THEORETICAL ESSAY

# OLD STORY, NEW RESULTS AND ANALYSES: **AN EYE-TRACKING AND ERP EVALUATION OF A CLASSICAL AMBIGUITY** INVOLVING THE ATTACHMENT POINT OF RELATIVE CLAUSE AND PREPOSITIONAL PHRASE MODIFIERS

Tom ROEPER iD ✉

Department of Linguistics – University of Massachusetts Amherst (UMass Amherst)

Marcus MAIA iD ✉

Department of Linguistics – Federal University of Rio de Janeiro (UFRJ)

Aniela Improta FRANÇA iD ✉

Department of Linguistics – Federal University of Rio de Janeiro (UFRJ)

ABSTRACT

An eye-tracking and an electrophysiological experiment using a sentence/picture matching task were carried out in order to assess whether there would be significant differences between semantic restrictiveness properties of Prepositional Phrases (PPs) vis-à-vis those of Relative Clauses (RCs), attached as modifiers respectively to a local PP or to a non-local DP (*e.g.* the horse with the parrot with brown spots/the horse with the parrot that has brown spots). Two hypotheses were entertained, namely, (i) an operator construction such as an RC would be construed

non-locally, that is, would   attach high as a default, even if there is semantic bias attracting it to a low attachment; (ii) a light constituent (PP) has no prosodic autonomy and will be more available to local attachment and therefore would tend to attach locally as a default, even if there is semantic bias attracting it to a high attachment. Results in both experiments were in favor of the hypotheses and we speculate whether they could be more deeply grounded into the representational alternatives projected by linguistic theory itself.

RESUMO

Reportam-se um experimento de rastreamento ocular e um experimento eletrofisiológico utilizando uma tarefa de compatibilidade entre frase/imagem, para avaliar se haveria diferenças significativas entre as propriedades de restrição semântica de Sintagmas Preposicionais (SPs) comparativamente a Orações Relativas (ORs), ligados como modificadores, respectivamente, a um SP local ou a um DP não local (por exemplo, o cavalo com o papagaio com manchas marrons / o cavalo com o papagaio que tem manchas marrons). Duas hipóteses foram consideradas, a saber: (i) uma construção de operador, com uma OR, seria interpretada não localmente, isto é, seria preferencialmente analisada como aposta não localmente, mesmo que haja viés semântico atraindo-a para aposição local; (ii) um constituinte mais leve (SP) não tem autonomia prosódica e estará mais disponível para a ligação local e, portanto, tenderá a se fixar localmente como default, mesmo se houver viés semântico atraindo-o para aposição sintática alta. Os resultados em ambos os experimentos foram a favor das hipóteses e especula-se se eles poderiam ser mais profundamente fundamentados nas alternativas representacionais projetadas pela própria teoria linguística.

KEYWORDS

Relative Clause Attachment; Prepositional Phrase Attachment;
Eye-Tracking; EEG.

PALAVRAS-CHAVE

Aposição de Orações Relativas; Aposição de Sintagmas Preposicionais;
Rastreamento Ocular; EEG.

# INTRODUCTION

Results from sentence processing studies using a wide range of psycholinguistic methods have shown that on-line parsing involves accessing and rapidly integrating various types of structural and non-structural information during comprehension (Cf. Gibson & Pearlmutter, 1998, for review). It is also widely assumed that the human sentence processing mechanism comprises a narrow set of universal parsing principles (FRAZIER, 1979; FRAZIER; FODOR, 1978), some of which have been claimed to be subject to parametric variation (see *e.g.* Frazier & Rayner [1988], Mazuka, Lust [1990]).

Among the different kinds of studies, the ones about sentence ambiguity may offer precious insights on the nature of the human sentence processing mechanism. The main aim of such studies is to tease apart semantic from structural factors to try to weigh them separately so as to deepen the understanding of the underlying forces in ambiguity resolution.

For instance, a sentence such as (i) *That is the horse with the parrot that has brown spots* is ambiguous because the Relative Clause (RC), *that has brown spots*, is preceded by a complex DP, *the horse with the parrot* and, therefore, it could be attached either to the first DP, *the horse*, or to the second one, *the parrot*. So if it is unclear whether it is the horse or the parrot that has brown spots, especially because there is nothing in one's world knowledge to define a preference in this case, the parsing choice, if any, could be ascribed to structural factors that might facilitate low or high attachment of materials. So, carefully controlling the semantics in ambiguous sentences seems to be a reasonable experimental path to follow if one wants to disclose the speakers` disambiguation criteria.

But things will tend to get a little more complex, because the literature shows that preferences do differ across languages (CUETO; MITCHELL, 1988). For instance, English, Norwegian and Swedish speakers would tend to prefer to attach the relative clause (RC), *that has brown spots*, to the second DP, *the parrot* (CUETOS; MITCHELL, 1988; FRAZIER; CLIFTON, 1996; GILBOY; SOPENA; CLIFTON; FRAZIER, 1995; EHRLICH; FERNANDEZ; FODOR; STENSHOEL; VINEREANU, 1999). This preference has been ascribed to a general parsing strategy dubbed Right Association (KIMBALL, 1973), Late Closure (FRAZIER, 1978) or Recency (GIBSON; PEARLMUTTER; CANSECO-GONZALEZ; HICKOCK, 1996). But, at the same time, Spanish, Greek, German and French speakers would prefer to attach the RC to the first or high DP, *the horse*. These contrasting findings might mean that at least some parsing strategies are language-specific rather than universal (HEMFORTH; KONIECZNY; SCHEEPERS; STRUBE, 1998; ZAGAR; PYNTE; RATIVEAU, 1997; FRENCK-MESTRE; PYNTE, 2000; PAPADOPOULOU; CLAHSEN, 2003).

Resulting from this diffuse literature that proposes a kind of parametric structure applied to parsing, different hypotheses arise to try to provide a systemic nature of the attachment preferences among the languages.

Another aspect of uncertainty is brought to the surface when the attachment of RCs is compared to that of PPs (Prepositional Phrase). In this case, comparing (i) *That is the horse with the parrot that has brown spots* to (ii) *That is the horse with the parrot with brown spots* will reveal that, because the PP is lighter, it would tend to attach high. So, the prediction is that, at least in English, high PP attachment would contrast with low RC attachment.

Frazier & Clifton's (1996) Construal theory is an attempt to capture these facts. They argue that the so-called non-primary phrases, i.e. non-obligatory constituents including RC adjuncts, are construed or associated with the closest thematic processing domain. That is, when the second DP (*the parrot*) receives a theta-role from the preposition (*with*), the RC is processed within this thematic domain and is consequently attached low. In this way, the Construal theory accounts for the fact that in sentences such as (ii) low attachment is preferred across languages. However, in sentences such as (i) the closest thematic processing domain is the entire DP (the horse with the parrot), which includes both DPs.

