

Pronoun Resolution to Commanders and Recessors: A View from Event-Related Brain Potentials

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Abstract. We present results from an online experiment designed to probe the cognitive underpinnings of intra-sentential pronoun resolution. Event-related brain potentials were used to test the hypothesis that the processing of anaphoric links established between pronouns and non-commanding antecedents demands more cognitive resources than the processing of anaphoric links to commanding antecedents. The experimental results obtained show, among others, a major N400-like effect elicited by the pronouns resolved to the non-commanding antecedent. This enhanced negativity suggests that, as hypothesized, resolving a pronoun to a non-commanding antecedent is a more resource demanding process than resolving it to an antecedent in a commanding position. Our results can be interpreted within a theoretical framework for anaphor resolution that distinguishes two processing routes: a more resource-demanding discourse-based route and a less taxing syntax-only route.

Keywords: Pronoun resolution, Intra-sentential anaphora, Cognitive processing, Binding theory, Command relation, Event-related potentials.

1 Introduction

Anaphora is a prominent research subject in cognitive science because it brings to fore one of the most startling properties of language: whereas most content words in a language determine their meaning by having a concept associated with it (e.g., the word *boy*), some words don't behave in this way. Instead, their meaning must be determined by another expression in the context. Such is the case of pronominals: in a context formed by the single sentence *The boy said the barber shaved him* the meaning of the word *him* is completely dependent on the meaning of its antecedent *the boy*. The only independent information

this pronoun conveys is of gender (masculine) and number (singular). Given this situation, the question arises as to what the mechanisms are that allow the pronominal to be interpreted. In other words, what are the mechanisms that allow to determine its antecedent, i.e. what is the process by which this anaphoric expression is “resolved”.

The full availability of pronominals (defined in terms of this referential dependency) is attested across the languages of the world. This ubiquitous presence seems then the manifestation of an organizing principle of the language system and of its connection to the rest of the cognitive system.

The inherently dynamic nature of anaphora resolution has inspired information processing-based models from a multiplicity of disciplines including artificial intelligence and psycholinguistics. Supported by current computational technology, the models designed and implemented in the area of computational natural language processing underlie anaphora resolution modules that aim at optimal performance when running on free input text. In accordance with the nature and goals of computer science as supporting discipline, these are algorithmic models, relying on fully specified and articulated information processing procedures (e.g. [2,9]) . By contrast, the models from psychological approaches are usually not specified at the algorithmic level and contain, therefore, substantially less computational detail (e.g. [5]). This is to be expected since their construction is driven by the higher level goal of capturing generalizations and generating testable hypotheses based on behavioral evidence obtained from human subjects. This difference in objectives and methods has led to a multifaced understanding of anaphora resolution which has been most beneficial to our understanding of this domain. Many experimental findings have been integrated on the anaphora resolution models subscribed by computational linguistics. And in the reverse direction, increasingly articulated models of anaphora resolution can inspire exploratory experimentation aimed at testing increasingly non trivial empirical hypotheses.

In a broad outline, the anaphora resolution process that emerges as common to all or most of these models is that the anaphoric links between anaphors and their antecedents can be viewed as being established as a result of the interplay of a number of constraints (e.g. [1,3]). These constraints can be conceptually split into two categories: filters (hard constraints) and preferences (soft constraints). For a given anaphor, the relevant hard constraints circumscribe the set of its admissible antecedents by filtering out the non admissible ones from the set of all the possible antecedent candidates around in the context. The relevant preferences, in turn, concur to favor, though not to determine, the selection of the actual antecedent (or actual antecedents, in cases of some occurrences of plural anaphors) against which the anaphor happens to be eventually interpreted.

Against this background, the present work investigates the operation of a particular subset of preferences, namely, those that rely on the use of structural information as criteria to single out the preferred antecedents. We further focus our study upon the operation of these preferences as they apply during the processing of intra-sentential anaphoric links i.e., cases where the anaphor and its

antecedent candidates occur in the same sentence. Preferences operate in tandem with hard constraints. The hard constraints relevant for the processing of intra-sentential anaphora are dubbed binding principles in grammatical studies. In this work, we will be concerned with binding principle B that holds for the anaphoric expressions classified as pronouns. Thus, we set out to study the operation of preferences defined upon structural relations – namely the *command* relation – holding between pronouns and intra-sentential antecedent candidates.

