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THE FUNCTIONAL ANALYSIS OF THE N400 COMPONENT: LEXICAL ACCESS, INTEGRATION OR CAN WE HAVE IT BOTH WAYS?

A ANÁLISE FUNCIONAL DO COMPONENTE N400: ACESSO LEXICAL, INTEGRAÇÃO OU OS DOIS?

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ABSTRACT

In this study, we provide a functional analysis of the N400 component. This is a much replicated neurophysiological response which occurs 400ms after the onset of stimuli. This response is said to reflect the degree to which preceding context (sentences or priming words) predicts an upcoming word, and thus affects its processing. Competing hypotheses claim that cognitive operations underlying N400 effects are either lexical access or integration of the word in the preceding context. Lau *et al.* (2006) compared N400 effects in priming pairs and sentential contexts, and found quantitative differences, but no qualitative differences. This led them to conclude that lexical access is the underlying operation reflected in N400 effects in both cases. We challenge that conclusion by showing that structure mediates relations between words, even when not in a sentential content.

KEYWORDS: N400, priming, sentence processing, ERP

RESUMO

Neste estudo, contribuímos para a análise funcional do componente N400, uma resposta neurofisiológica já muito descrita que ocorre aos 400 ms após o início de estímulos. Essa resposta é dita, refletindo o grau em que o contexto precedente (sentenças ou palavras primárias) prediz uma palavra futura e, portanto, afeta seu processamento. Hipóteses concorrentes afirmam que as operações cognitivas subjacentes aos efeitos do N400 são o acesso lexical ou a integração da palavra no contexto anterior. Lau *et al.* (2006) compararam os efeitos do N400 em pares de priming e contextos sentenciais e encontraram diferenças quantitativas, mas não diferenças qualitativas. Isso os levou a concluir que o acesso lexical é a operação subjacente refletida nos efeitos do N400 em ambos os casos. Desafiamos essa conclusão mostrando que a estrutura media as relações entre as palavras, mesmo quando não em um conteúdo sentencial.

PALAVRAS-CHAVE: N400, *priming*, processamento de sentenças, ERP.

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Introduction

Focusing on an illustrious event-related brain potential[3] (ERP), the N400, we provide a neurophysiological experiment customized to compare the most compelling accounts of this ERP's etiology: (i) a reflection of the degree to which preceding context (sentences or priming words) predicts an upcoming word, and thus affects its processing; (ii) a reflection of simple lexical access, both in prime target pairs or in richer sentential contexts, that are said to differ only qualitatively (Lau *et al*. 2006).

In order to assess these possibilities we replicated a study by GOMES (2009) adding priming pairs that allowed to probe for both semantic and syntactically mediated relations between prime and target (e.g. [*PEEL* [(of) [*banana*]]), which are faster to process at a greater cost, pointing to the specific cognitive nature of mechanisms involved. Like Lau *et al.*(2006), we also compared N400 effects in priming and sentences, but we repeated target words over all conditions to strengthen comparability. Moreover, we presented stimuli at short SOAs, which enhance the effects of fast automatized processing mechanisms. We found important qualitative differences in the topographical distribution of the effect and also in the direction to which the effect gravitates: semantic priming facilitation , and greater difficulty in syntactic integration. Additionally, we found that priming effects modulate both amplitude and latency, while in sentence context, mostly amplitude varies. These results indicate that a more unifying account explains the data better, in which lexical access and integration process interact in complex ways, a view that is also corroborated by recent functional neuroanatomic models of language processing.

Before presenting the study, we ponder about the most relevant findings in the literature which will also help to delimit the processing mechanisms involved in its occurrence.

The N400 component: a bit of history

As so many great discoveries, the N400 component, one of the most well-known Event Related brain Potentials (ERP), was found 'by accident' in 1978 when Kutas and Hillyard were carrying out a study with an oddball paradigm design, but instead of using the customary simple

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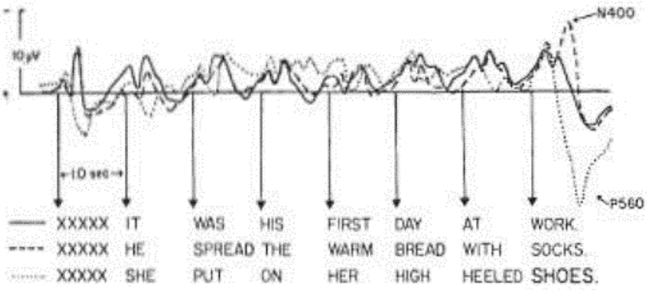
[3] Event Related brain Potentials are extracted from continuous EEG recordings in which stimulus presentation onset is marked so that the signal can be segmented to study neurophysiological responses to stimuli. Segments are added and averaged per experimental condition so that they may be compared for condition effects. This is measured by comparing amplitudes (in voltage) and latencies (moment of maximum peak in ms) in a given time interval. An N400 component is thus a negative amplitude peak approx. 400ms after stimulus onset, a P300 effect is a positive peak approx. 300ms after stimulus onset.

visual stimuli they decided to try out linguistic stimuli. Since the P300 effect (a salient positive peak amplitude around 300ms after stimulus onset) had been robustly captured in ‘oddball paradigms’, in which the subject’s expectation is violated by varying a much repeated stimulus with an infrequent deviating one (for example, a list of O’s suddenly alternated with an X), they anticipated that unpredictable sentence endings (e.g. *He spread the warm bread with* *socks*) would yield an effect as well. Much to their surprise they found a later component, a negative peak at about 400ms after word onset, which became known as the N400, with high negative amplitude peaks (by convention, negative voltage is plotted upwards) associated to cognitive difficulty of integrating semantically implausible words in sentences (KUTAS, M. HILLYARD, 1980) (see Figure 1).

Figure 1: Adaptation of the ERP graphs presented by Kutas & Hillyard (1980: 203). Marked by the arrow pointing to the negative inflection of the wave, we can see the high amplitude of the N400, which is characteristic of implausibility effects. We can see that the manipulation of the physical properties of the word (CAPITAL vs lowercase) does not lead to a similar effect (marked by the arrow indexed P560).



Although the component has since then been found with stimuli other than language - for example, with images (KUTAS & FEDERMEIER, 2011) - a violation of melody expectancy will not result in an N400 effect (KUTAS, M. VAN PETTEN, 1988). The neurophysiological signature seems to be engaged with the processing of significant symbolic representations that tie a form to meaning stored in long term memory - one of the primary characteristics of language (SOTO, 2014).

The cognitive specificity of these symbolic representations, and the possibility of testing hypotheses regarding the serial nature of language processing owing to the quintessential online nature of ERP measures quickly sparked researchers’ interest. Already within the first decade of its discovery, scientists confirmed the robustness of the N400 component in auditory and visual modalities (KUTAS, M. VAN PETTEN, 1988; HOLCOMB & NEVILLE, 1990; BROWN, C. HAGOORT, 1993), with a range of languages from different ‘language families’, for instance English as well as Finnish (RELANDER et al., 2009), with spoken or signed language (NEVILLE *et al*., 1997; KUTAS & FEDERMEIER, 2011), and at a wide range of presentation durations or SOAs[4], ranging from 40 to 250ms (KUTAS, M. VAN PETTEN, 1988; BROWN, C. HAGOORT, 1993; ROSSELL et al., 2003; GREWE et al., 2007; LAU et al., 2008; KUTAS & FEDERMEIER, 2011). Also from the early 90s, studies showed that by manipulating strictly lexical features, such as word frequency, word repetition, phonotactic probability, or morphological priming (OSTERHOUT *et al*., 1997; PYLKKÄNEN, 1997; MUNTE *et al*., 1999; KUTAS & FEDERMEIER, 2000a; PYLKKÄNEN *et al*., 2000; STRINGFELLOW & MARANTZ, 2002; DOM et al., 2004; MARANTZ, 2005a; FRANÇA, A.I., LEMLE, M. GESUALDI, A.R, CAGY, M. INFANTOSI, 2008; LAU et al., 2008; SOTO, 2010; GARCIA et al., 2012), in word stimuli, presented in isolation or in priming pairs[5] also rendered N400 effects, this time with lower peak amplitudes associated to facilitated access (SOTO, 2014).

However, from the start, its exact functional analysis has been a topic of debate. On the one hand, this stems from the different contexts in which the component is elicited (sentences and word contexts). This has led to opposing views which either see the N400 as reflecting integration of processes such as a word into the previous context () or lexical access (for reviews of current debate KUTAS, 2011; LAU *et al.*, 2009). There are furthermore discussions on how these progresses might be affected, by predictive strategies of a specific word in a context or by automatic spreading activation of semantic, phonological or morphological features of words irrespective of context (FEDERMEIER et al., 2007; LAU et al., 2009). Still, another view would be that, given the summed nature of ERP components[6], the N400 could be a complex component underlying multiple computations at once, or reflecting different computations depending on task demands or the stage of processing (LAU et al., 2008; KUTAS & FEDERMEIER, 2011).

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[4] SOA stands for stimulus onset asynchrony, which is the time between the onset of the first stimulus until the onset of the second (following) stimulus. SOA comprises of presentation time plus interval time. In general, it is assumed that if SOAs are short, faster automatic processing can be captured, while longer SOAs capture higher level processing, which packs in more processing information within the longer course of processing.

[5] In a word priming paradigm, different types of relations between prime (1st word) and target (2ndword) are manipulated, such as: semantic association (*apple-pear)*, morphological relation *(teach-teacher)*, phonologic similarity *(peach-pea)*, repetition*(peach-peach)*, to name a few. The rationale behind this is that the activation of the second word is affected (facilitated or hindered) by the activation of the previously presented word (the prime). Depending on the research hypothesis, a specific kind of relation can be manipulated in order to assess its involvement in word representation and processing.

[6] The EEG signal is the result of the activity of a given neuronal population, but from the signal captured by electrodes from the outside (the scalp), there's no unequivocal way to determine where the signal was generated, and whether it is the result of two or more populations firing at once or one after the other. Also, intervening brain tissue (between generator source and scalp) and varying angles of position of neurons in the gyrating layer of the cortex affect the signal in sometimes unpredicting ways (SOTO, 2014). So in analyzing ERPs, one should keep in mind that any data point in time represents the sum of all potential values and brain wave frequencies that make up a complex EEG signal (LUCK, 2005).

N400 and the matter of cognitive specificity of processing mechanisms

Crucially, the debate about the functional analysis of the N400 component is further complicated because scientists may differ in their theories regarding the specific nature of the language phenomena, and this directly influences the nature of the representations believed to be involved. Kutas, for instance, refers to the N400 as reflecting access to a “knowledge base, known as ‘semantic memory’, often in response to a linguistic cue in the form of a spoken, written or signed word” (KUTAS & FEDERMEIER, 2000b: 436). The notion of linguistic content as a ‘cue’ to rich conceptual structures is typical of theories that are semantic-centered; formal theories, on the other hand, emphasize the importance of language structure in constructing and organizing meaning, for example, in the way entities and events are marked by lexical categories (marry-V vs. marriage-N vs. marital-A), in the way events are structured by thematic grids (number of arguments and syntactic positions projected by the verb and their semantic interpretation: e.g. x-agent (marry (y-patient))) and case marking (e.g. x-NOM(inv*ite(y-ACC))*), or in the way duration of events are interpreted through aspect and object noun type (e.g. *eating the cake in ten minutes* vs. *eating cake all day*), etc. These examples show how meaning can be mediated strongly by language structure (SOTO, 2014). This does not mean that conceptual knowledge does not exist without language. On the contrary, it does. But the question is *whether* the architecture of language equips humans with a special way to make sense of the world and *how and when* we tap into the world knowledge through syntactic categories (aspect, tense, numerosity, etc.) and their combinations (SOTO, 2014).

If we look at the scope in which language specific properties can effect comprehension, indeed ERP methodologies have brought much evidence to show that very detailed linguistic information has an immediate effect on processing streams. Manipulations of word category information, for example, affect ERP signals at 40-90ms after word onset, and 120-150ms if there is a category violation (e.g. I washed my dirty *handed,* a verb where a noun is expected, see FRIEDERICI, 2012 and KUTAS, 2010 for reviews). Other structural variables that modulate the N400 effect are morphological priming (e.g. *teacher-teach*) independent from orthographic or semantic priming with both masked and unmasked priming (MARANTZ, 2005a; MORRIS & HOLCOMB, 2005; STOCKALL & MARANTZ, 2006; MORRIS et al., 2007; FRANÇA, A.I., LEMLE, M. GESUALDI, A.R, CAGY, M. INFANTOSI, 2008), and effects of syntactic complexity with Wh-questions (*Which songs will he sing* vs. *cook?*, (FRANÇA, 2002), pronominal referencing (*He took the knife and he’s going to sharpen/cut it*, noting that, in Portuguese, pronominal references agree in gender, which enhances the violation (FRANÇA, GESUALDI, & SOTO, 2012).

Given the evidence of syntactic involvement in the processes underlying the N400, which is generally characterized in literature as reflecting semantic processes (FEDERMEIER et al., 2007; FRANKLIN et al., 2007; LAU et al., 2008; KUTAS & FEDERMEIER, 2011), the phenomenon may be placed at the heart of the syntax-semantics interface. Under this view, in a sentence such as *Joe drank the tea vs. teepee (*'João bebeu o chá vs. chalé', FRANÇA *et al.* 2004) the neurophysiological response to a target word would reflect the moment in which the verb (or any other complement projecting item, such as a preposition) attributes a theta role (e.g. *theme* or *patient*) to a given argument. By attributing a theta role, and marking an argument morphosyntactically by case (turning it into a subject or object), structures are licensed as 'sound' or interpretable, or unlicensed and hard to process in the case of violation. This micro syntactic bootstrapping allows for the semantic interpretation of linguistic expressions because the structuring of objects (complements or internal arguments) and subjects is closely linked to the interpretation of the involvement of participants in the (verbal) event, for example as *agent* (for subjects) or *theme* undergoing the action (for objects). Moreover, lexical representations of verbs may contain not only a more abstract theta-grid, but also constrain their arguments with minimal semantic features, such as object [+drinkable] (SOTO, 2014).