Finally, if these investigations are structured using materials to be read by participants, another important intervening aspect will be the implicit prosodic contour that the participant will give to the sentences. The Implicit Prosody Hypothesis (FODOR, 1998, 2005), for example, predicts that even in silent reading, prosody can be designed mentally and will influence the course of syntactic processing. According to Kitagawa & Fodor (2006), a change in prosody may change one's interpretation from grammatical to ungrammatical, indicating again the importance of prosodic considerations in grammatical studies. The Implicit Prosody Hypothesis (IPH) resembles Construal in its assumption of a parser that operates under universal principles which apply no matter what language is being processed. But unlike Construal, it hypothesizes that speakers of different languages exhibit different attachment preferences because of differences in their internalized phonologies. The prosodic structure (intonation and phrasing) projected when reading out loud can influence ambiguity resolution. According to the IPH, a prosodic structure generated implicitly during silent reading can also influence ambiguity resolution. The idea of an "inner voice" heard during silent reading, already indicated in Huey (1908/1968) has been entertained by many studies of reading in English. Fodor (2002) has been recognized as the seminal study exploring how reader's inner voice influences sentence processing. In this important paper Fodor characterizes implicit prosody as:

> The Implicit Prosody Hypothesis (IPH): In silent reading, a default prosodic contour is projected onto the stimulus, and it may influence syntactic ambiguity resolution. Other things being equal, the parser favors the syntactic analysis associated with the most natural (default) prosodic contour for the construction. (FODOR, 2002, p. 1).

Crucially, Fodor (2002) claims that cross-linguistic variation in the high or low attachment of RCs or PPs may be attributable to the prosodic weight of the attaching constituent relative to that of the host constituent, lighter constituent: lighter constituents tend to attach to a local host in the syntactic tree, whereas heavier constituents would be prosodically autonomous and would be more likely to attach higher, in a type of anti-gravity effect. Thus, a locality processing principle[1] such as Late Closure (FRAZIER, 1978) could be subsequently adjusted in the on-line time course in comprehension, given prosodic considerations.

In view of the many and somewhat contradicting conclusions that can be extracted from the specialized literature on PP and RC attachment (Cf. Fernández, 2003, for a review), we designed two on-line experiments to be applied to English speakers to check such predictions by the use of very streamlined materials. One experiment used and eye-tracker and the other used an EEG-ERP platform, both assigning a Sentence-Picture Matching task. All the pictures and stimuli were designed from scratch specifically to be used in the eye-tracking and the EEG experiments presented here.

We believe that obtaining evidence from the same testing materials through two different methodologies would contribute to the clarity of our understanding about the mechanisms of high or low DP attachment in ambiguous sentences. Besides, stimuli were carefully put together to assess whether there were significant differences between semantic restrictiveness properties of Prepositional Phrases (PPs) *vis-à-vis* those of Relative Clauses (RCs), attached as modifiers respectively to a local PP or to a non-local DP. Two syntactic factors were taken as presuppositions in the studies. On the one hand, the highest DP was presented in a cleft construction. This made it salient and thereby more prone to attract modification. On the other hand, the Late Closure Principle predicts low attachment as a processing default. This principle goes hand in hand with the Implicit Prosody Hypothesis (FODOR, 2002a, 2002b) that was also expected to play a role in the results: since PPs are lighter than RCs they would tend to attach locally.

We held two hypotheses directly derived from these observations:

(i) an operator construction, such as an RC, will be construed non-locally, that is, will attach high as a default;

---

1 Principles of locality have been claimed to regulate both structure building and filler-gap processes in language processing (Right Association Kimball 1973; Late Closure Frazier 1978; Minimal Attachment, Frazier & Fodor 1978; Minimal Chain Principle, De Vincenzi 1991; Recency, Gibson 1991; Merge Right, Phillips 1996, among others.

(ii)   a light constituent, such as a PP, has no prosodic autonomy and will be more available to local attachment and therefore will tend to attach locally as a default;

# 1. ADDITIONAL CONSIDERATIONS ABOUT THE DESIGN

Figures 1 and 2 depict cases in which the lexical semantics was carefully manipulated not to favor high or low attachment.
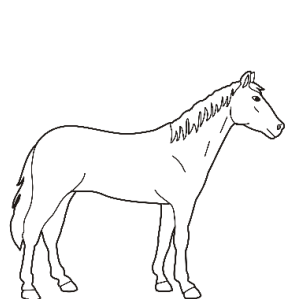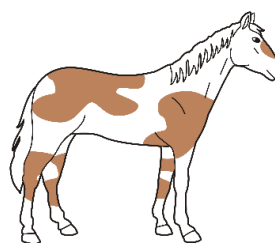


**Figure 1.** Neutral Case

**Figure 2.** Neutral case

Since having brown spots is an equally possible condition for either horse or parrot, we assume that the semantics was neutral and the choice between PP or RC will be driven structurally. So Figures 1 and 2 could be paired with either sentences 1a or 1b.

**1a:**  That is the horse with the parrot with brown spots;
**1b:**  That is the horse with the parrot that has brown spots.

Following from this, a set of stronger hypotheses hold that the preferences will not change even if we introduce semantic bias in the opposite direction of the default:

(i')  an operator construction such as an RC will be construed non-locally, that is, will attach high as a default, even if there is semantic bias attracting it to a low attachment;
(ii')  a light constituent (PP) has no prosodic autonomy and will be more available to local attachment and therefore will tend to attach locally as a default, even if there is semantic bias attracting it to a high attachment.
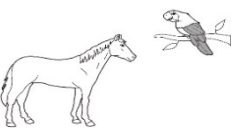
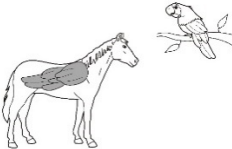These hypotheses allow for the following predictions in the experiments:

**a.**   Biased low PPs will be easier to process, displaying less Fixation Duration (hence, FD) latencies and Fixation Count (hence, FC) in the eye tracking test; lower amplitude and perhaps shorter latencies N400 in the EEG test) than biased high PPs;

**b.** Biased low RCs will be harder to process (more FD and FC; higher amplitude and perhaps longer latencies N400 and maybe even P600 in the EEG test) than biased high RCs.

The experiments had two independent variables, namely, type of construction (PP, RC) and Semantic bias (High, Low, Neutral) applied to a 2x3 design, generating six conditions: (i) PPN (preposition phrase, neutral semantics); (ii) RCN (relative clause neutral semantics); (iii) PPL (preposition phrase, low attachment); (iv) RCL (relative clause, low attachment); (iv) PPH (preposition phrase, high attachment); and (vi) RCL (relative clause, high attachment). The experimental stimuli comprised 18 sets of target sentences organized in Latin Square design, randomly dispersed among 36 fillers.  An example of a complete set is in Table 1.