The remainder of the paper is organized as follows. Section 2 presents in more detail the constraints on intra-sentential anaphoric links, with a focus on binding principle B, followed by a review of previous work on the linguistic, psycholinguistic and computational manifestations of this principle and by the full articulation of our present approach, including our hypotheses and corresponding predictions.

Section 3 describes our study including methods and results. Section 4 discusses the hypotheses in the light of the results obtained and concludes the paper.

2 Background and Hypotheses

2.1 Grammatical Studies

The subset of grammatical constraints impinging on intra-sentential anaphoric links, known as binding principles, are defined in terms of two auxiliary relations: the command relation and the locality relation. We introduce each in turn.

The command relation is established over predicate-argument structures. When an expression is an argument of a given predicator, it is said to be commanded by its less oblique co-arguments — i.e. by the other less oblique arguments of that predicator. For instance, a Direct Object of a given predicator is commanded by the Subject of that predicate, an Indirect Object by the Subject and the Direct Object, etc. In the example sentence *The brother of Mary offered a book to John*, the Indirect Object *to John* is commanded by the Direct Object *a book* and by the Subject *the brother of Mary*, both arguments of the predicator *offered*; even though *to John* is the most oblique of the arguments selected by the predicator *offered*, it is not commanded by *of Mary* as this expression is not an argument of that predicator.

Moreover, the command relation is established recursively along the embedding of successive argument selection relations. For instance, a Direct Object α is commanded by the Subject of its predicator and, if the corresponding predication domain is the argument of another, upwards predicator, α is commanded also by all the arguments of this upwards predicator that commands its predication domain. In the example sentence *Tom promised to Peter that the brother of Mary will offer a book to John*, the Indirect Object *to John* of the embedded clause is commanded also by the Subject *Tom* of the predicator *promised* as this predicator selects as its Direct Object the predication domain *the brother of Mary will offer a book to John*, where *to John* occurs; *to John* is not commanded

by *to Peter* as this expression is not less oblique than the predication domain where *to John* occurs.

The locality relation is also established over predicate-argument structures. Two expressions are local to each other when they are co-arguments with respect to a given predicator. For instance, the Direct and Indirect Objects of a given predicator are local to each other. In the example sentence *Tom promised to Peter that the brother of Mary will offer a book to John*, the Direct Object *a book* of the predicator *will offer* is local with respect to the Subject *the brother of Mary* and the Indirect Object *to John* of that predicate; it is not local with respect to the Subject *Tom* or the Indirect Object *to Peter* of the upwards predicator *promised*.

The grammatical constraints on intra-sentential anaphoric links of interest here are defined in terms of these two auxiliary relations. Given its aim and length, it is not in the scope of the present paper to offer a thorough discussion of these constraints. They will be partly introduced by way of two key examples.

- (1) a. Peter_i said that [[[John's]_k brother]_j shaved himself_{*i/j/*k}].
 b. Peter_i said that [[[John's]_k brother]_j shaved him_{i/*j/k}].

For an expression to qualify as an admissible antecedent of a reflexive anaphor like *himself*, that expression has to be one of its local commanders in case the reflexive is commanded (principle A).¹ This is exemplified with the contrasts in (1a). The Subject *John's brother* is the only expression in that sentence that is both local with respect to *himself* and commands it. The Subject *Peter* of the upwards predicator *said* is not local with respect to it. And the argument *John* of the relational noun *brother* does not command it. Only the first is an admissible antecedent of *himself* and this anaphoric link, between *himself* and *John's brother*, is an instance of the empirical generalization that principle A seeks to capture.

While this is a first example illustrating the role of the command and the locality relations in the definition of observed constraints on anaphoric links, the focus of the present paper is on the specific constraint on intra-sentential anaphoric links for pronouns, an empirical generalization that is sought to be captured by principle B. An instance of this generalization is exemplified with the contrasts in (1b).