A similar mechanism of the projection of argument structure and theta role attribution might also explain what occurs during word priming. Gomes (2009) showed that priming effects for word pairs such as *PEEL-banana* are greater –as reflected by faster latencies and larger wave amplitudes- than for PEEL-*fall*[7] and, surprisingly, also than for *BANANA-peel* (note that here by coincidence the literal translation of the original pair in Portuguese *BANANA-casca,* is a very logical combination in English*,* but not in Portuguese). Especially the fact that directionality matters, shows that not all semantic associations are similar. The explanatory hypothesis is that an inevitable underlying syntactic mechanism will always attempt to establish a syntactic link between words, by way of a preposition or verb phrase. As such, pairs that are easily structured [PEEL PP[of [banana]]], are recognized faster than those, such as *FALL-banana* or *BANANA-peel* in which structure cannot easily intervene. In linguistic theory, mechanisms that create juxtaposition (as in *BANANA-peel*) and those that create structure (as

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[7] The priming effect is explained by the probability of spontaneous syntactic structuring between nouns. Therefore, *PEEL* easily leads to *banana* by intermediation of a prepositional phrase headed by *de* or *com*. The word *BANANA* as a prime is much less constrained, in that it will relate to anything from *(in the) tree* to *(with a) peel* which, by virtue of being less specifically directed to either *tree* or *peel* than *PEEL* to *banana,* causes the lack of priming for a pair such as *BANANA-peel.* For a pair such as *PEEL-fall*, we can imagine a strong associative link, in that, a peel might easily cause a fall, but this associative relation is not easily syntactically structured, and, therefore, lacks the strong priming effect of *BANANA-peel.*

peel-BANANA) and are termed subordination and coordination, respectively. The former is the essential ingredient for recursion, the ability to embed a structure of a given nature (e.g.. a prepositional phrase (PP)) into a structure of the same nature, repeatedly until memory imposes its boundaries. In a recent study, recursion of repeated PPs was compared to coordination of PPs, in examples such as *The cook placed the silverware [in the drawer [in the cabinet [in the kitchen]]]* (ex. of recursion of PPs) vs. *The cook placed the silverware [in the drawer], [in the cabinet], and [in the kitchen]* (MAIA *et al.*, 2018). In the first example, only a recursive reading is possible in which the correct order of interpretation is crucial (i.e. the drawer is in the cabinet that is in the kitchen), in the second example the PPs may be interpreted in any order and still be true (i.e. the silverware is in the cabinet, and in the kitchen, and in the drawer). N400 measures indicated that although the first recursively embedded PP (the 2nd PP) requires additional cognitive effort as reflected by increased amplitudes, processing is faster from then on (as reflected in latencies), when compared to processing of coordinated PPs. This again shows that there is a cognitive difference between semantic relations mediated by syntactic hierarchy and those that are not, which can be effectively caught by N400 measures.

However, the predictability that modulates the N400 effect may depend on a wide variety of preceding cues. They might be syntactic in nature, but they may also include anything ranging from semantic fields to pragmatics, to world knowledge. There are many studies that attest to the influence of different levels of context. For example, with sentences such as *They wanted to make the hotel look more like a tropical resort. So along the driveway they planted rows of ...palms vs. pines vs. tulips,* Federmeier and Kutas (1999) wanted to study the effect of sentential context on endings varying in improbability. They found a modulation of the effect in which the word *tulips* shows the highest amplitude due to incompatibility with preceding sentential context (characterized by *tropical resort* and *driveway*); whereas pines, equally improbable, showed intermediate amplitudes, according to the authors due to semantic relatedness to the word *palms*, the preferred ending. This result shows a mixture of effects of specific context (as constructed by the sentence of a whole) and of a subset of semantic cues generated by the prediction of the specific context (anything tree-like). It is difficult to determine in this case, whether the probability effect is due to the context as a whole, or due to the priming effect of individual words in the sentence (ex. tropical, driveway, planted, rows of) (SOTO, 2014). Alternatively, the influence of a more immediate (syntactic-semantic) context rather than the whole sentence could also play a role in the gradual plausibility of the lexical item commonly following *rows* of… But with these types of studies, rarely are the predictive factors of global vs. local context considered as possible confounds. Moreover, if individual words generate automatic activation spreading, does that mean that automatic spreading is simply default for lexical access, or does it imply something like surface reading, as proposed by psycholinguistic models such as *The Good Enough* approach (FERREIRA; BAILEY; FERRARO, 2002)? This model basically claims that detailed complete syntactic processing is not always necessary to interpret sentences, rather processing based on heuristic parsing mechanisms, and more shallow or sometimes incomplete semantic processing is often good enough to reach satisfactory comprehension. That is, adhoc, we pick out most salient information (world knowledge, semantic and syntactic) and make some sense of it, due to the time pressure of the rate at which new information keeps coming in. That even world knowledge can generate N400 effects was shown by Hagoort *et al.* (2004). In their experiment, the authors manipulated conceptual knowledge vs. world knowledge, where conceptual violations *(Dutch trains are sour)* yielded similar N400 effects as world knowledge violations *(Dutch trains are white,* when in reality Dutch trains are yellow). These examples are among many that show that higher level information, including extralinguistic information, and surface reading processing might affect N400 responses.

Nevertheless, this field is immersed in a lot of contrasting viewpoints. Some eyetracking studies contradict these findings (RAYNOR, CARLSON & FRAZIER, 1983; RAYNOR, GARROD & PERFETTI, 1992). They presented garden path type stimuli in which world knowledge could guide processing such that garden path effects could be avoided (e.g. *The performer sent the flowers x The florist sent the flowers …was very pleased*), based on common knowledge that usually performers receive (i.e. *are* sent) flowers, while florists send them. In 1993, they published a study investigating the possible attenuation of garden path effects by discourse context (i.e. discourse context was either supportive or non-supportive of a reading that avoided garden path effects). In both studies, authors concluded that initially world knowledge and discourse context do not affect processing (as garden path effects were not avoided or reduced), but that reanalysis (i.e. attempt to reinterpret the sentence correctly) was easier when world knowledge and discourse context could aid interpretation. These data seem to indicate that which information is accessible is a matter of time. A view held by models that predict strict serial and modular processing streams according to which N400 effects as a result of manipulations of world knowledge or discourse information reflect post syntactic processes (i.e. after strictly linguistic modular processes have been completed) (SOTO, 2014).

Chow *et al.* (2016) also present evidence to show that which factors affect prediction (which they characterize in terms of memory retrieval) may vary as processing unfolds. They cite several examples from a series of studies on the predictive effect of preceding arguments on lexical access of verbs. In one study, in which they presented sentences with reversal of expected argument roles, N400 responses to verbs were not affected, whereas offline cloze measures[8] showed large effects (e.g. *The restaurant owner forgot which waitress the customer had served)*. On the other hand, when argument roles were substituted (e.g. *The superintendent overheard which realtor* [substituting *tenant*] *the landlord had evicted ...*), N400 effects paralleled offline cloze effects. This indicates that at an early stage meaning might be more influential than structural information, at least when it comes to verb prediction. However, yet another example presented argument substitution while leaving the expected argument in another structural position in the sentence (e.g. *The exterminator inquired which neighbor the landlord had evicted ... vs. The neighbor inquired which exterminator the landlord had evicted...*). In this case, the latter yielded an N400 effect showing that participants were especially sensitive to words in argument positions, and that the presence of the expected word in a different structural position was unable to repair the reduced predictability.

Pre-tests collecting cloze measures are a common practice in N400 studies. The assumption is that a percentage representative of how many times a given word was filled in a given slot in a given sentence by participants correlates with how easy or difficult that word is activated during sentence processing. Considering that this correlation mostly bears out for studies that use long SOAs, it might well be that cloze measures reflect more conscious processing well, but perhaps are not very representative of faster more automatic lexical access, nor for the complex interactions of the different types of information available over time as sentence processing unfolds. Many studies do not fully explore the combination of syntactic and semantic features that are at play during sentence processing the way the Chow *et al.*(2016) study does. In fact, conditions of cloze completing are barely comparable to those of online sentence processing, for which there is no total access to the entire scope of a sentence at once (we receive information linearly, and process it incrementally), nor time to consciously think of the most logical word among many options.

Thus, a crucial issue in N400 experimental design how much the time the participant has to process information. In real life conversation, we accept no interruption, and there is

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[8] Cloze tests are thought to say something about the probability of a lexical item to appear in a given (sentential) context. It was initially developed by Taylor in 1958 as a way to measure effective communication, and it was largely applied in the educational realm, for training and testing comprehension, reading and vocabulary knowledge (Sadegi 2008). In language studies, cloze tests have been used to determine the 'degree of fit' (Federmeier et al. 2007) of a particular item in a given sentence. The degree of fit is then measured according to the frequency with which it was used to complete a blank in a given sentence, and expressed as cloze probability in a percentage of the total number of blanks filled out. The best fit, or 'best completion', is than the item with the highest cloze probability (SOTO, 2014). In psycholinguistic as well as neurolinguistic studies, cloze probability is associated with facilitated cognitive processing to such a point that the level of cloze probability for congruous sentences is directly correlated by measures, be they reaction times or neurophysiological responses such as the N400 (Federmeier et al. 2007; Jordan and Thomas 2002; Rayner and Well 1996).

incredible time pressure. In an experimental setting, if the design is lenient, with presentation times of 300ms per word plus an interval of a 300ms more, subjects might have ampler time to incrementally process, using any cue, ranging from syntactic to world knowledge depending on both the duration of stimuli presentation and time pressure of task demands. The question is whether those are compatible with natural auditory comprehension processing rates, estimated at an average of approximately 300ms per word (without the interval, based on 190-200 word per minute rates) (HAYATI, 2010). Average reading rates are 4 to 5 words per second, or an approximate 20ms per letter (DAMBACHER et al., 2009). Thus, importantly, here it will be argued that depending on the SOA chosen for the experimental design, different types of information and processing strategies become available; that is, different variables can drive the N400 effect depending on the SOA (SOTO, 2014). In this study, we are interested in investigating how syntactic structuring mediates lexical access and integration. In accordance to serial models of language processing, we believe that, although many types of information may guide processing, syntactic computation is a default mechanism, minimal in nature, automatic and inevitable, constituting the first linguistic processing stage. Contrary to models of or superficial processing, we consider that 'deep' syntactic interpretation might have is not costly (both time and effort-wise) at all; on the contrary, it is the fastest, and most easily triggered mechanism for linguistic processing. Therefore, in the current study, SOAs are kept to a minimal 350ms.

N400 and its functional analysis

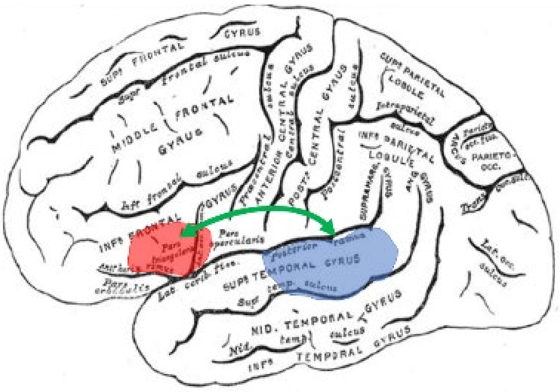
The first N400 studies in the 80s replicated results found by Kutas and Hillyard (1980) who presented subjects with sentences such as *I take my coffee with cream and dog* and found higher more negative amplitudes at 400ms after word-onset (of *dog*) in comparison to the same sentence with the semantically compatible ending *...and sugar*, thus, neurophysiologically marking semantically implausible endings to sentences. In the many studies that followed in the 80s and 90s (KUTAS, M. VAN PETTEN, 1988; OSTERHOUT et al., 1997; BERKUM et al., 1998; FEDERMEIER & KUTAS, 1999; KUTAS & FEDERMEIER, 2000b), scientists discovered that the N400 amplitude varies according to the degree of semantic (im)plausibility (e.g. higher amplitudes for *Joe ate a shoe* than for the less plausible, but slightly possible *Joe ate a Coca-cola*), directly linking higher voltage values with increased cognitive effort to integrate ill-fitting lexical items in preceding contexts. Given that the effect had been found in the context of complement selection by verbs and prepositions (both theta-role assigning predicates), linguists quickly correlated the N400 component to theta-role attribution, as it marks the moment of verb-complement *merging* as a result of the projection of the verb's theta-grid (CHOMSKY, 1993). Results obtained by França *et al.* (2004) showed that N400 is also modulated by long distance dependencies between verbs and their complements. For example, in Wh-questions *Which songs will he sing* vs. *11?*, França, 2004), pronominal referencing (*He took the knife and he's going to sharpen/cut it*, noting that, in Portuguese, pronominal references agree in gender, strengthening the violation, França, Soto and Gesualdi, 2012*)*, further confirming the involvement of semantic-syntactic dynamics (SOTO, 2014).

To complicate the picture even more, in the 90s, researchers started investigating the N400 in the context of *priming* and isolated word presentation. In these experiments, purely lexical variables, such as repetition, frequency and phonotactic probability, seemed to affect the component (HOLCOMB & NEVILLE, 1990; BROWN, C. HAGOORT, 1993; KUTAS, 1993; PYLKKÄNEN et al., 2000; KUTAS & FEDERMEIER, 2000b; LAU et al., 2008), equally correlated with relatively increased or decreased cognitive effort. Hence, hypotheses emerged linking the N400 also to lexical access. In fact, by framing the N400 effect as mainly a question of predictability, rather than implausibility, relative amplitude increase or decrease to words in sentences could just as easily be attributed to either facilitation due to high predictability or strong mismatch effects when the upcoming word strongly differs from the predicted lexical item. In fact, some studies show that the N400 is indeed mainly graded by facilitation effects, enhancing activation of lexical candidates according to predictability by the context, and less so by restricting the set of possibly activated candidates, for example by constraining the sentence context, either semantically or syntactically (Federmeier *et al.*, 2007, GASTON *et al.*, 2019).