Participants should perform a sentence picture-matching task, self-monitoring the visualization of a screen with a picture and a sentence, that is, each of the six conditions appeared on the screen after the presentation of one of two pictures rotated in the design, generating a total of 2 expected matches and 2 no-matches. These numbers were balanced with the distractors, reaching a total of 50% of matches and 50% of no-matches.

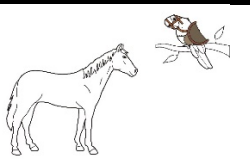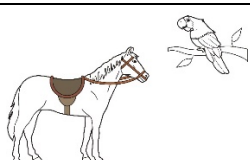| Pictures | # | Condition | Sentence | Match/Nonmatch expectation |
|---|---|---|---|---|
|  | 1 | PPN | That is the horse with the parrot with brown spots | Match |
| | 2 | RCN | That is the horse with the parrot that has brown spots | No-Match |
|  | 1 | PPN | That is the horse with the parrot with brown spots | No-Match |
| | 2 | RCN | That is the horse with the parrot that has brown spots | Match |
|  | 3 | PPL | That is the horse with the parrot with gray feathers | Match |
| | 4 | RCL | That is the horse with the parrot that has gray feathers | No-Match |
|  | 3 | PPL | That is the horse with the parrot with gray feathers | No-Match |
| | 4 | RCL | That is the horse with the parrot that has gray feathers | Match |

| | | 5 | PPH | That is the horse with the parrot with a new saddle | Match |
|---|---|---|---|---|---|
| | | 6 | RCH | That is the horse with the parrot that has a new saddle | No-Match |
| | | 5 | PPH | That is the horse with the parrot with a new saddle | No-Match |
| | | 6 | RCH | That is the horse with the parrot that has a new saddle | Match |

<p align="center"><strong>Table 1</strong> – Examples sentences in the experimental conditions</p>

# 2. THE EXPERIMENTS

## 2.1. THE EYE-TRACKING STUDY

### Participants

Thirty students, at the University of Massachusetts, Amherst, right handed, all native speakers of American English, with normal or corrected-to-normal vision, received course credit for taking part in the experiment. Despite the fact that bilingualism was not controlled, because it is so prevalent among college students in the US, we screened for the strongest language and only accepted in the study participants whose stronger, preferred native language was English.

### Procedure

A Tobii TX300 eyetracker monitored participants eye-movements at a frequency of 300 Hz, with an accuracy of 0.4°. Images were presented on a 23-inch multi-scan color monitor at a resolution of 1920 x 1080 pixels. The experiment was implemented using the Tobii Studio software. Pictures and sentences were presented on the same screen, and the picture was always displayed first. Sentences were written in Courier New 28pt Font (True Type) and were displayed in a single line. Participants were seated 62 cm from the computer screen. Before the experiment started, subjects read a set of instructions on how to perform the experiment.

A calibration procedure was performed at the beginning of each testing session and each participant read six practice items before the experimental items were shown. By pressing the space bar on a keyboard, the participant triggered the screen to be inspected. Once they had inspected the picture and understood the sentence, they indicated their decision about the matching between the sentence and the picture, by pressing buttons marked as yes or no on the keyboard. The order of experimental and

filler items was pseudo- randomized such that each experimental item was preceded by at least one filler item. The entire experiment lasted approximately 20 minutes.

### On-line measure Results

A two-way ANOVA by subjects is reported below (Graph 1) for total fixation durations on the target areas, the low PP and RC regions (*e.g.* PPL: That is the mechanic with the nurse with the stethoscope; RCL: That is the mechanic with the nurse that has the stethoscope). The ANOVA indicates a highly significant main effect of Structure ($F_{(1,89)}$ = 130 p<0,000001***) and a highly significant effect of Semantic bias ($F_{(2,178)}$ = 10,6 p<0,000043***), as well as a highly significant interaction between the two factors ($F_{(2,178)}$ = 24,1 p<0,000001***). Pairwise t-tests between conditions are also reported below. As indicated in Graph 1, overall, RCs demanded higher fixation latencies than PPs.

Crucially, semantically biased low PPs were significantly less fixated than semantically biased high PPs or than semantically neutral PPs. RCs are in complementary distribution with PPs, being less fixated when they are semantically biased for high attachment than when they are semantically biased for low attachment or when they are semantically neutral.
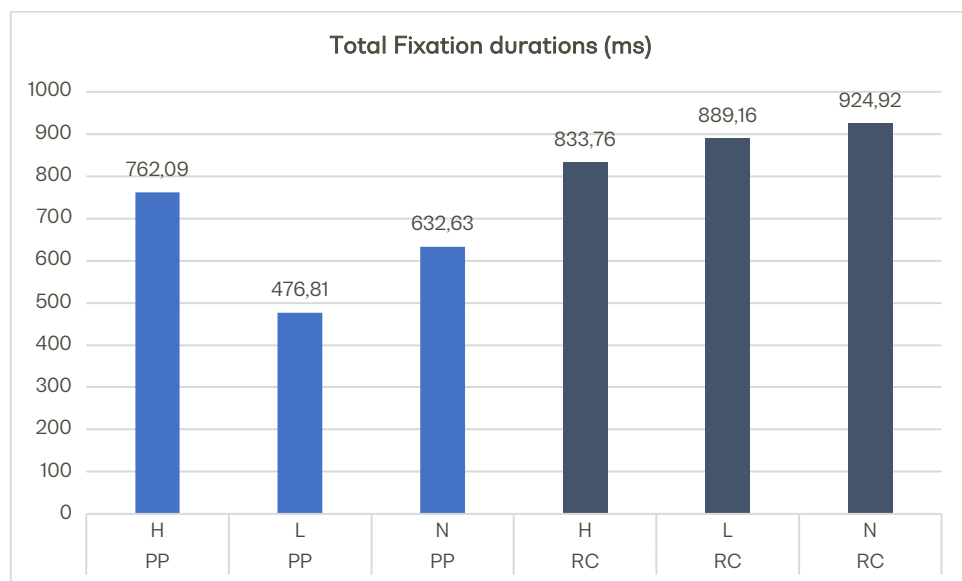


**Graph 1.** Total fixation duration in milliseconds in each of the six conditions

Pairwise t-tests comparisons indicate that low PPs are significantly less fixated than both high PPs ([PP_H]vs[PP_L] $t_{(89)}$=6,45, p< 0,0001) and neutral PPs ([PP_L]vs[PP_N] $t_{(89)}$=4,25, p< 0,0001). Interestingly, neutral PPs are also less fixated than high PPs ([PP_H]vs[PP_N] $t_{(89)}$=3,02 p< 0,0033), confirming that high PPs, which are not recursively embedded locally, are actually the costliest condition to process. Taking the neutral

condition as baseline, these results also indicate that (i) the default for PP attachment is the low locally embedded position; (ii) semantic bias plays an effect in gaze durations in the PP area in the sentence, which is significantly less fixated when there is a low bias than when there is no bias.