For an expression to qualify as an admissible antecedent of a pronominal anaphor like *him*, that expression cannot be one of its local commanders (principle B). The Subject *John's brother* is the only expression in that sentence that

¹ For a reflexive that is not locally commanded, the constraint expressed by principle A does not hold and the reflexive can establish anaphoric links with antecedent candidates that are not its local commanders. In such cases, the anaphoric expression has been characterized as a logophor [12]. In other theoretical settings, this behavior is explained on the basis that the reflexive is in a so-called exempt position, i.e. in a position where it is exempt from the discipline of principle A [11]. In either case, it is expected that the resolution mechanisms for these elements are different from those for pronouns with commanding antecedents.

is both local with respect to *him* and commands it. Therefore while *Peter* and *John* are admissible antecedents of *him*, *John's brother* is the only antecedent candidate in that sentence that does not qualify as an admissible candidate of the pronoun.

2.2 Previous Behavioral Work

As illustrated in the brief discussion above, the grammatical notions of command and locality have emerged chiefly to characterize the observed constraints on intra-sentential anaphoric links between anaphoric expressions and their admissible antecedents.

Concomitantly, the command relation has been claimed to play a role also in terms of characterizing preferences impinging on the selection of the actual antecedent. The set of admissible antecedents can, in fact, be split into two disjoint subsets: One of the subsets contains the admissible antecedents that command the anaphoric expression at stake, and the other subset the ones that do not command it.² It has been argued that these two subsets are not of equal standing with respect to the processing of anaphoric expressions with intra-sentential antecedents. This instance of anaphor resolution is allegedly subject to a preference that favors resolution against elements of one of these two subsets – the commanders – to the detriment of the elements of the other group – the recessors.

Some authors have proposed to explain these performance effects by resorting to syntactic and/or discursive factors possibly impinging on the cognitive processing of anaphora (e.g., [6,12]). Namely, the preference for commanders would be due to the fact that resolution to antecedents holding such status could obtain by syntactic means alone, while resolution to recessors would require processing at the discourse level. Koornneef et al. [8] expand on this rationale, by identifying two alternative fine-grained explanations for the preference towards commanders: either anaphor resolution involving the discourse level is intrinsically more resource demanding than resolution by syntactic means alone, or the experimental effects observed are in fact due to the processing time-course, in which commanders would be available before non-commanding antecedent candidates. The hypothesis most extensively explored in this connection has been the “increased processing load” hypothesis. We review below a couple of contributions that have assessed this hypothesis by resorting to behavioral experimentation.

Piñango and Burkhardt [10] studied possible differences in the processing of anaphoric links to commanders (2a) vs. links to recessors (2b) holding between reflexives and their antecedents. In one of the experiments, test materials like the following were used:

² The candidate antecedents that do not command the relevant anaphoric expression occur in a position of the predicate-argument structure of the sentence that can be viewed as a recess with respect to the position of that anaphor (when climbing up that structure from the anaphor's position). For the sake of brevity, non-commanding candidate antecedents (of a given anaphor) will be referred to in the remainder of this paper as recessors (of that anaphor).

- (2) a. [The driver_{*i*} who caused a crash blamed himself_{*i*}].
 b. The therapist_{*i*} rolled a ball [around himself_{*i*}]

In (2b), the reflexive *himself* is the sole argument of a predicate, namely the semantically-loaded preposition *around*. As this reflexive is not commanded, the constraint captured in principle A does not apply and it can establish anaphoric links with commanders or with recessors. In the present case, the reflexive is resolved against a recessor, namely *the therapist*.

In contrast, in (2a) *himself* is commanded and the constraint captured in principle A is in force. In this example, the reflexive is anaphorically linked to a commander, namely *the driver*.

For their experiment, these authors resorted to the cross-modal lexical decision interference paradigm. The lexical decision task consisted in pressing a button if the string displayed was a word. They recorded the reaction time to a visual probe appearing immediately after the occurrence of the anaphor in the sentence being listened.