After more than 3 decades of robust evidence, there is now an impasse as to which functional analysis best fits the N400 data: (i) semantic-syntactic integration of lexical items, or (ii) lexical access? Alternatively, it is quite possible that the N400 is in fact a complex component that may reflect different subjacent operations depending on the context in which it was evoked. In addition, it is not yet clear what information or process is responsible for facilitation effects: is it caused by predictability created by the global context of the sentence, or is predictability generated more locally at phrase level, or is it just a random automatic spreading activation effect? And are these processes part of natural language processing or by-products of time and task demand specifics of experimental paradigms?

Chow *et al* (2016) state that prediction is the biggest factor in modulating the N400 effect. According to the authors, prediction is a mechanism that is ever present in language comprehension as it helps inferring the speaker's message as quickly and efficiently as possible under the given time pressure. In their view, prediction is a matter of memory retrieval: highly predictive contexts pre-activate stored memory representations before an upcoming word even arrives. As such, the authors see the N400 as indexing the relative difficulty or ease with which lexical items can be accessed depending on the predictive cues available in the preceding context. This process is considered in light of a "content addressable memory (CAM) architecture, in which the terms in memory are directly accessed by matching cues to the contents of memory in parallel" (CHOW *et al.*, 2016, p. 622). They do not exclude any type of clue (syntactic, semantic, phonological, pragmatic etc.), nor limit the mechanisms that may further memory retrieval (such as constraint of sentential context, or priming). Mostly, they bring to light evidence (aforementioned in the present article) that what may enhance memory retrieval in a given moment depends on the when the specific cue is available over the course of processing, as well as the interaction of available cues (ex. semantic and structural cues that converge may enhance memory retrieval, a mismatch may delay retrieval). Thus, an effect of facilitation is a matter of efficient cue matching due to high predictability; whereas cognitive difficulty may arise when cues are not quickly matched. For example, in the sentence *The restaurant owner forgot which waitress the customer had* <u>*served*</u> ..., cloze measures indicated a high probability for the final verb *served* in the expected argument role order (*which waitress the customer had served*) and low probability for the reversal of role order (*which waitress the customer had* <u>*served*</u>). These different predictabilities did not show in the N400 measures on the verb, however. According to the authors a mismatch between cues offered by the context and the manner in which the stored memory is encoded might explain the absence of facilitation. They hypothesized that cues available from context, such as *waitress-as an agent or patient,* may have difficulty mapping on to more specific memory encoded event-related representation, such as *waitress-as a server or serve*. Therefore, the delay in accessing the stored memory that would speed up the pre-activation of the verb *to serve* causes the lack of facilitation effect (CHOW, 2016). Nonetheless, the authors caution that this explanation may not account for other semantic and structural relations, for example, in the reverse case of the prediction of arguments by verbs. Indeed, it is not very obvious how this account count would explain the timing advantage of lexical access of the word *banana* in the priming pair *PEEL-banana* (originally, *CASCA-banana*) as compared to *BANANA-peel* (originally, *banana CASCA*). This would mean that there is a specific memory encoded for (*peel of-) banana* easier to find than the memory encoded for *peel (of banana)*, at the same time implying there are similar memories for (*peel of-*) *apple, orange,* etc. While this may not be ruled out, we consider an explanation in which minimal phrase structure ([noun [*of* [noun]) enhances a semantic relatedness between *peel* and *banana* more elegant, and one which clearly explains the directionality of the priming effect (GOMES, 2009; SOTO, 2014). By entertaining the role of minimal phrase building in enhancing the relatedness between prime and target, we effectively say that the effect of (at least syntactic) integration cannot be ruled out as cognitive operation subjacent to the N400 component. That memory retrieval of lexical items and integration are intertwined is also shown in a recent paper by Hultén *et al.* (2018). They used magnetoencephalography (MEG)[9] to track processing of individual words in a sentence context. They found that in the first 150 to 400ms activation bursts traveled from the left occipital, and left occipito-temporal sites (areas related to grapheme recognition and visual word form processing) to the left posterior temporal cortex and finally the left inferior frontal gyrus and anterior temporal lobe (see Figure 2). This sweep of activation suggests that initially bottom up processing drove activation. However, there were two peaks of activation in the left posterior temporal region, first between 150 and 230ms, and second, between 314 and 400ms.

Figure 2: Graphic representation of the anatomical connections proposed by Hultén *et al.*(2018). On the left hemisphere, part of the inferior frontal gyrus (IFG) is marked red, the superior posterior temporal cortex is marked blue. The green arrow connecting the two areas represents existing anatomical connections between the IFG and the SPTC.



The latter peak correlated in activity with activation in the left inferior frontal gyrus from 300 to 450ms after word onset. As such, there appear to be two stages in the retrieval and unification of the retrieved memory representation in the preceding context. The authors stress that there

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[9] Magnetoencephalography (MEG) is used to measure weak magnetic fields that are generated by synaptic activity of neuronal populations using very sensitive magnetometers. SQUIDs (superconducting quantum interference devices) are a type of magnetometer which are currently used for cognitive research by combining temporal precision (similar to EEG) with relatively accurate anatomic localization using powerful mathematic signal localization functions.

is no clear temporal boundary between two stages, rather, the second is characterized by reverberating activity between the left superior temporal cortex and the left inferior frontal gyrus. This activity is bidirectional, in which each direction is characterized by a different frequency band (α waves for the temporal to frontal direction, and β waves for the opposite direction). According to the authors, this *communication through coherence* (Fries, 2015) between oscillatory activity of neuronal populations marks operations that modulate retrieval by unifying it with preceding context, a processes to develops over a period of 500ms. This interpretation ties evidence from ERP components, such as N400, in with Hagoort's Memory Unification Control (MUC) model for the neuroarchitecture of language comprehension, in which functionally and anatomically linked (by extensive fiber tracts) areas such as the left posterior temporal cortex and the inferior frontal gyrus (2005) play a central part. Similar ideas are also reflected in more modular anatomic models, such the one proposed by Friederici (2012).

In important study, Lau *et al.* (2009) addressed the dichotomy of the integration versus lexical access hypotheses, by comparing N400 components in an experimental design with both word priming and sentential contexts. In accordance with the claims defended by Chow *et al.* (2016), they foresee that prediction is key to the N400 effect in both sentence context and priming paradigms. The comparability is based on the supposition that sentence congruency vs. incongruency (e.g. *Joe ate a pizza* vs. *message*) and related vs. unrelated semantic relationships (e.g. *BANANA –apple* vs. *chair*), both manipulate the level of predictability (high vs. low, respectively) and that both impact wave amplitude and, possibly, latency (SOTO, 2014). We concur with their experimental approach, but not with their conclusion. They reported quantitative differences, but no qualitative difference between the N400 effect elicited by sentence and by word priming contexts. They concluded that given the lack of qualitative differences, a similar underlying process in both contexts must be affecting the N400 component, which could, therefore, only be lexical access. Their conclusion is in part built on their assumption that there are no integration processes at work within word priming pairs. As described above, this has already been proven wrong by Gomes' work in 2009, in which she manipulated the 'structurability' factor between semantically related pairs, a variable that Lau *et al.*(2008) did not control for (SOTO, 2014).

It is on these grounds, that in the current experiment we compare N400 effects in sentence context with word pairs that are controlled for syntactic relation; whereas Gomes compares directionality and gradation of this effect, we compare syntactic-semantic priming (e.g. *CAPACETE-moto;* as in *[HELMET (for a) [MOTORBIKE]]*) to associative-semantic priming for which supposedly no syntactic mediation occurs (e.g. *ÔNIBUS-moto* , as in *bus-motorcycle*). In addition, we strengthened comparability by repeating the very same word targets in both sentence and word priming contexts (e.g. *Todos os dias, João dirige a moto feito louco,* as in *Everyday, João rides the motorcycle like crazy*). Lau et al. (2009) favored using cloze measures and a previously used set of priming pairs, which may strengthened predictability; but by not repeating target words, comparability may have suffered.

Hypotheses and expectations

Our premise can be thus formulated as follows: targets of word pairs that can be related both semantically and syntactically, are faster to process at a higher cognitive cost due to the intermediation of syntactic structure as compared to semantically related pairs by association. Consequently, our expectation is that in a word priming paradigm, syntactic-semantic word pairs (e.g. *HELMET-motorcycle*) generate higher amplitudes and faster latencies than associative semantic pairs (e.g. *BUS-motorcycle*), and that both types of priming pairs are faster than unrelated pairs.

Another premise is that lexical access to target words in word priming pairs, and access and integration of words in sentential context are to be compared with great caution, because both reflect subtly different underlying cognitive processes. Experimental manipulation of the predictability factor may yield qualitatively different effects; therefore, we expect neurophysiological responses to target words in sentences and priming pairs to be qualitatively and quantitatively different.

The ERP Experiment

For clarity, we will present the experimental design, data collection and analysis criteria joining both sentence task and the priming task. In fact, data were collected in one session, but in two separate blocks. Results will be presented separately first, and, at the end, comparisons between the two experimental paradigms will be presented.

Materials

For the sentence task, each subject saw 120 sentences: 60 distractors, 30 congruous sentences with a supporting context, and 30 incongruous sentences with the same sentence frame, but with implausible verb complements. Thirty of the distractor sentences were incongruous, to balance YES/NO answers for the incongruency judgment task. After the sentence task, subjects saw 150 word pairs, of which 30 semantically related, 30 syntactically and semantically related, 30 unrelated words and 60 non-words. None of the words were seen more than once by the subjects. Four versions were compiled in which target words were repeated for all conditions except for incongruous sentences and unrelated word pairs (see Table 2).

Table 2: Experimental conditions and sample stimuli for the ERP experiment

Sentence Task			
Condition	**Congruence**	**Stimulus example (n=30 for each condition)**	**Repeated item**
1. CS	Congruous	Até sem capacete, João dirige ↑ a moto feito louco	dirige a moto
2. IS	Incongruous	Até sem capacete, João dirige ↑ a pera feito louco	dirige -

Word Task				
Condition	**Relation**	**Stimulus example (n=30 for each condition)**		**Repeated item**
1. SSR	Syntactic and Semantic	CAPACETE	moto	- moto
2. ASR	Associative Semantic	ÔNIBUS	moto	- moto
Control 1: UR	Unrelated Words	FACA	nuvem	-
Control 2: PW	Pseudo Word Target	FILTRO	garipa	-

Abbreviations: congruous sentence (CS); incongruous sentence (IS);; associative semantic relation (ASR); syntactic and semantic relation (SSR); unrelated pair (UR); pair with pseudo word target (PW)

For each version, 2 pseudo randomizations were created, such that there was an even distribution of conditions in the list. During the study, 8 different lists (4 versions x 2 randomizations) were distributed over all participants.

The stimuli were controlled for length (for the sentence task, average of 9 words (7-11) and for the word task, an average of 5 letters (4-7 letters)) as well as frequency (by applying a google hit count).

To guarantee participants' attention, they were asked to judge whether the sentences made sense or not by pressing a button as soon as the screen presented them with the word RESPONDA ("answer") (i.e. congruency judgment). Similarly, for words, participants were asked to judge whether target words were actual words in Portuguese or pseudowords (e.g. *garrafa* ("bottle") vs. *garufa* (pseudoword) (i.e. lexical decision).

Stimulus presentation

Participants first saw four blocks of sentences (4x30, a total of 120 sentences) in pseudorandomized order. In between blocks there was an interval, the duration of which was determined by the participant. After that, 150 word pairs were presented in pseudorandomized order, in 3 blocks of 50 with 2 intervals. The presentation was programmed and presented with E-prime software, version 2 (developed by Psychology Software Tools, Inc.). Sentences were presented segmented into inseparable linguistic constituents (1-3 words) and word pairs were presented word by word (except for the last segment, which could contain up to 2 words) on a 19 inch screen in white 25 pts times new roman font. For presentation rates, see Table 3:

Table 3: Presentation protocol and SOA for the ERP Experiment

Presentation protocol ERP Experiment: sentence task										
Presented:	+	Até sem capacete,	(blank)	João	(...)	a moto	(blank)	feito louco	(blank)	RESPONDA
Action:						*Target*				*Congruent Y/N?*
Timing: (ms)	1500	300	100	250	(...)	250	100	250	350	1500

Presentation protocol ERP Experiment: word task									
Presented:	+	(blank)	CAPACETE	(blank)	moto	(blank)	muito veloz	(blank)	RESPONDA
Action:			*Prime*		*Target*				*Lexical Decision Y/N*
Timing: (ms)	1500	100	250	100	250	100	250	350	1500

Procedure

Participants were placed in an airconditioned room (ACESIN Lab at UFRJ) in a comfortable chair, approximately 100cm from a 19-inch screen. First participants had to read and sign the Ethical Consent form. Then 64 active electrodes were placed in the appropriate holes according to a 10-20 set-up (JASPER, 1958), with mastoid reference electrodes. Impedance was kept at a minimum, varying from 0 to 30 kOhms.

Participants were placed at approximately 1m from the screen, and instructed to remain as still as possible, and keep blinking, frowning, swallowing and shuffling of feet to a minimum. The task was explained to participants, after which they did a short training session to get used to pace and to verify task comprehension. Participants' judgements were recorded by pressing with one of two fingers of the right hand either a red or a green button on a button box. The position of the green and red buttons, destined for YES and NO responses, was swapped for each participant.

Preparing the subject and recording the data took about 90 minutes.

Participants

Twenty-one university students participated in the study (fem=11), distributed evenly over 4 versions, average age 22 years old, all right-handed, with normal or corrected-to-normal vision.