The RC conditions, on the other hand, display only one robust difference in pairwise comparisons, which is the semantically neutral versus the high attachment biased conditions ([RC_H]vs[RC_N] t(89)=3,08  p< 0,0028). High attachment biased RCs are significantly less fixated than neutrally biased RCs, suggesting the existence of a semantic effect in action. The locally attached RC, however, is only visually different from both the neutral ([RC_L]vs[RC_N] t(89)=1,10  p< 0,2739) and the high conditions ([RC_H]vs[RC_L] t(89)=1,82  p< 0,0725).

### Off-line measure Results

Results in Graph 2 were treated statistically. Accuracy rates were submitted to a two-way ANOVA by subjects, yielding no main effects of structure ($F(1,89) = 0,116$ $p<0,73$) or semantic bias ($F(2,178) = 0,948$ $p<0,38$).[2] There were no interactions between the two factors either ($F(2,178) = 0,027$ $p<0,97$). There is no interesting discrimination between conditions in this measure, but the significantly high levels of accurate answers indicate that subjects were engaged in the experiment task.
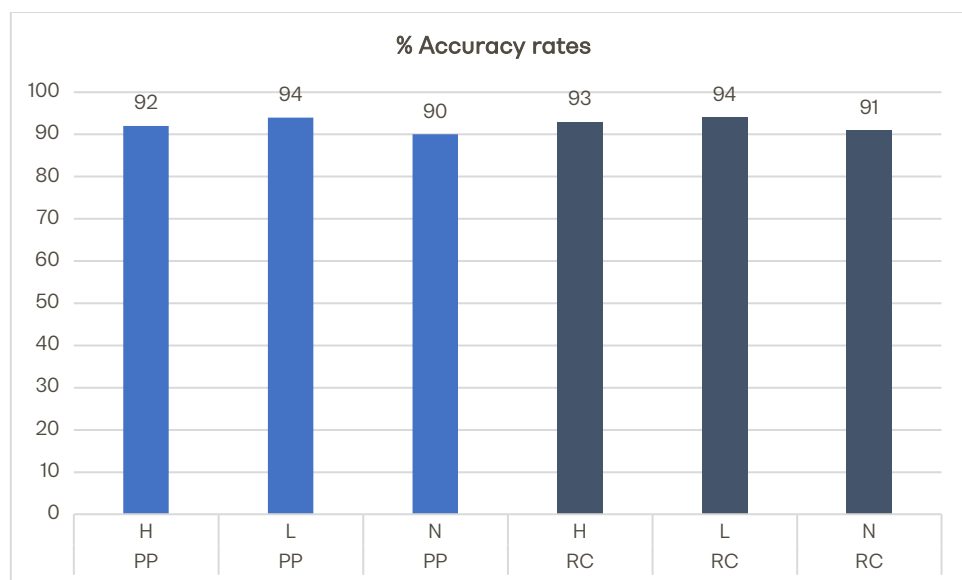


**Graph 2.** Accuracy tests in percentage

2  Average decision times were likewise not different and will not be reported.

## Discussion of the Eye-tracking Experiment

Let us start by comparing the heatmaps[3] of a typical PPL condition and of a typical PPH condition. Figure 3 illustrates a PP construction which has a bias for low attachment, indicated both for the semantic properties of the PP (athletes deal with weights) and for the picture (the athlete has the weight).



That is the mailman with the athlete with the weight

**Figure 3.** low attachment pp



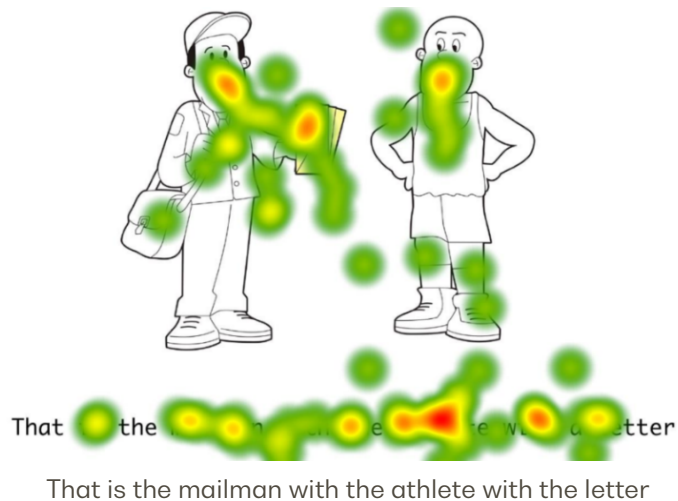That is the mailman with the athlete with the letter

**Figure 4.** High attachment pp

3   A heatmap is a graphical representation of data where the individual values contained in a matrix are represented as colors. The areas where readers looked the most are colored red; the yellow areas indicate fewer views, followed by the least-viewed green areas.

Figure 4, on the other hand, illustrates a PPH construction in which there is a bias for high attachment of the PP "with the letter". Mailmen typically deal with letters, as confirmed by the picture. As indicated in the Results section, critical areas of PPH sentences received an average total fixation duration of 762ms, whereas critical areas of PPL sentences received a total fixation duration of 477ms, yielding a highly significant difference ([PP_H]vs[PP_L] t(89)=6,45 p< 0,0001***). It seems clear that the locally embedded PP in Figure 3 is the default, requiring less fixation time than the PP in the sentence in Figure 4, which is biased for high attachment and requires longer latencies to be processed. From a parsing perspective there are two explanations for this difference. The Late Closure Principle (Frazier & Fodor, 1978; Frazier, 1979)[4] is a universal principle of cognitive economy which predicts that a low or local analysis of a structurally ambiguous construction is to be preferred to a high or non-local attachment, even though the grammar may license both analyses, as it is the case in the PP constructions here. A second possible processing explanation for the PP low attachment preference can be found in Janet Fodor's Implicit Prosody Hypothesis. According to Fodor (2002), there would be a tendency in the languages to "glue" down the lighter constituents, which would search for a local host. Heavier constituents, on the other hand, would be more autonomous to search for non-local hosts, depending on the prosodic patterns of each language. From a grammatical representation point of view, it may be said that recursive local embedding is preferred to a non-local conjoining construction (the mailman with an athlete and with a letter). Even though local conjoining has been shown to be less favored than local embedding, that does not seem to be the case with a non-local conjoining type of construction.

