality and Compositionality. In: *Journal of Logic, Language and Information,* v. 10, p. 115-136, 2001.

KAMIDE, Y.; ALTMANN, G. T. .; HAYWOOD, S. L. The time-course of prediction in incremental sentence processing: Evidence from anticipatory eye movements. In: *Journal of Memory and Language,* v. 49, n. 1, p. 133-156, jul. 2003.

KIM, A.; LAI, V. Rapid interactions between lexical semantic and word form analysis during word recognition in context: evidence from ERPs. In: *Journal of cognitive neuroscience*, v. 24, n. 5, p. 1104-12, maio. 2012.

KIM, A.; OSTERHOUT, L. The independence of combinatory semantic processing: Evidence from event-related potentials. In: *Journal of Memory and Language,* v. 52, n. 2, p. 205-225, fev. 2005.

KOTCHOUBEY, B. Event-related potentials, cognition, and behavior: a biological approach. In: *Neuroscience and biobehavioral reviews*, v. 30, n. 1, p. 42-65, jan. 2006.

KUTAS, M. Event-related brain potentials (ERPs) elicited during rapic serial visual presentation of congruos and incongruous sentences. In: *Current Trends in Event-Related Potential Research,* v. 40, p. 406-411, 1987.

KUTAS, M.; HILLYARD, S. Reading Senseless Sentences: Brain Potentials Reflect Semantic Incongruity. In: *Science*, v. 207, n. January, p. 203-205, 1980.

KUTAS, M.; HILLYARD, S. Brain potentials durig reading reflect word expenctancy and semantic association. In: *Nature*, v. 30, n. 307, p. 161-163, 1984.

KUTAS, M.; NEVILLE, H.; HOLCOMB, P. A preliminary comparison of the N400 response to semantic anomalies during reading, listening and signing. In: R. ELLINGSON, N. MURRAY, A. H. (Ed.). *The London Symposia - EEG Supplement-39*. 1. ed. London: Elsevier Science Publisher / Biomwdical Division, 1987. p. 325-331.

LAGE, A. C. et al. Potenciais relacionados a eventos (ERP) revelam o curso da derivação sintática e a dinâmica da integração entre micromódulos de cognição de linguagem. In: *Ciências e Cognição*, v. 13, p. 3-13, 2008.

LAU, E. F.; PHILLIPS, C.; POEPPEL, D. A cortical network for semantics: (de)constructing the N400. In: *Nature reviews. Neuroscience*, v. 9, n. 12, p. 920-33, dez. 2008.

LENT, R. *Neurociência da mente e do comportamento.* Rio de Janeiro: Guanabara Koogen, 2008. v. 66, p. 374

MÜNTE, T. F. et al. Decomposition of morphologically complex words in English: evidence from event-related brain potentials. In: *Brain research. Cognitive brain research,* v. 7, n. 3, p. 241-53, jan. 1999.

PHILLIPS, C.; KAZANINA, N.; ABADA, S. H. ERP effects of the processing of syntactic long-distance dependencies. In: *Brain research.* Cognitive brain research, v. 22, n. 3, p. 407-28, mar. 2005.

POEPPEL, D.; HICKOK, G. Towards a new functional anatomy of language. In: *Cognition,* v. 92, n. 1-2, p. 1-12, 2004.

PYLKKÄNEN, L. et al. Neural correlates of the effects of morphological family frequency and family size: an MEG study. In: *Cognition,* v. 91, n. 3, p. B35-45, abr. 2004.

PYLKKÄNEN, L.; LLINÁS, R.; MURPHY, G. L. The representation of polysemy: MEG evidence. In: *Journal of cognitive neuroscience*, v. 18, n. 1, p. 97-109, jan. 2006.

RIEKE, F. et al.. *Spikes: Exploring the Neural Code.* (1997). Cambridge (MA): MIT Press, 1999. p. 395

SANFORD, A.J. et al.. Anomalies at the borderline of awareness: an ERP study. In: *Jounal of Cognitive Neuroscience,* v. 23, n. 3, p. 514–523, 2011.

SHEPHERD, G. *Neurobiology.* 1st. ed. London: Oxford University Press, 1994. p. 784

SMITH, M. E.; HALGREN, E. Event-related potentials during lexical decision: Effects of repetition, word frequency, pronounceability, and concreteness. In: *Electroencephalogr. Clin. Neurophysiol.Suppl*, v. 40, p. 417-421, 1987.

VAN PETTEN, C.; KUTAS, M. Interactions between sentence context and word frequency in event-related brain potentials. In: *Memory & cognition,* v. 18, n. 4, p. 380-393, 1990.

VAN PETTEN, C.; KUTAS, M. Influences of semantic and syntactic context on open- and closed-class words. In: *Memory & cognition*, v. 19, n. 1, p. 95-112, jan. 1991.