The result was in line with the hypothesis as the reaction time for the condition concerning anaphors resolving to recessors was “statistically significantly higher” than the condition for anaphors resolving to commanders. This experiment was later replicated with materials involving the Dutch *zich*, leading to similar results [4].

Another experimental assessment of the hypothesis at stake was undertaken by [8]. This study resorted to the eye-tracking experimental methodology. It tested possible differences in the processing of pronouns anaphorically resolved to commanders (3a) or to recessors (3b), by resorting to materials illustrated by the following excerpts:

- (3) a. [Every worker who just like Paul was running out of energy]_{*i*}
 thought it was very nice that he_{*i*} could go home early this
 afternoon.
 b. [Every worker who knew that Paul_{*i*} was running out of
 energy] thought it was very nice that he_{*i*} could go home
 early this afternoon.

It was found that “readers refixated the critical region (i.e. containing the pronoun) and the preceding region longer in the [recessor] condition than in the [commander] condition”. Hence, the results reported in this study can also be interpreted as being in line with the above hypothesis.

2.3 Previous Electrophysiological Work

A number of studies, with a specific focus on anaphora resolution, have resorted to evidence based on indicators of neural activity obtained through event-related brain potentials (ERP). However, to the best of our knowledge, the present is the first attempt at measuring antecedent selection using this methodology. Moreover, this is also the first time that this kind of research is carried out in

European Portuguese, which differs in interesting ways from the better studied Germanic counterparts such as English, German and Dutch.

Some studies have been concerned with ambiguous anaphors or the contrast between different types of anaphoric expressions. For instance, Streb et al. [14] found a 270-400 ms frontal negativity and a 510-600 ms parietal negativity elicited by pronouns in contrast to definite descriptions that are resolved to the same extra-sentential antecedent. Van Berkum et al. [15,16] identified a sustained frontal negativity, emerging at about 300-400 ms, elicited by ambiguous pronouns in contrast to non-ambiguous ones. The authors dubbed this effect Nref and suggest that it specifically indexes ambiguity, possibly reflecting the additional neuronal activity required to simultaneously keep two competing referential interpretations in working memory.

Harris et al. [7], concerned with a specific constraint on intra-sentential anaphoric links, identified a P600 effect elicited by a violation of principle A while resolving reflexives.

Still other studies have focused on preferences for anaphora resolution. Streb et al. [13] studied the recency preference and brought to light a N400 effect elicited by pronouns resolved to more distant inter-sentential antecedents than pronouns resolved to more recent ones. Streb et al. [14], in turn, found a 510-630 ms parietal negativity elicited by pronouns resolved to inter-sentential antecedents in a non parallel grammatical function, in contrast to pronouns resolved to antecedents in parallel grammatical functions. The authors interpret this enhanced negativity as a member of the N400 family. This indexing increased the processing demands for resolution of antecedents in a non parallel grammatical function.

2.4 Hypotheses

In this paper, we test the hypotheses that intra-sentential anaphor resolution to recessors differs from resolution to commanders (i) in terms of computational cost, with resolution to a recessor being more costly than resolution to a commander; and (ii) in terms of processing time course, with commanders being made available to the processor before recessors.

We expect (i) to entail a N400-like effect, as described by [14], elicited by pronouns resolved to recessors, and (ii) to entail a Nref effect, as described [15,16], elicited by pronouns resolved to recessors.

Hypothesis (i) stands straightforwardly from [14], taking the amplitude of the N400-like effect evoked by pronouns as an index of computational cost.

The rationale for hypothesis (ii) is as follows: In our material, in the cases where resolution is made to recessors, this resolution is forced by gender agreement – only the non-commanding antecedent candidate agrees in gender with the pronoun. If the morphological information relevant to determine gender agreement can be accessed in parallel for both the commanding and non-commanding antecedent candidates, resolution to the commander should be blocked, given that an antecedent with the suitable gender inflection value is available to the processor. However, if the commander bearing the gender mismatch is momentarily the only alternative

available, the processor should pursue the possibility of resolving the pronoun to that antecedent, repairing the gender mismatch at a later stage, in the P600 window. As a candidate with the suitable gender value is eventually made available to the processor, repairing the gender mismatch is rendered unnecessary: a referential ambiguity should emerge instead, indexed by a transient Nref effect, as the ambiguity is subsequently resolved on the basis of gender information.