Recording set-up

For EEG recording ActiCHamp equipment (sold and developed by BrainProducts) was used. The active electrodes are connected to the ActiCHamp amplifier which digitalizes the analogue signal captured by the electrodes. Synchronous to stimuli presentation trigger pulses are sente to the amplifier which mark the beginning of events on the continuous EEG recording. During acquisition the signal was filtered with a 100Hz low-pass and 0,01Hz high-pass filter. The EEG was referenced on-line to left and right mastoid channels. Data were digitalized at a 500Hz sample frequency.

Processing and statistical analysis

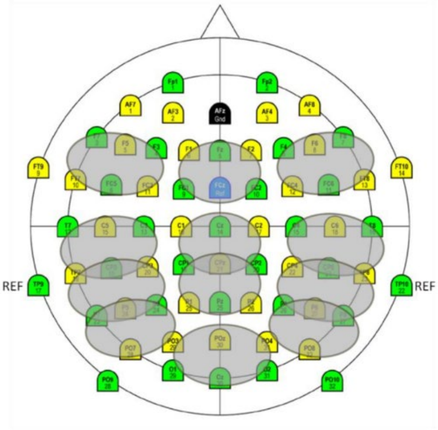
The raw data (the continuous EEG signal with trigger markers) were further processed by the software Analyzer (version 2.0 was used). The continuous EEG signal was segmented into epochs of 1200ms, starting 200ms before and ending 1000ms after trigger markers. During segmenting, baseline correction was carried out (-200 to 0ms). After these steps, the segmented signals were visually inspected for artifacts, and, finally, the signal was filtered with a lowpass Butterworth filter of 30Hz, and corrected for DC Detrend.

Subjects with outlier values (mean + or – 3*SDEV) in every condition or over 30% epoch rejection after artifact inspection were left out of the grand average - the result of averaged ERPs from all subjects.

For statistical analysis, from each subject's ERP, mean amplitude values (in µV) and amplitude peak latencies (in ms) were generated measured within a predetermined time interval (100-300ms; 300-500ms; 500-800ms). The time intervals were chosen based on findings in literature that the component of interest (N400) occurs between 350 and 500ms (KUTAS & FEDERMEIER, 2011). Choosing an ample time interval (300-500ms) avoids data-driven bias, and captures the broad negativity that generally characterizes responses to linguistic stimuli. Mean amplitudes are averages of all µV data points in the predetermined time interval, while peak latencies reflects the moment (in ms) of the highest peak within the predetermined time interval, as measured by the peak measuring algorithm of the processing platform (Analyzer

Amplitudes and latencies were analyzed with repeated measures analyses of variance (ANOVA) within 12 six-channel-groups (see Figure 3), or so-called Regions of Interest (ROIs). ROIs were chosen based on anatomic proximity. Along the mid-line, they were: Frontal (F1, F2, FC1, FC2, FCz and Fz); Central (C1, C2, CP1, CP2, CPz and C), Parietal (CP1, CP2, CPz, P1, P2, and Pz), and Occipital (O1, O2, Oz, PO3, PO4, and POz). On the left hemisphere, they were Frontal (F3, F5, F7, FC3, FC5 and FT7); Central (C3, C5, CP3, CP5, T7 and TP7), Parietal (CP3, CP5, P3, P5, P7 and TP7), and Occipital (P3, P5, P7, PO3 and PO7). And on the right hemisphere, they were: Frontal (F4, F6, F8, FC4, FC6 and FT8); Central (C4, C6, CP4, CP6, T8 and TP8), Parietal (CP4, CP6, P4, P6, P8 and TP8), and Occipital (P4, P6, P8, PO4 and PO8).

Figure 3: ROI definition as based on anatomical proximity



After pooling channels for each subject, a grand average (joining all subjects´ averages) was generated to plot the final ERP graphs. However, three-way ANOVA model (Type III)analyses are based on subject averages. Experimental variables, as well as ROI, and hemisphere were included for analysis. Statistical analysis was carried out in R (version 3.4.4).

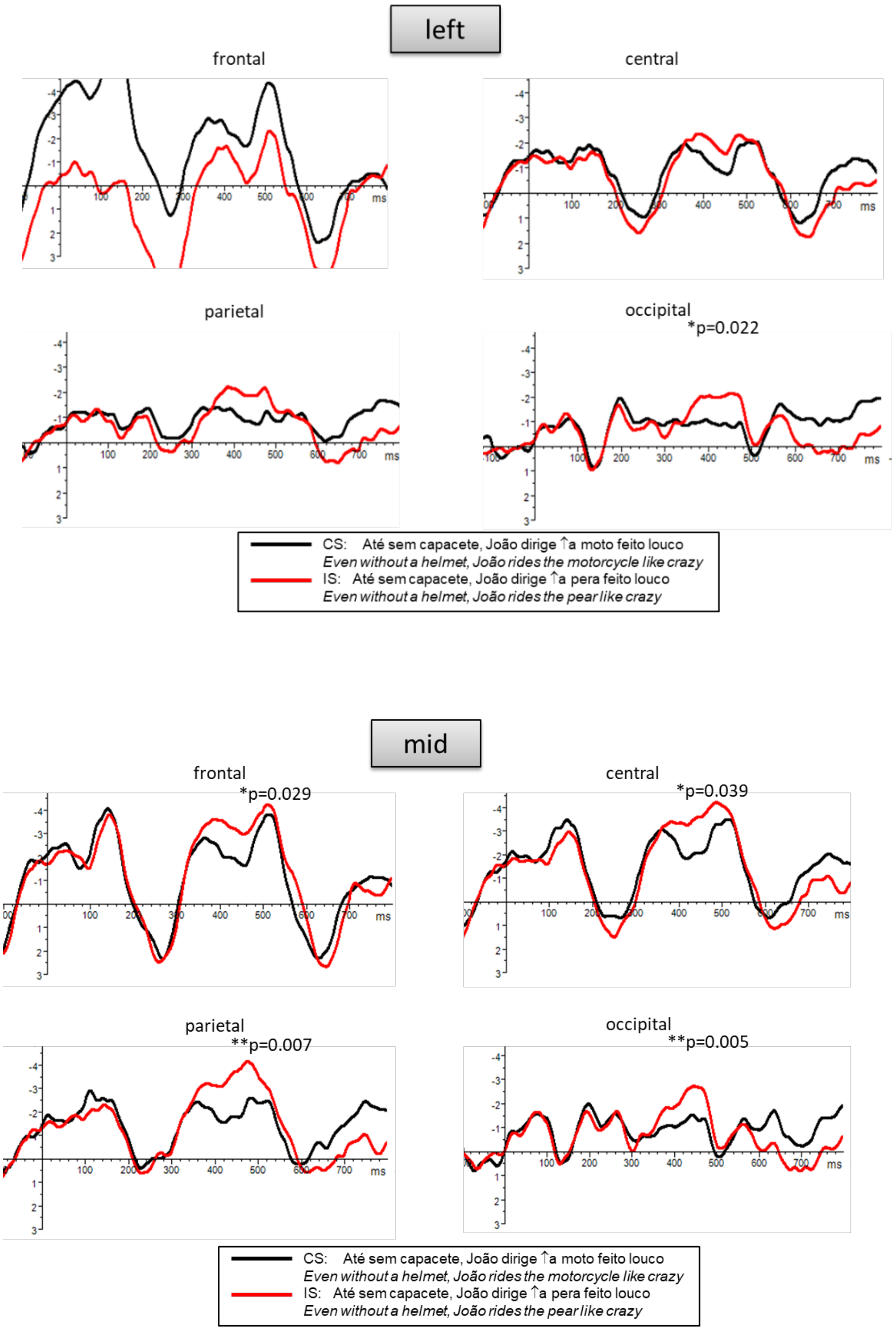
Results: sentence task

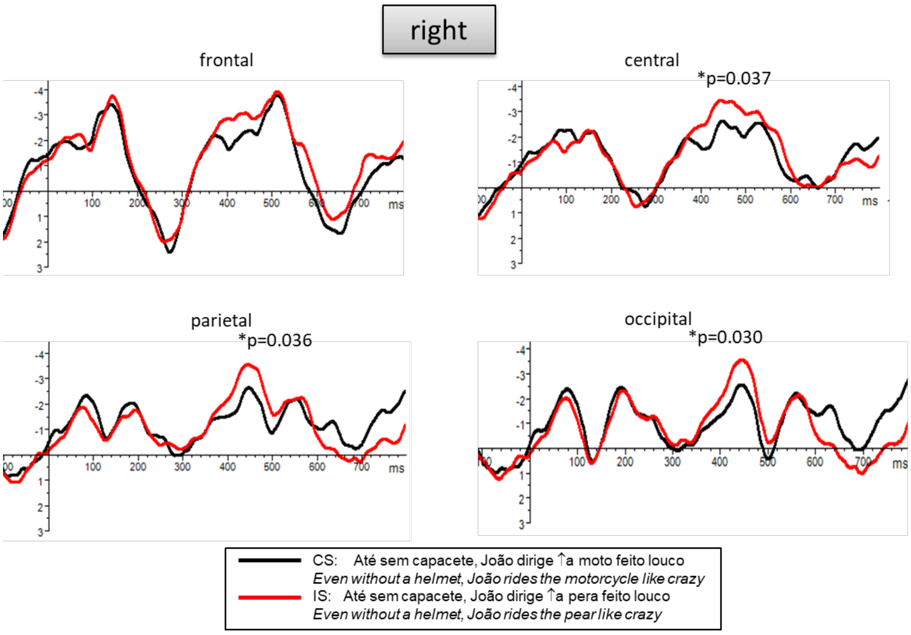
From 21 data sets, 17 were processed; 3 were rejected due to low signal to noise ratios (due to high frequency noise and eye blinking artifacts etc.) which lead to an epoch rejection of over 30%. One subject was excluded from analysis due to technical problems during recording.

The behavioral measures showed that on average subjects judged 89,2% of sentences correctly as either congruous or incongruous, thus qualifying their level of attention as adequate.

In Figure 4, we can see the waveforms for all of the ROIs for the conditions (i) congruous sentence (CS); and (ii) incongruous sentence.

Figure 4: ERP graphs for the sentence task for left hemisphere, mid area, and right hemisphere, separated by ROI





In the ERP graphs (Figure 4), we can see that wave patterns are roughly similar for all ROIs with two major peaks: the first in the 0-300ms interval, and the second in the 300-500ms window. In the negative peaks in the second interval, the main effect for congruency (congruous vs. incongruous) is visible. In the following sections statistical analyses for this variable, as well as interactions with ROI and hemisphere are presented.

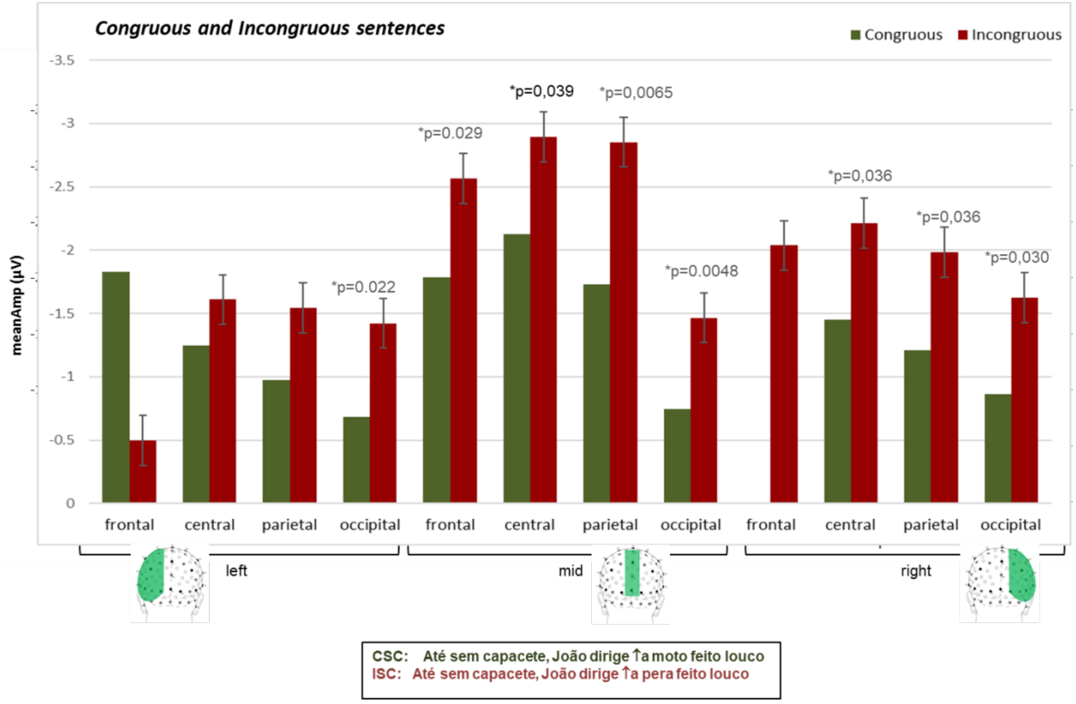
In the statistical analysis, three time intervals will be analyzed: 100 to 300ms, 300 to 500ms, and 500 to 700ms. Given that for the hypotheses of our experiment, we are especially interested in effects in the 300 to 500 ms interval, we will present statistical analysis for data from this interval first.

Mean Amplitude

Results: 300-500ms interval

There is a strong main effect for congruence, with F(1,469)= 7.892, p=0.005. There is no specific interaction between the variables and the ROIs (ROIxCongruency: F(11,469)=1.12, p=0.34). However, ROI as a variable has significance, with ROI F(12,469)=1.84, p=0.039, which indicates that neurophysiological responses vary mostly in the strength of the effect, and not in the tendency of the effect. When we investigate contributions of hemisphere, we see an effect F(2, 488)=4.304, p=0.014,and a near interaction F(2,488)= 2.569, p=0.077. This reflects that effects of congruency are significant on all ROIs in mid regions and on the right hemisphere, but not for all ROIs on the left hemisphere. Moreover, amplitudes are overall higher in the mid area, especially for incongruous endings.