In contrast, Figure 5 and Figure 6 illustrate heatmaps of low attachment and high attachment RCs. Note that the low attachment RC in Figure 5 seem to receive longer fixation durations in critical areas than the high attachment RC in Figure 6. However, a direct comparison of fixation durations in the critical RC areas between conditions do not yield a significant result [RC_H]vs[RC_L] t(89)=1,82 p< 0,0725. However, RCH is faster than RCL, suggesting the operation of the semantic bias factor in the on-line measure. Nevertheless, it is interesting to note that, even though sizes of the PP conditions were smaller than RC conditions, due to the presence of the operator, PPL, the preferred PP attachment is even faster than RCL, the unfavored RC attachment

4 "The Late Closure strategy is not a decision principle which the parser relies on when it is unsure about the correct attachment of incoming materials; rather, late closure of phrases and clauses is a result of the fact that the first stage parser functions most efficiently by (minimally) attaching incoming material with material on its left which has already been analyzed." (Lyn Frazier, "On Comprehending Sentences: Syntactic Parsing Strategies." Indiana University Linguistics Club, 1979).

([PP_L]vs[RC_L] t(89)=10,52  p< 0,0001), but, crucially, PPH, the unfavored PP attachment is not significantly faster than RCH, the hypothesized preferred RC attachment ([PP_H]vs[RC_H] t(89)=1,91  p< 0,0594).



That is the woman with the tray that has glasses

**Figure 5.** Low Attachment Rc
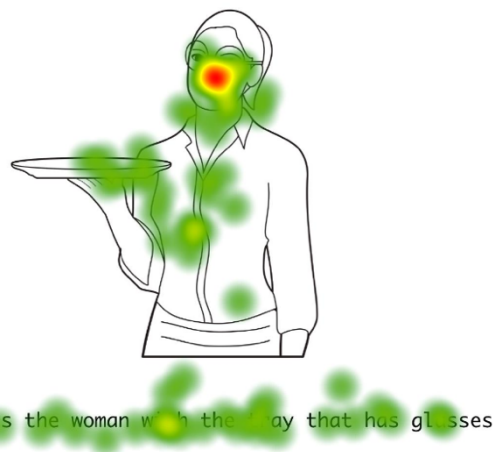


That is the woman with the tray that has glasses

**Figure 6.** High Attachment Rc

## 2.2 THE EEG-ERP STUDY

Electroencephalography is the neurophysiological measurement of electrical activity in the brain as recorded by electrodes placed on the scalp. The resulting traces are known as an electroencephalogram (EEG) and represent a summation of post-synaptic potentials from a large number of neurons.

The use of EEG in neuroscience research delivers a number of benefits. One is that EEG is non-invasive for the research participant. Another is that EEGs have a high temporal resolution compared with techniques such as fMRI and PET and are capable of detecting changes in electrical activity in the brain on a time scale in the millisecond region. Finally, because the technique used, named ERP (Event-Related Brain Potential), can amplify the real subtle cognitive responses and separate them from noise, the researcher is able track changes in the brain activity over time and related to a specific experimental condition with great temporal resolution.

In this technique the electric signals that are captured during the experiment are amplified and digitized technically by way of grand-averaging in order to suppress noise and enhance electric potentials. This procedure is justified by considering spontaneous EEG as zero-mean white Gaussian noise and the ERPs as the only responses, which are really synchronized with the stimulus. This way, the effect of the grand-average is to increase the signal/noise ratio (SNR), thus allowing for the visualization of the specific effect of the linguistic stimulus that might otherwise present a lower signal-to-noise ratio (SN) than those of the original waveforms (GESUALDI, FRANÇA, 2011)

In the system used in this study (a *32-channel Brain-Products active electrode amplifier*), the electrode attachment was performed with a cap in which electrodes are embedded, a method particularly effective for cognitive research. Besides the system is equipped with a number of noise reduction techniques such as active noise cancellation and active electrodes to ensure maximum data quality.

## Participants

Thirty-two right-handed students at the University of Massachusetts, Amherst, all native speakers of American English, with normal or corrected-to-normal vision, received course credit for taking part in the experiment. During data processing, we identified that the signals coming from 4 of these students had high interference and were not used. So, we analyzed data from 28 participants, 16 males, with an average of 21,4 years of age.

## Procedure

The EEG signals were recorded continuously from 32 sintered Ag/Ag–Cl electrodes attached to an elastic cap (Brain) in accordance with the extended 10-20 system (NEWER *et al.*, 1998). Several of these electrodes were placed in standard International System locations, including six sites along midline (AFZ, FZ, FCZ, CZ, PZ,OZ) and 14 lateral/ temporal sites, seven over each hemisphere (FP1, FP2, F7, F3, F4, F8, FC5, FC1, FC2, FC6, T7,C3,C4,T8) and 10 posterior locations, five over each hemisphere (CP5, CP1, CP2, CP6, P7,P3,P4,P8, O1 and O2). EEG was also recorded over left and right mastoid sites (Figure 7).

**Figure 7.** Thirty-two channel scalp-electrode array: frontal-left, frontal-mid, frontal-right, central-left, central-mid, central-right, centro-parietal-right, occipital-right and occipital-left.

EEG was referenced on-line to a vertex electrode and later re-referenced to an average of the left and right mastoid channels. Impedances were maintained below 10 kΩ. EEG was amplified and digitized at a sampling frequency of 1000 Hz (BrainProducts Systems). After recording, data was *down-sampled* to 200 Hz and filtered with a bandpass of 0.01–30 Hz. ERPs were averaged off-line within each experimental condition for each subject at each electrode site in epochs spanning –200 to 800ms relative to the onset of the target stimulus. Epochs characterized by eye blinks or excessive muscle artifacts were rejected by BrainProducts Systems depending on the experimenter's visual inspection. Accuracy was computed as the percentage of correct responses (min 95%).

ERP components of interest were identified based on visual inspection of ERPs, ROIs and topographic maps. For each of the channels, we quantified ERPs for analysis as mean voltages within windows of 350–550ms (capturing a broad negativity); and 550–800ms (capturing a broad positivity) after stimulus onset. Grand-averages were formed by averaging over participants.