The contribution of this study relies not only on the novelty of the hypotheses — which focus on intra-sentential pronoun interpretation —, but also on the methodology used — event-related response potentials (ERPs) —, and on being the first one which reports on observation from Portuguese, a Romance Language.

3 Experiment

3.1 Methods

Participants: Eighteen students (five female) at Coimbra University participated in the experiment for partial fulfillment of course requirements. All participants were right handed monolingual native speakers of Portuguese, with normal or corrected-to-normal vision. Their age ranged from 18 to 25 years (mean age: 20.75; SD = 2.34). Data from six subjects were excluded from further analysis due to insufficient number of valid trials.

Materials: Two conditions were tested in this study: pronouns resolved intra-sententially to commanding antecedents (Antec-Comm) and to non-commanding antecedents (Antec-Recess).

Forty eight pairs of items were designed, differing in the factor Antecedent Command Status (Antec-Comm/Antec-Recess). Gender agreement was used to disambiguate the intended resolution either to the commanding antecedent (4a) or to the non-commanding antecedent (4b).

- (4) a. [O mordomo-MASC de [a condessa-FEM]]-MASC_i discutiu com [a criada]-FEM a quem ele-MASC_i tinha emprestado algum dinheiro. (Antec-Comm)
 The butler_{male} of the countess quarreled with the servant_{female} to whom he had lent some money.
- b. [A empregada-FEM de [o talhante-MASC_i]]-FEM discutiu com [a cliente]-FEM a quem ele-MASC_i tinha vendido carne estragada.
 The employee_{female} of the butcher quarreled with the client_{female} to whom he had sold spoiled meat.

Forty eight different matrix verbs were used to create the experimental sentences. Each verb occurred once in both conditions, yielding 48 pairs of sentences sharing the same matrix verb. Gender inflection values of the pronominal element

and of its intended antecedent were counterbalanced across pairs. Except for the intended antecedent, all other nominal phrases occurring before the pronominal bear a gender value that is opposite to the gender value of that pronominal. The pronominal element was immediately followed by an auxiliary verb, counterbalanced across pairs. The remainder sentential material, occurring after the time-windows of interest for the ERP analysis, was tailored in order to maximize the pragmatic acceptability of each individual sentence. In addition to the 96 experimental stimuli, 144 filler sentences were created. Items were pseudo-randomized and counterbalanced. Three different orderings were used across subjects to control for sequence effects.

Procedure: Participants were seated comfortably in front of a 19" computer screen, at a distance of approximately 100 cm, and presented with the task instructions, followed by a block of 9 practice trials. They were asked to process the sentences for comprehension and instructed to move as little as possible.

The experimental stimuli were presented visually, word by word, in the center of the computer screen. A fixation cross, appearing for 500 ms, served as a reminder for the participants to stop blinking. Each word was displayed for 300 ms, followed by a 300 ms blank screen interval. The final word of the experimental sentences was presented together with a period sign. Following the final word, three dots were displayed in the center of the screen, signaling to the participant that she was free to blink until the next fixation cross would appear. In order to foster the participant's commitment to the sentence comprehension task, 800 ms after each sentence, a force-choice question was presented. The next trial began 2500 ms after collection of the participant's answer to the comprehension question.

Answers were collected by means of two response switches, one held in the participant's right hand, the other in her left hand. The comprehension question was displayed on the top-middle section of the screen, together with two answer options, one on the left lower corner of the screen, the other on the right lower corner. Three different types of questions were used, asking the participant to decide (i) which of the two entities referred before the main verb was the agent of the action conveyed by the main clause; (ii) which entity was the possessor in the genitive construction occurring before the main verb; (iii) which of the two entities referred before the main verb was the agent of the action conveyed by the relative clause. The participants were instructed to press the switch that they were holding in the hand directly in front of the correct option.