In Graph 1, we can see amplitude measures (in µV) for the 12 selected ROIs, comparing congruous vs. incongruous sentences. There is a constant trend of lower amplitudes for congruous sentences in comparison to higher amplitudes for incongruous sentences; indeed, this trend is reflected in statistic difference for all regions on the midline and right hemisphere (except for the frontal ROI), especially for the parietal region on the Graph1: Mean amplitude measures for incongruous vs. congruous sentences



midline: CS: -1.73(1.66)µV vs. IS: --2.85(1.95) µV, p=0.0065. Differences on the left hemisphere are not very robust. There is only a significant difference on the left occipital site: : CS: -0.69(1.20)µV vs. IS: -1.42 (1.17) µV, p=0.022. These results reflect a stronger effect for congruency for all regions on the midline, and right hemisphere with an emphasis on parietal regions. (For means per ROI and p-values, see Table 4)

Table 4: All estimated means and p-values for mean amplitude measures for the sentence task

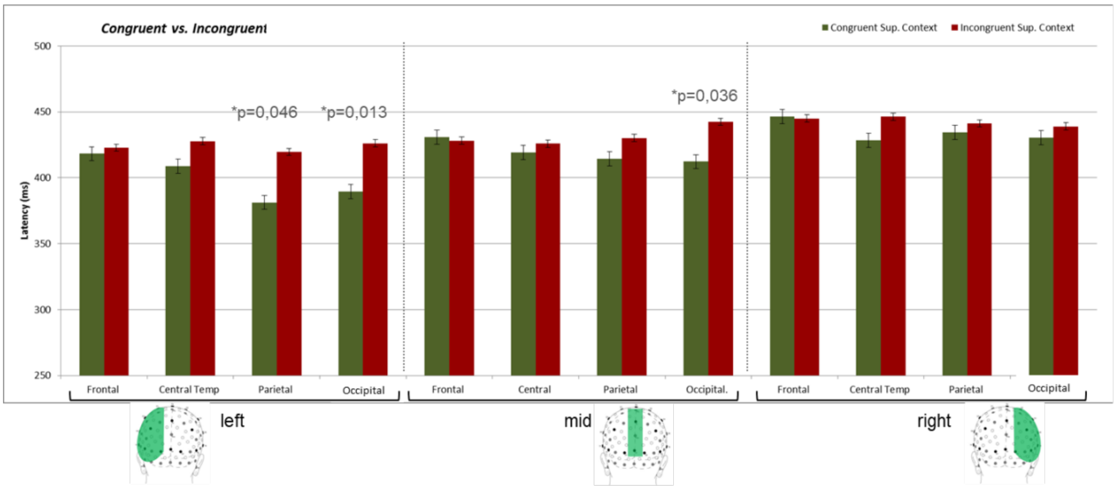
Mean Amplitudes (in µV) for sentence conditions per ROI											
Congruous											
left				mid					right		
frontal	central	parietal	occipital	frontal	central	parietal	occipital	frontal	central	parietal	occipital
-1.82649	-1.24689	-0.9767	-0.6867	-1.78446	-2.12332	-1.73287	-0.74601	NA	-1.45127	-1.20731	-0.86568

Incongruous											
left				mid				right			
frontal	central	parietal	occipital	frontal	central	parietal	occipital	frontal	central	parietal	occipital
-0.49861	-1.60961	-1.54499	-1.4233	-2.56487	-2.89234	-2.85297	-1.46588	-2.03735	-2.21478	-1.98346	-1.62666
P-values (from t-test)											
0.4366	0.2328	0.06501	0.02249	0.02866	0.03945	0.006516	0.004784	0.1775	0.03689	0.03619	0.03037

Peak Latency

Peak latency analysis did not yield any main effects for the variable congruency. There was near significance: F(1, 16)=3,21, p=0.092. ROI as a factor showed strong significance (F(12,192)=0.007, but there was no interaction between ROIs and variables (ROI x congruency: F(12,192)=0.434, p=0.948. This indicates that responses varied strongly from one ROI to another, but there was no stable correlation with the variable. Nonetheless, if we look at hemisphere, there is a slight significance: F(1,16)=4.68, p=0.046. Observing Graph 2, we may conclude that these effects are driven by the fact that there are faster latencies for congruous sentence endings on the left hemisphere for parietal and occipital ROIs (left parietal: CS: 381.29(12.94)ms vs. IS: 419.65(13.77)ms, p=0.046; left occipital: CS: 389.53(11.89)ms vs. IS: 426.24(11.32)ms, p=0.013); hence, a small laterality effect. There is also a difference between faster latencies for congruous sentences in the occipital ROI on the midline (CS: 412.24(15.02)ms vs. IS: 442.59(8.59)ms, p=0.036. For all mean latency values and relevant p-values see Table 5.

Graph 2: Peak latency measures (in ms) for congruency variable for sentences



CSC: Até sem capacete, João dirige ↑a moto feito louco
ISC: Até sem capacete, João dirige ↑a pera feito louco

Table 5: mean latency values for all ROIs with (near) significant p-values

Latencies (in ms) for sentence conditions per ROI											
Congruous											
left				mid				right			
frontal	central	parietal	occipital	frontal	central	parietal	occipital	frontal	central	parietal	occipital
418.235	408.824	381.294	389.529	430.824	419.176	414.471	412.235	446.353	428.588	434.353	430.471
Incongruous											
left				mid				right			
frontal	central	parietal	occipital	frontal	central	parietal	occipital	frontal	central	parietal	occipital
422.941	427.765	419.647	426.235	428.235	425.882	430.235	442.588	445.059	446.353	441.176	439.059
P-values (only mentioned when significant)											
-	-	0.046	0.013	-	-	-	0.036	-	-	-	-

Results: 100-300ms interval

Analyses of measures for the 100-300ms interval revealed no main effect for congruence F(1,15)=0,584, with p=0.457

Results: 500-700ms interval

Analyses of measures for the 500-700ms interval revealed no main effect for congruence F(1,15)=0,417, p=0.528.

Conclusions for the sentence task

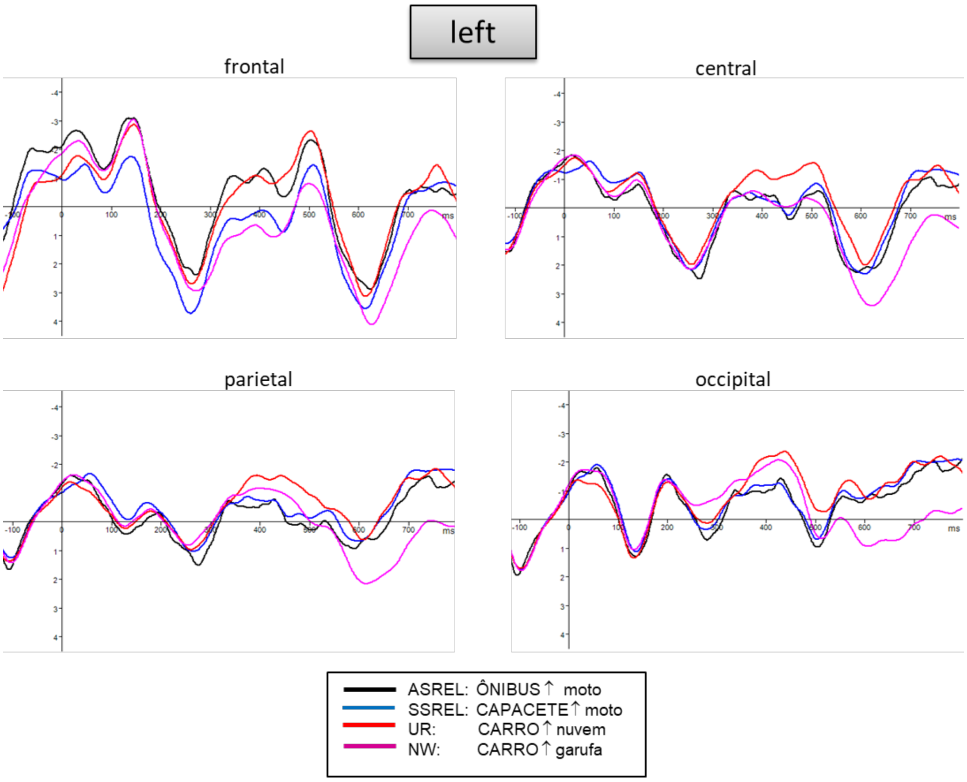
We expected to see modulation of the N400 effect for incongruency, which in fact occurred as a main effect F(1,469)= 7.89, p=0.005, presenting higher amplitudes for incongruous sentences than for congruous sentences, indicative of a cognitive effort in the integration of an ill-fitting complement in the verb phrase. This effect was strongest in mid areas and right hemisphere sites. Although there was no main effect for congruency for latency measures, F(1, 16)=3.21, p=0.092, latency was faster for congruous endings than incongruous endings in parietal and occipital ROIs as well as a the occipital ROI in the mid area. The faster latencies for congruous sentences seem to reflect a spatially limited facilitatory effect, while the more widespread increased amplitudes for incongruous endings in mid areas and right hemisphere seem to index an increased cognitive effort due to the difficulty of integrating the implausible target word in the preceding context.

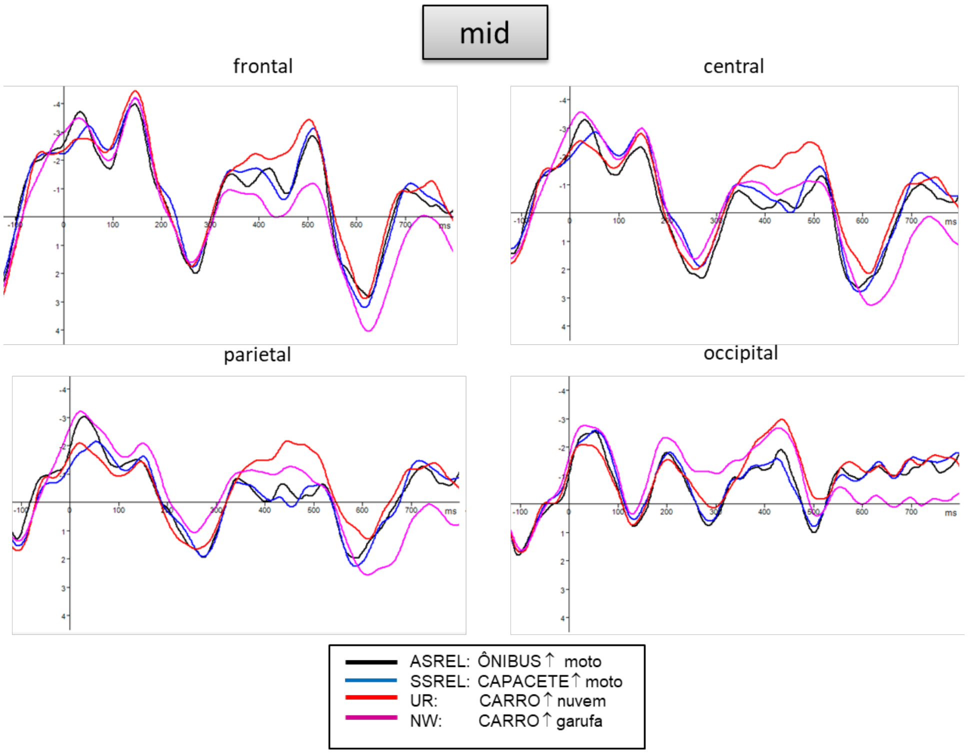
Results: word task

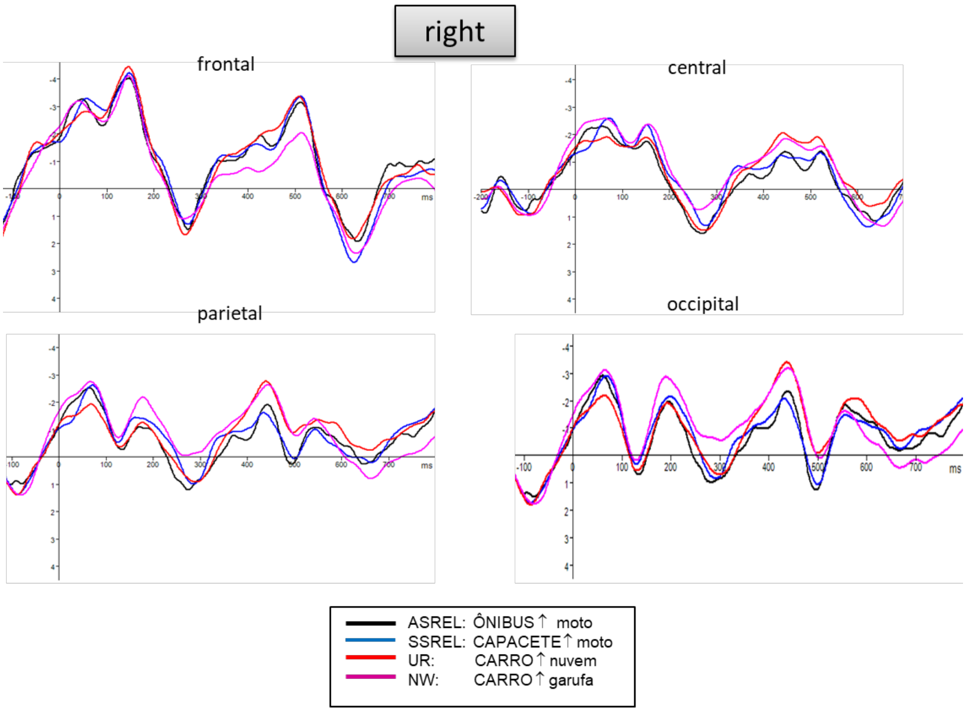
From the total dataset, the same participants as in the sentence task were excluded, and thus 17 datasets were processed and analyzed. The behavioral measures showed that on average subjects judged 98% of words correctly as either words or pseudowords, thus qualifying their level of attention as adequate.