## Results

Figures 8 and 9, of respectively PP and RC attachments, display the comparison of the ERPs relative to the three semantic conditions (neutral, low and high):

left-cent ROI: PPH, PPN, PPL
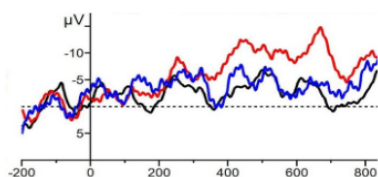
left-cent ROI: RCH, RCN, RCL



**Figure 8.** ERP of the PP sentences. Grand-average ERPs from 28 right-handed subjects submitted to the PP experiment. EEG was extracted from 32 different cortical regions, but just the left central ROI was transcribed here. The red line line refers to ERPs resulting from PPs that would get their best reading by attaching to a high DP, the blue line from PPs that would get their best reading by attaching to a low DP and the black line to those that would accept equally well to attach to high or low DPs .
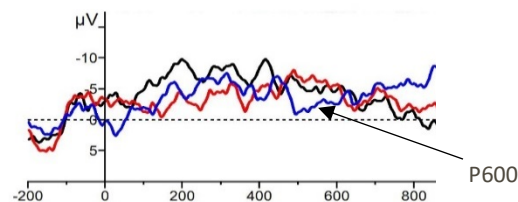
**Figure 9.** Grand-average ERPs from 28 right-handed subjects submitted to the Relative Clause experiment. EEG was extracted from 32 different cortical regions, but just the left central ROI was transcribed here. The red line line refers to ERPs resulting from RCs that would get their best reading by attaching to a high DP, the blue line from RCs that would get their best reading by attaching to a low DP and the black line to those that would accept equally well to attach to high or low DPs .

Through visual inspection of the ERPs at the left center ROI in Figure 8, it is easy to perceive that as expected, the preferred PP attachment, PPL, makes a faster and lower amplitude peak than PPH ([PP_High]vs[PP_Low] t(27)=14,71  p< 0,0001).

In Figure 9, the differences in amplitude are not so clear, but still it is possible to depict by visual inspection that the opposite happens with the ERPs in the RC condition. The preferred RC attachment, RCH, is a faster and lower amplitude peak than RCL ([RC_High]vs[RC_Low] t(27)=6,43  p< 0,0001).

### Discussion of the EEG Experiment

Very interesting is the black line, the one referring to the semantically neutral condition, that stands out in the RC condition. Notice that this was not predicted, but came to be exactly the same finding as the one in the eye tracking experiment: the longest fixation duration average in all the experiment stemmed exactly from the RC Neutral condition. Likewise the highest peak in amplitude and the longest latency came from the ERP related to the RC Neutral condition. This suggests that since the relative clause attachment renders more independence to this computation than the PP attachment, the lack of semantic bias in the neutral condition promoted more doubt as to the best attachment point, and thus took longer (longer latency) and demanded more cognitive effort (higher amplitude). Both latency and amplitude indicate that this was the hardest attachment to process.

The second hardest, as predicted, was the high attachment in the PP condition, because a light constituent, such as a PP,  with little prosodic autonomy, will only be

available to  distant attachment upon great effort. As predicted, the highest N400 and also the longest latency one comes from this condition.

Finally comes the low attachment in the RC condition. This built a slow N400 actually at 520ms, followed by the only clear P600 in all conditions. A P600 following and earlier negative component (N400-P600) is commonly found in repair situations or in a difficult wrap up, as could be found in this condition (FRIEDERICI, HAHNE, SADDY, 2002; KAAN, SWAAB, 2003).

To quantify these observations, first made by visual inspection, ANOVAs were performed in the latency window of 300 to 650ms post-stimulus onset of 'the last PP', concerning two parameters: amplitude and latency, as can be visualized in graphs 3 and 4 below, respectively of ERP amplitudes and latencies.
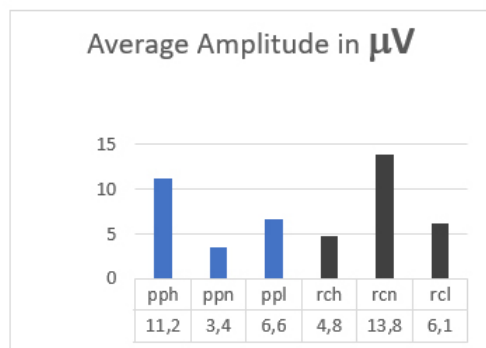
**Graph 3.** Average amplitudes of ERPs across conditions
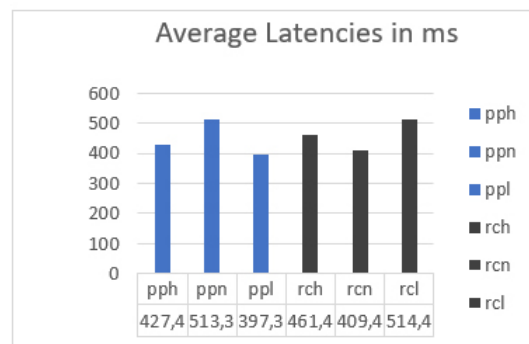
**Graph 4.** Average latencies of ERPs across conditions

These dependent measures, that is, the voltages within the N400 mean voltage time-window and P600 mean voltage time-window, were analyzed with repeated measures of variance (ANOVA). ANOVAs were performed separately at each electrode site. A two-way ANOVA model was used, and the factors were structure (PP or RC) and attachment position (neutral, low and high).

The Greenhouse and Geisser (1959) correction for inhomogeneity of variance was applied to all ANOVAs with greater than one degree of freedom in the numerator. In such cases, the corrected p value was reported. Significant main effects were followed by simple-effects analysis.

Voltages were also averaged for analysis within two-channel-groups. For each of these channel-groups, we quantified ERPs as mean voltages within the windows of 350–550ms (capturing a broad negativity); and 550–800ms (capturing a broad positivity) after stimulus onset. Grand-averages were formed by averaging over participants.

These dependent measures, that is, the voltages within the N400 mean voltage time-window and P600 mean voltage time-window, were analyzed with repeated measures

analyses of variance (ANOVA). ANOVAs were performed separately at each channel-group. A two-way ANOVA model was used.

Concerning the amplitude, there was a highly significant main effect of structure, that is between PP and RC (Structure: $F(1,27) = 29,9$ $p<0,000009$) and also a highly significant main effect of attachment position, that is between Neutral, Low and High (Attachment Position: $F(2,54) = 45,0$ $p<0,000001$). Finally, there was a highly significant interaction between the two factors (Ampl_Structure*Amp_Attachment Position $F(2,54) = 713$ $p<0,000001$). Pairwise t-tests between conditions came out almost all significant as reported in Table 2:

| PAIRWISE COMPARISONS FOR AMPLITUDE | PAIRWISE COMPARISONS FOR LATENCY |
|---|---|
| [PP_High]vs[PP_Neutral] t(27)=25,84 p< 0,0001 | [PP_High]vs[PP_Neutral] t(27)=7,00 p< 0,0001 |
| [PP_High]vs[PP_Low] t(27)=14,71 p< 0,0001 | [PP_High]vs[PP_Low] t(27)=2,61 p< 0,0146 |
| [PP_High]vs[RC_High] t(27)=19,95 p< 0,0001 | [PP_High]vs[RC_High] t(27)=2,42 p< 0,0226 |
| [PP_High]vs[RC_Neutral] t(27)=3,68 p< 0,0010 | [PP_High]vs[RC_Neutral] t(27)=2,20 p< 0,0365 |
| [PP_High]vs[RC_Low] t(27)=15,68 p< 0,0001 | [PP_High]vs[RC_Low] t(27)=7,35 p< 0,0001 |
| [PP_Neutral]vs[PP_Low] t(27)=15,41 p< 0,0001 | [PP_Neutral]vs[PP_Low] t(27)=10,34 p< 0,0001 |
| [PP_Neutral]vs[RC_High] t(27)=7,03 p< 0,0001 | [PP_Neutral]vs[RC_High] t(27)=3,38 p< 0,0022 |
| [PP_Neutral]vs[RC_Neutral] t(27)=27,82 p< 0,0001 | [PP_Neutral]vs[RC_Neutral] t(27)=8,57 p< 0,0001 |
| [PP_Neutral]vs[RC_Low] t(27)=11,85 p< 0,0001 | [PP_Neutral]vs[RC_Low] t(27)=0,08 p< 0,9392 |
| [PP_Low]vs[RC_High] t(27)=8,75 p< 0,0001 | [PP_Low]vs[RC_High] t(27)=4,56 p< 0,0001 |
| [PP_Low]vs[RC_Neutral] t(27)=20,62 p< 0,0001 | [PP_Low]vs[RC_Neutral] t(27)=1,30 p< 0,2032 |
| [PP_Low]vs[RC_Low] t(27)=2,16 p< 0,0395 | [PP_Low]vs[RC_Low] t(27)=9,03 p< 0,0001 |
| [RC_High]vs[RC_Neutral] t(27)=20,85 p< 0,0001 | [RC_High]vs[RC_Neutral] t(27)=3,87 p< 0,0006 |
| [RC_High]vs[RC_Low] t(27)=6,43 p< 0,0001 | [RC_High]vs[RC_Low] t(27)=3,06 p< 0,0050 |
| [RC_Neutral]vs[RC_Low] t(27)=18,81 p< 0,0001 | [RC_Neutral]vs[RC_Low] t(27)=10,44 p< 0,0001 |

Table 2. Pairwise t-tests between conditions

# 3. OVERALL REMARKS

From the processing point of view, relative clauses ambiguously attached to a low or high host have been a puzzle for decades, ever since the seminal paper of Cuetos & Mitchell (1988) challenged the universality of the Late Closure Principle. The literature on the processing of RC attachment ambiguity is complex and contradictory (cf. Fernández, 2003, for a review).

More recently, however, Hemforth, Fernández, Clifton, Frazier, Konieczny and Walter (2015) compared the comprehension of short and long versions of relative clauses in written questionnaire studies in English, Spanish, German and French and found that in all three languages, more high attachment interpretations were observed for long relative clauses than for short ones, perhaps reflecting differences in implicit prosodic phrasing provided by participants in reading the sentences.

Notice that the short RCs in Hemfort *et al.* (2015) study is formed by the relative pronoun and a single word, a one-syllable verb (the doctor met the son of the colonel who died). We do not think, however, that the RCs attachment preferences in our experiments may have also been influenced by an implicit prosody effect. Even though these RCs might have been taken as long, since they were typically formed by a verb and words adding up to an average of three syllables (that has the weight, that has a new saddle), why would PPs not have been subject by the implicit prosody effect as well, since they are only one word smaller than the RCs? Therefore, the difference between the attachment properties between RCs and PPs assessed in both our experiment has to be sought elsewhere.

Liversedge, Paterson and Clayes (2002) offer a possible independent confirmation for our hypothesis that an operator construction as an RC may be construed non-locally, tending to high attachment as a default, even if there is semantic bias against it. In our materials, the highest DP is presented in a cleft construction, which we claim makes it salient and thereby attract modification. In an eye-tracking study, Liversedge, Paterson and Clayes (2002), investigate the influence of the focus operator *only* on syntactic processing of "long" relative clause sentences. They find that this operator affects initial parsing decisions for long relative clauses, arguing that the operator makes the DP more salient, attracting modification in their case by a reduced relative clause. A similar effect could be in operation in the case we are investigating: the long RC would tend to attach high to a salient DP in a cleft construction, overriding the LC parsing principle. Of course, for this analysis to be maintained, we need to have an explanation for the fact that PPs are not attracted high by the same salient construction. Such an explanation may be found in the comparison between the complementizer that introducing the RC clause and the preposition with, introducing the PP phrase.

Additionally, the PP is embedded to a local PP, a construction with the same label, while the RC attachment would have the choice of locally attaching to a PP or non-locally attaching to a salient DP. Even though the size difference between the RC and the PP is only one word, the verb *has*, there is a structural weight coming for the fact that a clause is to be attached. Then, in the case of the RC, a "heavier" constituent (a clause) is preferably attached high, overriding the locality principle by its structural configuration affecting its size. On the other hand, the PP would be analyzed as short, from the outset and would be attached locally to a phrase with the same label, in

compliance with the LC Principle. If this analysis is correct, then the IPH, in a way, is in operation here, constituent length being measured not only by the sheer number of words, but by their structural weight.

Our analyses, thus, provide both stunning and subtle evidence for the classic paradigms discussed in the parsing literature. The PP prefers low attachment and the RC, an Operator construction, prefers high attachment. These preferences are even evident when their pragmatics would favor the opposite.   It is important nonetheless to ask whether our results reach deeper into the representational alternatives projected by linguistic theory itself.  Do the results reflect upon different theoretical options or the formalisms themselves? One such question is: what is the ideal representation of recursion? With respect to the most basic form of recursion, merge, we expect little parsing differentiation since it is the operation behind every step of phrase-building. What about our cases of self-embedding: PP's and pictures with two comitative with phrase-building. And ultimately, we would like to see if parallels arise for,  alongside  PP,  Relative clause embedding in our examples, and there exists self-embedding in sentence-embedding (John said that Bill said that...), Possessive (John's friend's father's hat), adjective (second big  green ball) and compound  (coffee-maker-maker), all of which make special processing demands.

Maia *et al.* (2018) report "at each VP layer, the recursive embedding gets progressively easier" with an ERP experiment on recursive PP's ("the man took the fish from the bucket on top of the stone").  How can we explain why recursion can make something easier?  We know from other evidence that (a) recursion is delayed in acquisition (See Amaral et al. (2018), and acquisition papers by Hollebrandse (2018), Perez-Léroux *et al.* (2018), Roeper and Oseki (2018), Terunuma and Nakato (2018), Correa *et al.* (2018), and (b) children will avoid recursion by substituting another form (like relative clause for PP). Could the acquired grammar mark the recursive structure in a way that facilitates processing?