Short breaks were introduced approximately every 8 minutes.

EEG recording: Electroencephalogram recordings were collected from 64 Ag/AgCl scalp active electrodes mounted in an electrode cap conforming to the 10-20 system for electrode positioning. Vertical eye movements and blinks were monitored via a supra- to sub-orbital bipolar montage. A right-to-left canthal bipolar montage was used to monitor for horizontal eye movements. Electrode offsets were kept within the interval $25 \mu\text{V}$ to $-25 \mu\text{V}$. The signals were recorded continuously with a digitization rate of 512 Hz and referenced to the average of all electrodes.

3.2 Results

Behavioral data: All participants performed at near ceiling level.

ERP data: Data were band-pass filtered offline to 0.5-40 Hz and screened for eye-movements, muscle artifacts, and electrode drifting. A total of 18% trials were rejected due to artifact contamination. Blink artifacts were removed using an independent component analysis filter algorithm. Data from six subjects were excluded from further analysis because one of the experimental conditions had less than 25 acceptable trials. ERPs were time-locked to the pronominal element and computed using the waveforms from all the trials of the remainder twelve participants: epochs ranging from 150 ms pre stimulus to 1500 ms post stimulus were extracted, baseline corrected using the pre stimulus period, and averaged per condition.

ERP data from 61 electrodes were analyzed for the LAN (250-450 ms), N400 (400-600 ms) and P600 (550-800 ms) time windows, by means of repeated-measures ANOVAs. Separate ANOVAs were performed for lateral and central scalp regions. The electrodes were grouped into nine regions, on the basis of their topographical distribution. The lateral ANOVAs were conducted with the factors Gradient – anterior, medial and posterior - and Hemisphere – left and right, corresponding to six regions: anterior left (AF7 AF3 F7 F5 F3), medial left (FT7 FC5 FC3 T7 C5 C3 TP7 CP5 CP3), posterior left (P7 P5 P3 PO7 PO3), anterior right (AF8 AF4 F8 F6 F4), medial right (FT8 FC6 FC4 T8 C6 C4 TP8 CP6 CP4) and posterior right (P8 P6 P4 PO8 PO4). The central ANOVAs

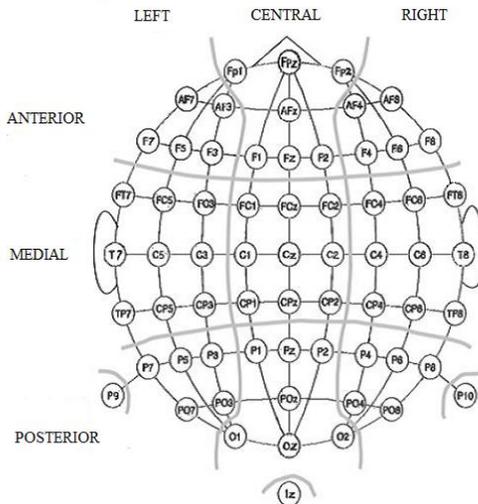


Fig. 1. Electrode groupings corresponding to the regions of interest used in the lateral ANOVAs (anterior left, medial left, posterior left, anterior right, medial right, posterior right) and central ANOVAs (anterior central, medial central, posterior central)

were conducted with the factor Gradient, corresponding to three regions: anterior central (FP1 FPz FP2 AFz F1 Fz F2), medial central (FC1 FCz FC2 C1 Cz C2 CP1 CPz CP2), and posterior central (P1 Pz P2 POz O1 Oz O2). Electrodes P9, lz and P10 were excluded from the analysis.

We report below the results for the two analyses that yielded significant effects or trends involving the Antecedent Command Status variable (Antc. Status). Huynh-Feldt correction was used whenever there was more than one degree of freedom in the numerator. Follow-up pairwise comparisons were computed using Bonferroni adjustment for multiple comparisons.