In Figure 5, we can see the ERP graphs for the 12 ROIs comparing the 4 conditions: (i) Associative semantic relation (ASREL: e.g. *ÔNIBUS – moto* ('BUS-car'); (ii) Syntactic-Semantic relation (SSREL: e.g. *CAPACETE-moto* ('HELMET-motorcycle'); (iii) Unrelated pair (UR: e.g.: *CARRO-nuvem* ('CAR-cloud')); (iv) Pseudoword target (PW: e.g. *CARRO-garufa* ('CAR-garufa'). We can see two major peaks for most ROIs, the first in the -100 to 200ms interval, and the second in the 300 to 500ms interval. Variables modulate amplitude and latency nearly exclusively in the 300 to 500ms interval, which is when the component of interest, the N400 occurs. We will, therefore, present the analysis of this later window first, analyses for the three other time windows, -100-100ms, 100-200ms, and 500-700ms will be presented subsequently.

Figure 5: ERP Graphs for the word priming experiment




mid
frontal
central
parietal
occipital
ms
ASREL: ÔNIBUS↑ moto
SSREL: CAPACETE↑ moto
UR: CARRO↑ nuvem
NW: CARRO↑ garufa


right
frontal
central
parietal
occipital
ms
ASREL: ÔNIBUS↑ moto
SSREL: CAPACETE↑ moto
UR: CARRO↑ nuvem
NW: CARRO↑ garufa

Amplitude

Results: 300-500ms interval

There is a main effect for the variable of relation type with F(2,32)=4,83, p=0.015. In Graph 9, we can verify that this effect is driven by differences between unrelated pairs and related pairs (whether they are associatively or syntactic-semantically related). Thus confirming the control effect of related vs. unrelated word pairs that characterizes the priming paradigm. There is no difference between associative semantic and syntactic-semantic priming effects for any of the ROIs.

There is also no effect nor interaction of ROI as a factor (ROI: F(2,32)=1.436, p=0.252; ROI x relation type: F(2,32)=1.413, p=0.228). However, if we analyze ROI and hemisphere interaction, we see a near significance F(2,32)=3.15, p=0.066, reflecting that ROIs contribute differently to the signal depending on the hemisphere. However, this difference in response is not correlated to the relation type variable (hemisphere x ROI x relation type: F(2,32)=0.756, p=0.49). For all ROIs, the nature of the effect is thus similar, but it differs in strength slightly, depending on the hemisphere. We can verify this tendency in Graph 5, in that overall amplitudes for unrelated pairs are significantly different from pairs that are semantically related (both associatively and syntactically), with distinctively lower p-values for left hemisphere and midline in comparison to right hemisphere. This difference is most expressive in parietal ROIs where the comparisons for associative semantically related x unrelated word pairs yield p=0.007 for left hemisphere and p=0.008 for the midline (left parietal: ASRel: -0.-64(0.18)μV vs. UR: -1.51(0.18) μV; mid parietal: ASRel: -0.28(0.40)μV vs. UR: - 1.34(0.45) μV); whereas for the right parietal ROI, the p value is 0.041 (ASRel: -0.56(0.25)μV vs. UR: - 1.25(0.28)μV. Also for the right hemisphere, the frontal region does not present significance with regard to this variable. For all other regions, there is a significant difference between the associative semantically related pairs vs. the unrelated pairs, and a significant or near significant difference between syntactic-semantically related pairs (see Table 6, for all p-values and amplitude means).

The pseudoword targets yielded more negative amplitudes for several ROIs; most consistently over the occipital sites in the comparison with associative semantically related pairs (mid: PW: -1.74(0.31) x ASRel:-0.81(0.33) μV, p=0.028; left: PW: -1.39(0.27)x ASRel:-0.64(0.18) μV, p=0.028; and right: PW: -1.55(0.17) x ASRel:-0.52(0.26) μV, p=0.005). However, for frontal sites, pseudoword amplitudes are much lower, i.e. more positive, than for both the related and unrelated conditions, presenting significance for the left frontal site (PW:-

0.56(0,59) x SSRel: -3,18(0.47), p=0.030, and PW x UR=-1.99(0.56), p=0.004) and the midline frontal site (PW:-0.22(0.54) x UR=-1.52(0.55), p=0.032) , as well as near significance for the right frontal site (PW:-0.71(0.54) x UR=-1.39(0.55), p=0.093). For all mean Amp. measures and p-values, see Table 6.

Graph 5: mean amplitude measures for all conditions of word priming experiment

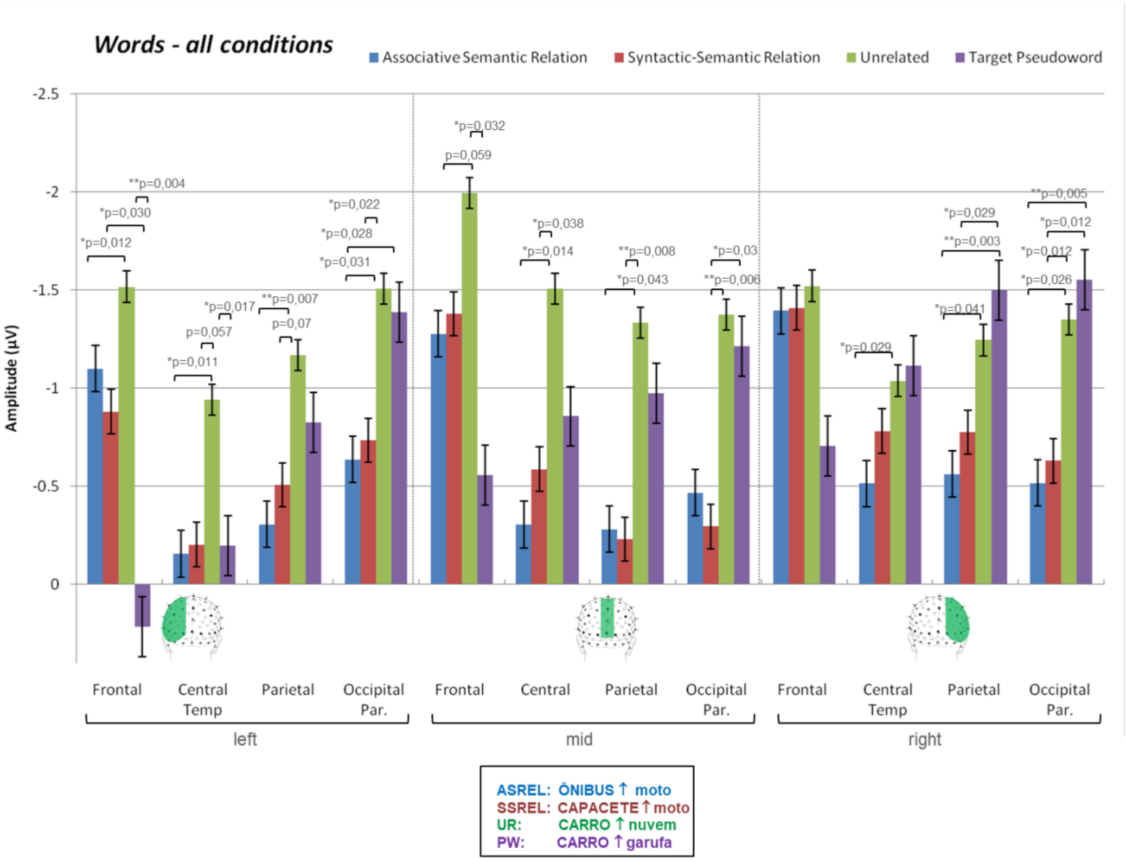


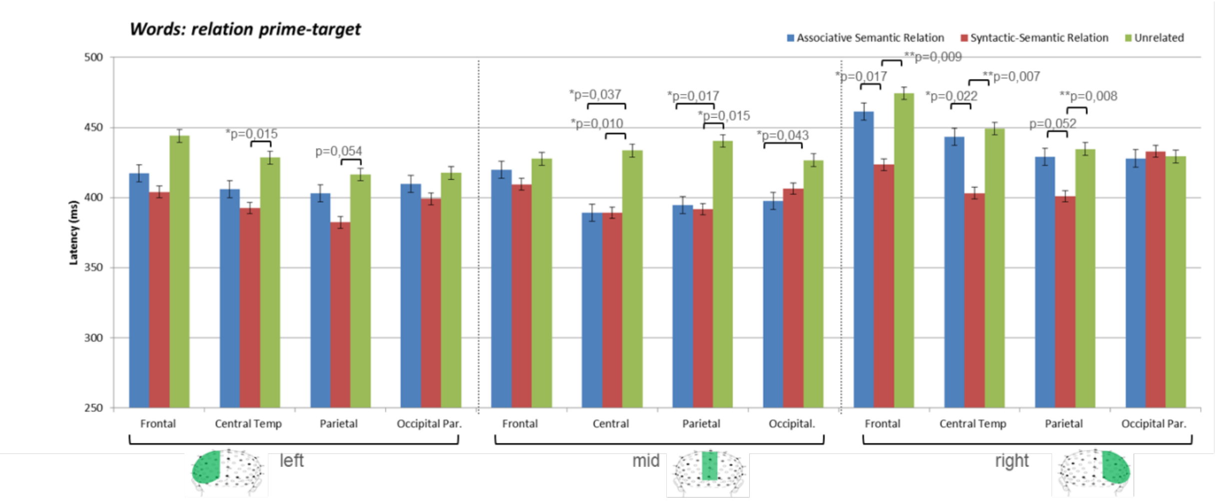
Table 6: mean amplitudes for all ROIs with (near) significant p-values for word priming

ROI		conditions	mean	std. Error	when significant		ROI		conditions	mean	std. Error	when significant		ROI		conditions	mean	std. Error	when significant or	
left	frontal	ASR	-1.099	0.564	0.012	ASR x PW	mid	frontal	ASR	-1.278	0.541	0.032	UR x PW	right	frontal	ASR	-1.395	0.553	.093	ASR x NR
		SSR	-0.880	0.543	0.030	SSR x PW			SSR	-1.379	0.471	0.059	ASR x UR			SSR	-1.409	0.616		
		UR	-1.518	0.552	0.004	UR x PW			UR	-1.995	0.557					UR	-1.522	0.466		
		PW	0.218	0.541					PW	-0.556	0.594					PW	-0.705	0.539		
	central	ASR	-0.155	0.263	.011	ASR x UR		central	ASR	-0.305	0.449	.014	ASR x UR		central	ASR	-0.514	0.329	.095	ASR x NR
	temp.	SSR	-0.202	0.356	0.017	UR x PW			SSR	-0.587	0.368	.038	SSR x UR		temp.	SSR	-0.781	0.291	.029	ASR x PW
		UR	-0.941	0.284	0.057	SSR x UR			UR	-1.509	0.446					UR	-1.038	0.280		
		PW	-0.198	0.297					PW	-0.856	0.512					PW	-1.113	0.382		
	parietal	ASR	-0.306	0.174	.007	ASR x UR		parietal	ASR	-0.281	0.402	.043	ASR x UR		parietal	ASR	-0.561	0.247	.041	ASR x NR
		SSR	-0.507	0.344	.059	ASR x PW			SSR	-0.230	0.376	.008	SSR x UR			SSR	-0.776	0.241	.003	ASR x PW
		UR	-1.170	0.281	0.070	SSR x UR			UR	-1.335	0.454					UR	-1.245	0.275	0.066	SSR x UR
		PW	-0.826	0.243					PW	-0.975	0.421					PW	-1.499	0.313	0.029	SSR x PW
	occipital	ASR	-0.637	0.184	0.031	ASR x UR		occipital	ASR	-0.809	0.331	.042	ASR x UR		occipital	ASR	-0.517	0.260	0.026	ASR x NR
		SSR	-0.735	0.346	0.028	ASR x PW			SSR	-0.784	0.400	.028	ASR x PW			SSR	-0.631	0.262	0.005	ASR x PW
		UR	-1.508	0.366	0.022	SSR x UR			UR	-1.650	0.390	0.014	SSR x UR			UR	-1.351	0.268	0.012	SSR x UR
		PW	-1.387	0.268	0.068	SSR x PW			PW	-1.743	0.314	0.015	SSR x PW			PW	-1.553	0.168	0.012	SSR x PW

Results latency:

There is a strong effect for relation type for latency measures, with F(2,32)=11.26, p<0.000. There is also a strong effect for ROI, with F(2,32)=4.36, p=0.001, but no interaction between ROI and relation type (F(2,32)=1.13, p=0.353. This indicates that responses of the various ROIs differ greatly in strength, but not in tendencies. There is a strong significance also for hemisphere (F(1,16)=10.02, p=0.006), but again no interaction with the relation type (F(2,32)=0.299, p=0.744). We can see in Graph 6 that there is a robust priming effect for the syntactic-semantically related word pairs in terms of latency for central and parietal sites for midline and both left and right, with highest significance for right central temp. and parietal sites (SSRel: 403.17(15.29) ms x UR: 449.18(6.91)ms, p=0.007, and SSRel: 400. 94(12.61)ms x UR: 434.71(6.12)ms, p=0.008, respectively) (for all latency measures and significant p-values, see Table 7). For associative semantically related word pairs, there is only a priming effect (i.e. a significant difference between UR and ASRel), for central, parietal and occipital midline regions, of which the most significant difference presented is for mid parietal with p=0.017 (ASRel: 394.70(15.19)ms .

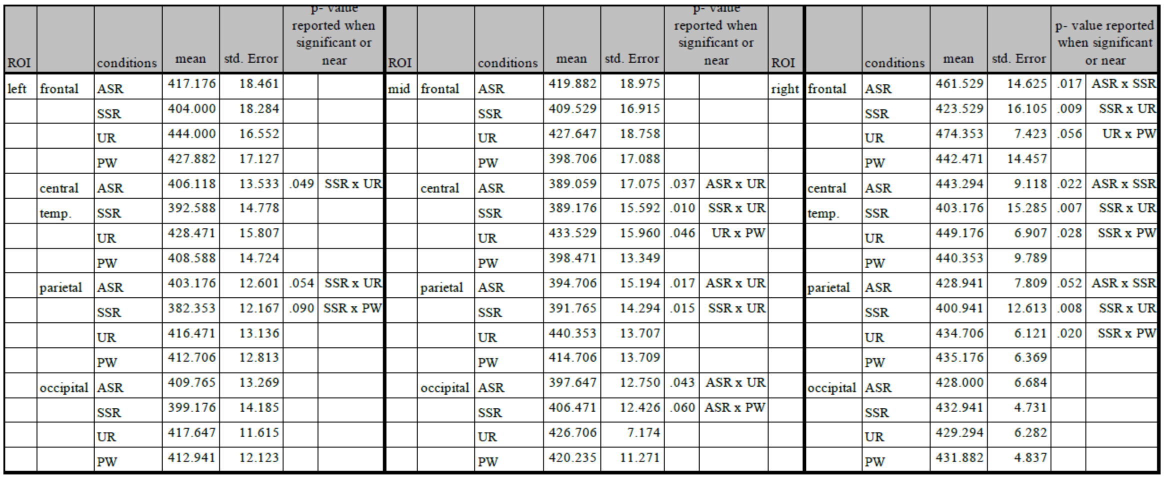
Graph 6: latency measures for the variable relation type



ASREL: ÔNIBUS ↑ moto
SSREL: CAPACETE ↑ moto
UR: CARRO ↑ nuvem

On the right hemisphere, we see significantly faster latencies for syntactic-semantically related pairs, not only in comparison with unrelated words, but also faster as compared to associative semantically related pairs. This is true for all ROIs, but occipital, with highest p values for the frontal site, with p= 0.017 (ASRel: 461.53(14.63)ms x SSRel: 423.53(16.12)ms).

Table 7: mean latency values for all ROIs with (near) significant p-values for word priming experiment



ROI		conditions	mean	std. Error	p- value reported when significant or near		ROI		conditions	mean	std. Error	p- value reported when significant or near		ROI		conditions	mean	std. Error	p- value reported when significant or near	
left	frontal	ASR	417.176	18.461			mid	frontal	ASR	419.882	18.975			right	frontal	ASR	461.529	14.625	.017	ASR x SSR
		SSR	404.000	18.284					SSR	409.529	16.915					SSR	423.529	16.105	.009	SSR x UR
		UR	444.000	16.552					UR	427.647	18.758					UR	474.353	7.423	.056	UR x PW
		PW	427.882	17.127					PW	398.706	17.088					PW	442.471	14.457		
	central	ASR	406.118	13.533	.049	SSR x UR		central	ASR	389.059	17.075	.037	ASR x UR		central	ASR	443.294	9.118	.022	ASR x SSR
	temp.	SSR	392.588	14.778					SSR	389.176	15.592	.010	SSR x UR		temp.	SSR	403.176	15.285	.007	SSR x UR
		UR	428.471	15.807					UR	433.529	15.960	.046	UR x PW			UR	449.176	6.907	.028	SSR x PW
		PW	408.588	14.724					PW	398.471	13.349					PW	440.353	9.789		
	parietal	ASR	403.176	12.601	.054	SSR x UR		parietal	ASR	394.706	15.194	.017	ASR x UR		parietal	ASR	428.941	7.809	.052	ASR x SSR
		SSR	382.353	12.167	.090	SSR x PW			SSR	391.765	14.294	.015	SSR x UR			SSR	400.941	12.613	.008	SSR x UR
		UR	416.471	13.136					UR	440.353	13.707					UR	434.706	6.121	.020	SSR x PW
		PW	412.706	12.813					PW	414.706	13.709					PW	435.176	6.369		
	occipital	ASR	409.765	13.269				occipital	ASR	397.647	12.750	.043	ASR x UR		occipital	ASR	428.000	6.684		
		SSR	399.176	14.185					SSR	406.471	12.426	.060	ASR x PW			SSR	432.941	4.731		
		UR	417.647	11.615					UR	426.706	7.174					UR	429.294	6.282		
		PW	412.941	12.123					PW	420.235	11.271					PW	431.882	4.837		

Results: -100-100ms interval

Analyses of measures for the 100-300ms interval revealed no main effect for relation type of priming words F(2,32)=1.814 with p=0.182.

Results: 100-300ms interval

Analyses of measures for the 100-300ms interval revealed no main effect for relation type of priming words F(2,32)=0.220 with p=0.803.

Results: 500-700ms interval

Analyses of measures for the 500-700ms interval revealed no main effect for relation type of priming words F(2,32)=1.288, with p=0.290.

Conclusion and Discussion: word task

In the analysis of mean amplitudes, we see a main effect for relation type, reflecting the priming effect: F(1,16)=6.33, p=0.023. This effect is driven by facilitation in lexical access for targets of related pairs (both associatively and syntactically semantic word pairs) in comparison to targets of unrelated pairs. This contrast is slightly more expressive for associative semantic priming pairs and more evenly distributed over all ROIs. The contrast between syntactic-semantic and unrelated pairs was most expressive in midline regions and, to a slightly lesser degree, in the left hemisphere. Both contrasts were quite expressive over all three occipital sites. This might be explained by the nature of the task, which drew uneven attention to the visual aspects of the words, for two reasons: (i) people were instructed to judge the word in lower case letters (the target was presented in lowercase, the prime in capital letters); (ii) people were concentrated on deciphering letter strings, given that the task was to recognize when letter strings were not actual words (e.g. garifu). Also, the occipital ROI included occipital-parietal sites, thus, slightly overlapping with parietal sites (SOTO, 2014).

Differently from Gomes (GOMES, 2009) whose main focus was to test directionality of the priming effect which revealed the syntactic structuring of priming pairs, we compared semantically related word pairs that were easily mediated by syntactic structure to merely associative semantic pairs. Our hypothesis was that syntactic-semantically related pairs were faster to process, based on Gomes´ findings that syntactic structuring leads to an advantage in processing rates (as measured in latency), but perhaps so at a higher cost (as reflected in amplitude measures). However, in terms of mean amplitude, in our study there was no significant difference between syntactic-semantic and associative semantic pairs, indicating that there is little (as reflected in priming effects) to no (as reflected in amplitude measures for both types of semantically related pairs) difference in terms of cognitive effort.

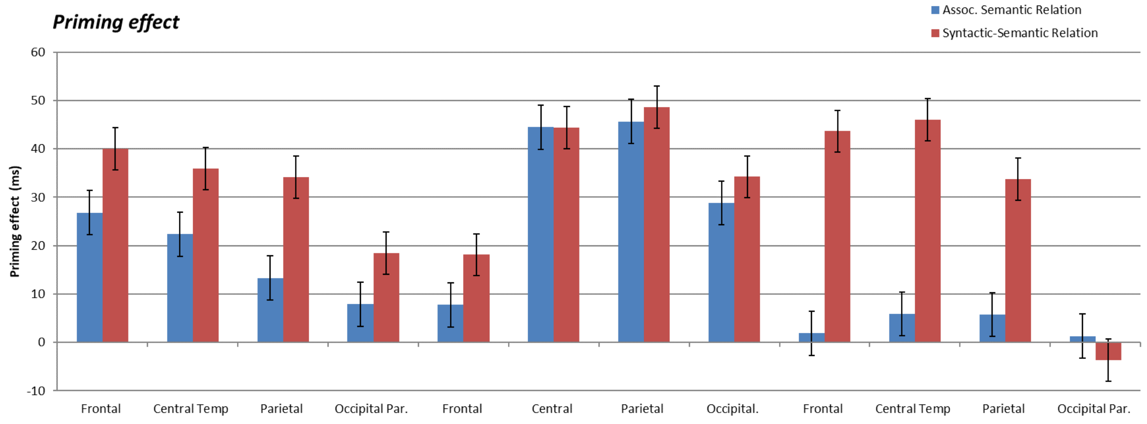
However, when we look at latency measures, there is a strong effect for relation type (F(2,32)=11.26, p=0.000), which is not only driven by related vs. unrelated contrasts, but also by differences in priming gain for associative semantic pairs and syntactic-semantic pairs. For associative semantically related word pairs, there is only a priming effect (i.e. a significant difference between UR and ASRel), for midline regions, of which the most significant difference presented is for mid parietal with p=0,017 (ASRel: 394.70(15.19)ms). For syntactic-semantic pairs, there is a robust priming effect that is much more distributed, over central and parietal sites for midline and both left and right, with highest significance for right central temp. and parietal sites (SSRel: 403.17(15.29) ms x UR: 449.18(6.91)ms, p=0.007, and SSRel: 400. 94(12.61)ms x UR: 43471(6.12)ms, p=0.008, respectively).

Moreover, for the right hemisphere sites we see significantly faster latencies for syntactic-semantically related pairs than for associative semantically related pairs. This is true for all ROIs, but occipital, with highest p values for the frontal site, with p= 0.017 (ASRel: 461.53(14.63)ms x SSRel: 423.53(16.12)ms).

In Graph 7, we can see a translation of this priming gain (in ms), obtained by subtracting latencies for the two types of unrelated pairs from latencies for unrelated pairs. The priming gain is thus measured as a time difference, where greater difference (higher positive values) reflects greater priming gains. Thus, we see an expressive difference in priming gain for syntactic-semantic pairs in comparison to associative semantic pairs, in both hemispheres, but significantly so in right hemisphere sites, where there is nearly no difference at all between latencies of unrelated pairs and associative semantic pairs (frontal: ASR: 1.882(8.29)ms x SSR

43.65(15.73)ms, p=0.007 and central temp.: ASR: 5.88(9.983)ms x SSR: 46.00(14.87)ms, p=0.022 and, marginally, for occipital: ASR: 5.8(8.7)ms x SSR: 33.77(11.11)ms, p=0.052).

Graph 7: Priming effect as measured in ms (UR-ASRel and UR-SSRel)



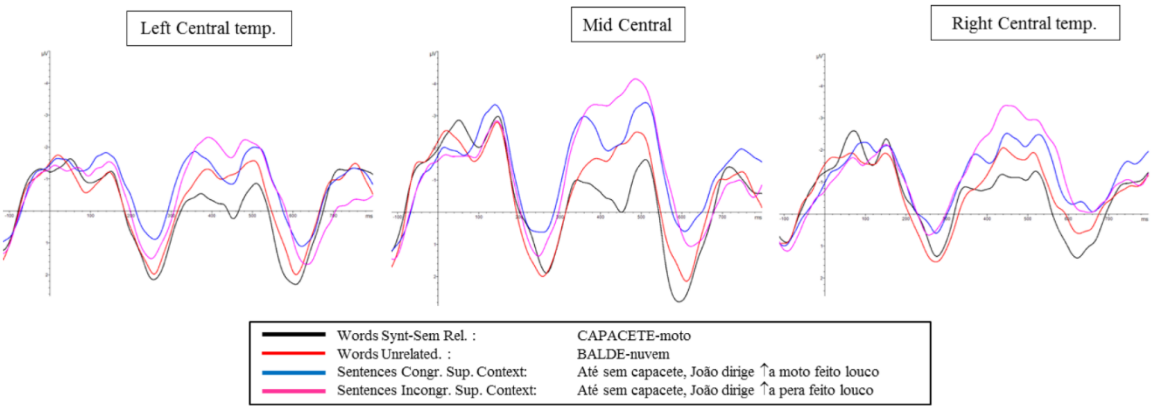
We might interpret this result as a strong bilateral activation resulting in faster and deeper processing for word pairs that can be easily connected by both semantic and syntactically constructed relations. In our opinion, it is strong evidence of how language effectively uses syntactic highly automated mechanisms to strengthen and deepen semantic bonds between words and their combined meanings. As such, it is suggestive of the cognitive specificity that are involved in language processing, and how linguistic computations, such as *merge*, are more stable, and, generally, faster in effectively compounding meaning in language comprehension.

Results: comparing word priming and sentence paradigms

We compared the data for peak latency and mean amplitude for sentences and words in the 300 to 500ms interval, given that the effect of the experimental variables was measured in that time window. In Figure 6, we can see 4 conditions overlaid. Just by visual inspection we may notice that the wavelines look very similar in their morphology, but sentence contexts generate clearly higher amplitudes.

Our statistical analysis paired up variables that supposedly are comparable in variable manipulation of predictability: we compared the conditions related x unrelated to the pair congruous x incongruous, such that syntactically-semantically related pairs (e.g. *CAPACETE-moto* (‘HELMET-motorcycle’) vs. unrelated pairs (e.g. *BALDE-nuvem* (‘BUCKET-cloud’)) were compared to congruous sentences vs. incongruous sentences (e.g. *Até sem capacete, João dirige a moto x pera feito louco* (‘Even without a helmet, João rides the motorcycle x pear like crazy’). In the statistical analysis, congruence was coupled with relatedness, and incongruous with unrelatedness, such that one variable was congr/rel vs. incongr/rel. The other variable presented stimulus as a factor with two levels: word and sentence. Thus, we have an analysis in which relatedness/congruence and stimulus type are crossed.

Figure 6: ERP overlays for sentence and word stimuli conditions, for the central ROI on the midline, and on the left and right hemisphere: SSREL: 'HELMET-motorcycle'; UR: 'BUCKET-cloud'; SC: 'Even without a helmet, João rides the motorcycle like crazy'; IS: 'Even without a helmet, João rides the pear like crazy'



When we analyze mean amplitude measures, that which is visible from the waveforms, a difference in amplitude between stimulus type, is confirmed by the statistical analysis, with a strong main effect for stimuli type: F(1,16)=39.234, p=0.000. There is also a robust effect for the congr/relatedness factor: F(1,16)=9.53, p=0.007. There is a small interaction between congr/relatedness and stimulus type: stimulus_type x congr/rel: F(1,16)=5.01, p=0.04, which is driven by the fact that incongruency is stronger, but more locally distributed (strongest at midline central and parietal sites for the contextualized sentences), while the effect of unrelatedness is slightly more subtle and much more broadly distributed. This is also confirmed by the interaction ROI x stimulus type: F(1,16)=5.46, p=0.003. There is, however, no effect for hemisphere x stimulus type: F(1,16)=0.594, p=0.452.