The central ANOVA for the 400-600 ms window showed a significant main effect for the variable Antec. Status ($F(1, 11)=11.93, p<0.01, MSE=0.062$). Inspection of the estimated marginal means for this variable reveals a more pronounced negativity when the pronoun is bound to a non-commanding antecedent. A significant polynomial quadratic trend occurs for the Gradient x Antec. Status interaction ($F(1, 11)=12.80, p<0.01, MSE=0.043$). Pairwise comparisons for the Gradient x Antec. Status interaction show a significant effect for the Antec. Status variable only for the medial central region.

The lateral ANOVA for the 250-450 ms window showed a significant main effect for the variable Hemisphere ($F(1, 11)=11.93, p<.05, MSE=0.62$), a significant interaction Gradient x Hemisphere ($F(2, 22)=4.91, p<.05, MSE=0.339$), and a marginally significant main effect for the variable Antec. Status ($F(1, 11)=3.89, p<0.1, MSE=0.09$). Inspection of estimated marginal means for Hemisphere reveals a more pronounced negativity over the left hemisphere. Follow-up pairwise comparisons for the Gradient x Hemisphere interaction show that this lateralized negativity only holds for the medial and posterior regions; the anterior region bears a negativity that spreads to the right hemisphere. The marginally significant main effect for Antec. Status suggests that pronoun resolution with a non-commanding antecedent elicits a more pronounced overall negativity, which conforms to the previously described spatial distribution pattern.

4 Discussion

As mentioned above, the contribution of this study relies on the novelty of the hypotheses, concerning anaphora resolution against commanders vs. recessors, which focus on intra-sentential pronoun interpretation, and not on reflexives as in previous related works. It relies also on the methodology, which for the first time explores ERPs to investigate the issues at stake. And last but not least, it relies on being the first one to report on observation from Portuguese, thus extending this type of inquiry to language materials from Romance Languages.

In line with [14], we interpret the medial relative negativity found in the 400-600 ms window as an N400-like effect, signaling the effects of the experimental manipulation upon the formation of the pronoun-antecedent dependency. This enhanced negativity for pronouns resolved to non-commanding antecedents suggests that, in line with hypothesis (i), resolving a pronoun to a recessor is a more resource demanding process than resolving it to a commander.

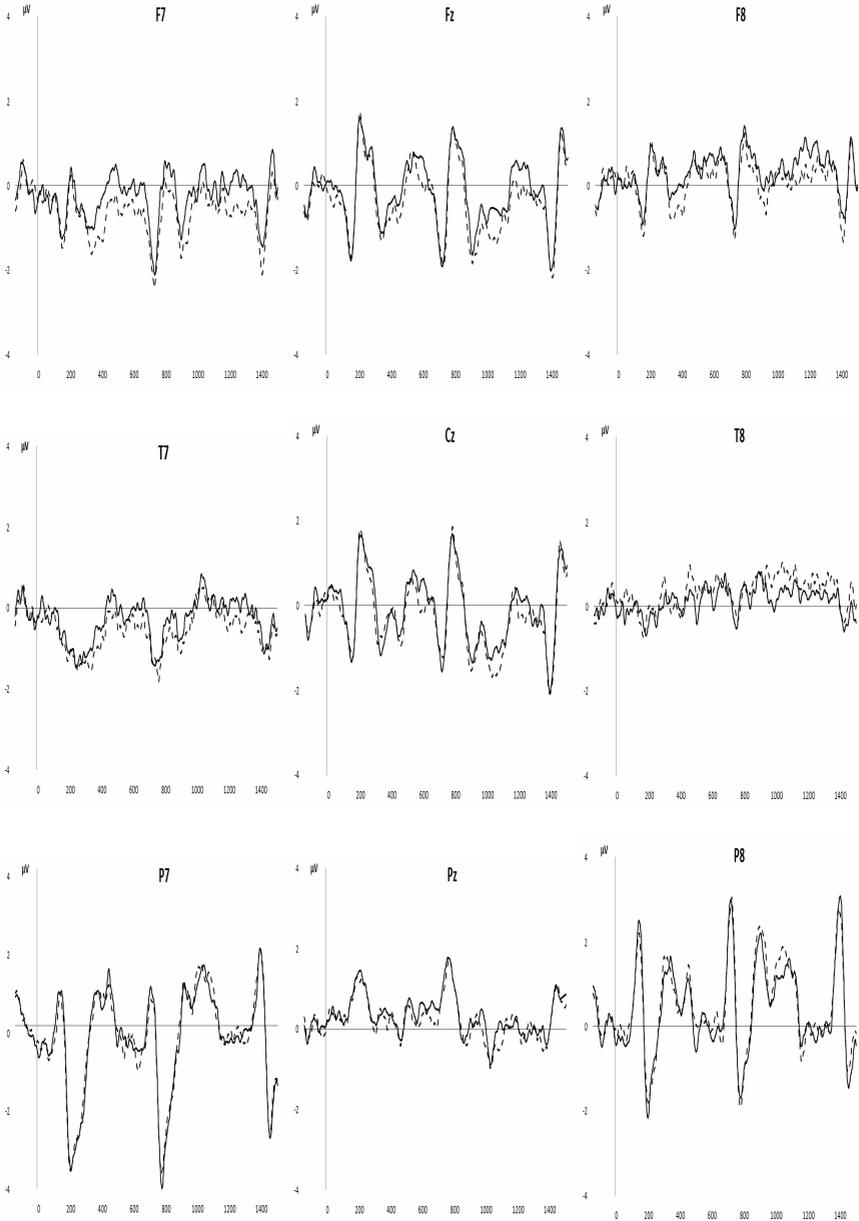


Fig. 2. Grand average ERPs ($n=12$) measured to the onset of the critical pronoun resolved with a commanding antecedent (solid line) and pronoun resolved to a non-commanding antecedent (dashed line). Waveforms are plotted from a 150 ms pre stimulus baseline to 1500 ms post stimulus. Pronouns resolved to a non-commanding antecedent elicit a fronto-lateral dominant negativity in the 250-450 ms window, as illustrated at F7 and F8, and a central negativity in the 400-600 ms window, as illustrated at Cz. Negative is plotted down.

The most apt explanation for this difference is that whereas the selection of commanders as antecedents is done through syntactic means alone, the selection of recessors as antecedents requires the implementation of the selection through an additional informational layer, namely, discourse representation. The level of complexity is thus determined by how many layers of information (syntax only vs syntax+discourse) are required to ultimately establish the antecedent selection.

Hypothesis (ii) also gathered confirmatory evidence. The marginally significant effect found in the 250-450 ms window for the Antecedent Command Status variable consists of a wide-spread relative negativity elicited by pronouns resolved to recessors. This enhanced negativity is distributed according to an overall pattern of Hemisphere and Gradient effects, characterized by (i) a similar gradient pattern over each hemisphere, with anterior and medial regions more negative than the posterior region, (ii) a left-lateralized negativity for the medial and posterior regions, (iii) a bi-hemispheric negativity for the anterior region. The spreading of the anterior negativity to the right hemisphere is mainly due to the contribution of the Antec-Recess condition. The relative negativity elicited by pronouns resolved to recessors is, therefore, indicative of a (short-lived) Nref-like effect. Van Berkum et al. [15,16] describe the Nref as a bilaterally and globally distributed negativity, frontally dominant, elicited by anaphors with two admissible antecedent candidates in contrast to anaphors with a single admissible antecedent candidate.

We interpret the Nref-like pattern found in our experiment as indicating that the commanding antecedent is made available to the resolution process before the recessor, and momentarily entertained as the sole available alternative. The processor therefore pursues the possibility of resolving the pronoun to that antecedent even when it mismatches the pronoun in gender. A referential ambiguity emerges when a recessor with a suitable gender value is eventually made available to the processor, indexed by Nref effect. The Nref negativity is not a sustained one, unlike what is more frequently observed in manipulations that evoke the Nref effect. This is to be expected, since in this instance, the ambiguity is readily resolved on the basis of gender information.

Altogether, these findings nicely converge with a large body of work based on behavioral evidence showing that establishing this kind of discourse-based dependency (resolution to recessor) is more computationally demanding than establishing dependencies based on syntactic mechanisms alone (resolution to commander).

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