Latency measures show no main effect for stimulus type F(1,16)=0.52, p=0.48, but there is an effect for congr/relatedness: F(1, 16)=9.31, p=0.008. By observing analyses presented before separately for the word task and sentence task, we can conclude that this is driven by relatedness effects for words as reflected in faster latencies for syntactic-semantic pairs (words: main effect relatedness: F(2,32)=11.26, p=0.000 x no main effect for congruency F(1, 16)=3.21, p=0.092). There is also a strong effect for hemisphere: F(1,16)=12.74, p=0.003, but no interaction for stimulus type x hemisphere: F(1,16)=0.689, p=0.419, which reflects faster latencies overall for both sentences and words on left hemisphere irrespective of condition (i.e. no interaction between hemisphere and congr/relatedness: F(1,16)=0.561, p=0.465).

Discussion: comparing word priming and sentence paradigms

Our data show that there are important qualitative (for example, whether amplitude or latency measures are modulated by experimental conditions) and distributional differences between N400 effects elicited by sentences and those elicited by words. N400 effects in the priming paradigm is more broadly distributed, both for latency and amplitude measures, as compared to N400 effects for sentence contexts, which are distributed mostly along the midline and on the right hemisphere; and for which differences in latencies are much more limited to parietal and occipital sites on the left hemisphere. Just as Lau et al. (2009) we found quantitative differences in terms of higher amplitudes, but whereas they found lower amplitudes for congruous sentences than for unrelated target words, we found generalized higher amplitudes for words in sentence context as compared to responses to target words in priming pairs. Lau *et al.* attributed this difference to the fact that for sentences there is a more effective facilitation due to higher degree of predictability caused by both structural and semantic constraints than for “unstructured word pairs”. We disagree with that line of reasoning, given that we present evidence that there is no such thing as “unstructured word pairs” (SOTO, 2014). Automatic syntax building will always attempt to establish structural connections between words, and when that attempt is felicitous, as in *CAPACETE-moto* (“HELMET-motorcycle”), processing gains in velocity as is shown by faster latencies for syntactic-semantically related targets, for both left and right hemispheres as well as mid areas.

This argument is even stronger when we consider that the target words on which amplitudes were measured were repeated in both word priming and sentence context task. We favored controlling for target words, whereas Lau *et al.* (2009) favored using cloze measures and a previously used set of priming pairs. This might explain why facilitation effects in the sentences they used were stronger, due to higher predictability as measured by cloze probabilities; on the other hand, comparability between word and sentence task may have been weaker since target words were not repeated over all conditions.

We agree with Lau *et al.* (2009) that the N400 effect for related pairs as reflected in lower amplitudes is related to facilitation and not to inhibition, as shows Figure 7A. Here we can clearly see the priming effect, visible in the comparison of the amplitude peaks in the -50 to 150ms interval as compared to the peaks in the 300 to 500ms interval (both shaded in grey).

The first window (-50 to 150ms) begins 300ms after the presentation of the prime (e.g. *HELMET*), and thus spans the 300 to 500ms interval supposedly reflecting lexical access to this word. The second window relates to the 300 to 500ms interval after the onset of the target word. Comparing amplitudes in the two intervals, we can see that in the second window, the peaks have decreased considerably for semantically related conditions, reflecting the facility in lexical access after priming (see p-values for the comparison between amplitude values in Table 8). The peaks for unrelated targets and pseudoword targets are higher in comparison, the latter still relatively low, because pseudowords are easily discarded (there is no extensive search for a lexical match); however, the second window peak for the unrelated target is nearly as high as the first window peak, attesting the lack of priming effect – the target word is accessed in the much the same fashion as the prime. In fact, this is the only condition for which there is no statistical difference between amplitudes from both time windows. This puts the comparability of congruency judgment and priming paradigms into a different perspective, considering that for priming pairs the effect is clearly driven by a lack of facilitation for unrelated pairs (and not an obstacle), whereas for the integration of an incongruous word in a sentential context, there seems to be an obstacle in the integration as well as a facilitation for congruous words that are highly expected in plausible sentences.

Nonetheless, that experimental effects differ becomes clear if we observe Figure 7B, in which we again compare amplitudes in two time intervals in the sentence conditions. The first interval relates to 300 to 500ms after the onset of the verb preceding the target word, the second relates to a similar interval in relation to the onset of the target word (both shaded in grey). We can see that in contrast to what happens in the priming paradigm, the mean amplitude in the second interval is not significantly lower than the amplitude in the first interval for predictable words. That is, although *motorcycle* as a complement of *to ride* is certainly predictable, as would be perhaps *bike,* or (in Portuguese) *car*, the effect on the N400 component is too subtle to attain statistic relevance. The facilitation of highly predictable verb-complement pairs (e.g. *ride a motorcycle*) was thus not explicit in the difference between amplitudes in the first and second interval. Given the importance to time as a factor in which information becomes available during processing, the short SOAs may have attenuated predictability effects (CHOW *et al.*, 2018). Nonetheless, the unexpected ending *pear* renders a statistically higher mean amplitude in comparison to the amplitude in the first interval.

Figure 7A: Analysis of wave lines with SOA overlay of word priming conditions ASREL: 'BUS – motorcycle', SSREL: 'HELMET – motorcycle', UR: 'CAR – cloud', and PW: 'CAR-garufa'; 7B: Analysis of wave lines with SOA overlay of sentence conditions: CS: 'Even without a helmet, he rides the motorcycle like crazy' and 'Even without a helmet, João rides the pear like crazy.'

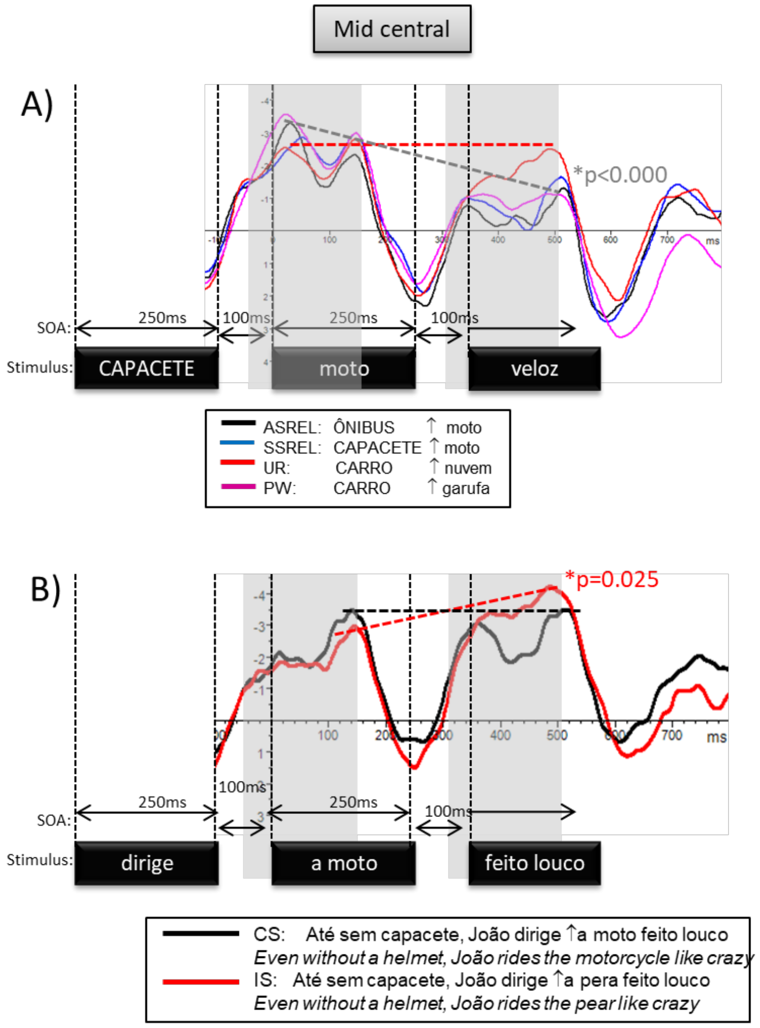


Table 8: Comparison of mean amplitude measures from the -50 to 150ms interval (relating to 300 to 500ms after preceding verb onset) and from the 300 to 500ms interval after target word onset.

Comparison of mean amplitudes for all conditions in two intervals					
interval:	**-50 to 150ms**		**300 to 500ms**		t-test comparison
condition	*mean (µV)*	*sd (µV)*	*mean (µV)*	*sd (µV)*	*P-value*
ASREL	-2.117	1.835	- 0.305	1.853	<0.000
SSREL	-2.283	1.276	-0.587	1.516	<0.000
NW	-2.625	1.719	-0.856	2.112	0.006
UNREL	-2.087	1.741	-1.50859	1.839	0.191

interval:	**-50 to 150ms**		**300 to 500ms**		t-test comparison
condition	*mean (μV)*	*sd (μV)*	*mean (μV)*	*sd (μV)*	*P-value*
CS	-2.112	1.809	-2.167	1.357	0.891
IS	-1.841	2.258	-3.019	2.286	0.025

In general, we may attribute the N400 effect in sentences to a combination of factors, one of which might be facilitation (e.g. *ride a motorcycle*), and another to a combination of mismatch affecting lexical access and integration difficulties of ill-fitting verb complements (e.g. *ride a pear*). In fact, if we look at the data it is not at all very likely that only one effect is at play. For the sentences, for instance, mean amplitudes for incongruous sentence endings is high, especially in the mid area. High amplitudes may relate to cognitive effort involved in complicated integration of implausible verb complements. Latency measures, on the other hand, were significantly faster on parietal and occipital ROIs on the left hemisphere, as well as parietal ROI on the right hemisphere. These faster latencies may index ease of access as foreseen by predictability. In short, both effects may impact depending on the stimulus type and time course of processing.

In our experiment, we see that the mismatch between the predicted word (i.e. *motorcycle*) and the upcoming word (i.e. *pear*) may have caused great difficulty. However, the fact that for unrelated priming pairs there was no similar effect (i.e. no increased amplitudes in the second interval), indicates that something different is going on. On the one hand, it makes sense that if predictability is higher (in sentence contexts as compared to priming pairs), a mismatch of features might have a bigger impact. On the other hand, since there was no independent facilitation effect for congruous sentences (i.e. amplitudes of target words did not decrease as compared to preceding context), this seems an unlikely suggestion. Rather, this difference in magnitude can be probably explained, firstly, by higher complexity of features involved in sentence context structuring, implicating in higher cognitive demands, and, secondly, by a combination of operations involved, including lexical access and integration.

Brouwer *et al.* (2017) present a neurocomputational model of N400 effects with similar outcomes. They built a computational model for language processing, specifically to predict language typical ERP components. One of the computational layers of this model is the comparison between the semantic features of previous context and those of the upcoming word. Their model successfully predicted the modulation of the N400 component, matching with data they collected previous experiments. One of the factors that most effectively predicted N400 amplitude was the degree of *dissimilarity,* rather than compatibility, between features of preceding context and the upcoming word.. Furthermore, they suggest that while priming effects are mostly explained by semantic feature overlap between prime and target, in sentences, a more complex ‘message’ representation must interact with overlapping features. The more complex nature of sentence context can be attested by the gradation of N400 amplitudes that was correctly predicted by the model correlating to the different types of sentences that were tested (e.g. congruous passive sentence<argument role reversal in an active sentence<mismatch in an active sentence). Although these authors also do not consider structural factors in priming pairs, their conclusions are partly converging to ours in the way they detect qualitatively different N400 effects in priming and in sentence contexts.

The interaction between lexical access and integration is not only in line with formal linguistic theories, which foresee that the N400 component probably reflects *merge* operations, but also evidenced by several studies that explicitly modulated N400 amplitudes with syntactic variables (FRANÇA, 2002; FRANÇA, GESUALDI, & SOTO, 2012; FRIEDERICI, 2012; MAIA *et al.*, 2018).

More recent neurophysiological data, such as those presented by Hultén *et al.*(2018) also confirm these claims. These data show that memory retrieval and integration are operations that develop over time roughly in the 300 to 500ms interval, and that there is no radical time limit between one and the other; instead they influence each other mutually, as reflected by reverberation between left posterior temporal cortex and the left inferior frontal cortex. These areas have been amply identified in literature, the first as correlated to storage and activation of lexical items, and the second to operations involving grammatical complexity, non-canonical word order, context controlled checking of lexical access, etc. (SOTO, 2014; FREDERICI, 2012; LAU, 2006; HAGOORT, 2005). Given the evidence these authors collected, they concluded that total activity in response to individual words in sentences is completed by 500ms (as attested by the end of activity burst in these language specific areas), when both retrieval and integration in preceding context are concluded

The suggestion by Chow et al. (2018) that the matching of content addressable cues in memory is the underlying operation to what instantiates prediction seems correct in part. It may explain a possible mismatch causing higher mean amplitudes for the incongruous sentence endings and account for facilitatory effect for semantically related priming pairs, as reflected in lower amplitudes. Even so, to account for the syntax driven priming effects in the case of pairs such as CASCA-banana (“PEEL-banana”), as well as the higher amplitudes reflecting difficult integration in the incongruous sentence endings, cognitive operations that are more abstract, context independent, and automatic may have to be considered.

This indicates that the comparison of N400 effects in sentences and word pairs involves complex features, probably due to different underlying processes, as reflected in difference in magnitude of effects, in different measure effects (i.e. for words latency is affected, for sentences it is less so), and different anatomical distributions. Both the specific configuration of the stimuli and the timing of SOAs were essential in unveiling the full complexity of these effects.

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