Now to bring in the evidence at hand, we find that precisely when there is low attachment of a recursive PP, it shows a sharp decrease in comprehension time. Note that, even though sizes of the PP conditions were smaller than those of the RC conditions, due to the presence of the *that* operator, PPL, the preferred PP attachment is even faster than RCL, the unfavored RC attachment [PP_Low]vs[RC_Low] t(27)=9,03  p< 0,0001 for latency). However, here, differently from the measures found in the eye-tracker, PPH, the unfavored PP attachment is also significantly faster than RCH, which was the hypothesized preferred RC attachment [PP_High]vs[RC_High] t(27)=2,42  p< 0,0226).

We would in fact predict that if a further PP were added, this decrease might be even more dramatic:

Here is horse with a bird with brown spots with red stripes.

[= [horse [PP [P with [NP brown spots [ pp [with [NP red stripes]]].
[That is, the spots have red stripes on them]

It should be more dramatic than an addition of a non-recursive PP to a relative clause:

c. here is a horse with a bird that has brown spots with red stripes.

That is, we predict that *with red stripes* will be processed more rapidly in the recursive than the non-recursive environment because the parser is "looking for" the recursive marker. Why should that follow? Can we articulate the grammar so that the parsing efficiently follows the notation we choose?

We argue, following DiSciullo (2015) and Sevcenco *et al.* (2015) that recursion is marked by a Feature on a recursive node. Therefore it can function as an Operator that indicates where self-embedded constructions arise because the same category recurs. In Romanian and Japanese, in fact, recursive P's are morphologically explicit. Therefore, not surprisingly, they can also function as Operators, which are reflected in prosody. Nursery rhymes give special intonation to each new relative clause:

b. this is the cat that chased the rat that ate the cheese that Mom bought.

Franchetto (2018) as well shows that in Kuikuro, a Carib language spoken in Brazil, there are recursion constructions which are clearly marked for possessives and PP's. Based on these assumptions, we can sketch a system in which a feature like [+POSS] or [+NEG] is an Operator that marks every eligible constituent, like an indefinite NPI. If a form of Negation precedes an indefinite in its scope, the indefinite will carry an NPI feature that leads to a morphological spell-out like any:

a. John doesn't give any money to any organization on any holiday.

From the processing point of view, we suggest the parser carries the NEG feature much like a wh-filler is carried in memory and then satisfied by a gap. And likewise a potentially recursive element like PP, or a POSS, or an CP will carry that potential and immediately recognize a necessary "binder" in an identical category. In this respect it resembles what can be called a "habituation" routine which allows immediate recognition of an anticipated constituent.

DiSciullo (2014) has proposed that Indirect Recursion is marked directly on specific nodes. Therefore, such features can be regarded as Probes which are satisfied when the same feature arises on a new node.

$$[PP]p \ldots\ldots\ldots[PP]p\ldots[PP]P$$

It is just like the fact that it feels easier to comprehend (a) than (b) because the parser wants to see  each new indefinite as a Polarity item after a negation is expressed (didn't), rather than see it as an unaffected indefinite as in the following comparison:

a. John didn't give anything to anyone;
b. John didn't give something to anyone.

where failure to mark something as an NPI makes the sentence more difficult.

In sum, our argument pursues the theoretical goal of developing a representation of grammars which captures grammaticality intuitions, parsing evidence through eye-tracking and EEG, and a theoretically coherent notation. It marks progress toward fulfilling the goal that linguistic theory provides a psychologically real mechanical system.

## REFERENCES

AMARAL, Luiz; MAIA, Marcus; NEVINS, Andrew; ROEPER, Tom (Org.). *Recursion Across Domains*. Cambridge, UK: Cambridge University Press, 2018, 409p.

CARREIRAS, M.; CLIFTON, C. "Relative Clause Interpretation Preferences In Spanish and English". *Language & Speech*, v. 36, p. 353-372, 1993.

CORRÊA, L.; AUGUSTO, M.; MARCILESE, M.; VILLARINHO, C. 2018. "Recursion In Language and the Development of Higher-Order Cognitive Functions: an Investigation With Children Acquiring Brazilian Portuguese". In: AMARAL, Luiz; MAIA, Marcus; NEVINS, Andrew; ROEPER, Tom (Org.). *Recursion Across Domains*. Cambridge, UK: Cambridge University Press, 2018: 48-67.

CUETOS, F.; MITCHELL, D. C. "Cross-Linguistic Differences In Parsing: Restrictions on the Use of the Late Closure Strategy In Spanish". *Cognition*, v. 30, p. 73-105, 1988.

DANEMAN, M. ; CARPENTER, P. A.  "Individual Differences In Working Memory and Reading". *Journal of Verbal Learning, and Verbal Behavior*, v. 19, p. 450-466, 1980.

DE VINCENZI, M. *Syntactic Parsing Strategies In Italian*. Dordrecht: Kluwer, 1991.

DI SCIULLO, A.M. "Minimalism and I-Morphology". *In*: KOSTA, P.; FRANKS, S.; RADEVA-BORK, T. (Eds.). *Minimalism and Beyond: Radicalizing the Interfaces*. Amsterdam: John Benjamins, 2014: 267-286.

DI SCIULLO, Anna Maria. "On the Domain Specificity of the Human Language Faculty and the Effects of Principles of Computational Efficiency: Contrasting Language and Mathematics. *Revista Linguística*, v. 11, n 1, p. 57-70, 2015.

EHRLICH, K., E. FERNÁNDEZ, E.;  FODOR, J.; STENSHOEL, E.; VINEREANU, M. "Low Attachment of Relative Clauses: New Data from Swedish, Norwegian and Romanian". Poster Presented at the 12th Annual CUNY Conference, New York, 1999.

FERNÁNDEZ, E.M. *Bilingual Sentence Processing*: Relative Clause Attachment In English and Spanish.  Amsterdam: John Benjamins Publishers, 2003.

FODOR, J. "Prosodic Disambiguation in Silent Reading". *In*: HIROTANI, M. (Ed.). *Proceedings of NELS 32.* Amherst, MA: GLSA; University of Massachusetts, 2002a.

FODOR, J. "Psycholinguistics Cannot Escape Prosody". Speech Prosody ISCA Workshop, Aix-en-Provence, p. 83-88, 2002b.

FODOR, J. D. "Learning to Parse?". *Journal of Psycholinguistic Research*, v. 27, 1998.

_____. "A Psicolingüística não pode escapar da prosódia". *In*: MAIA, Marcus; FINGER, Ingrid. *Processamento da linguagem*. Pelotas: EDUCAT, 2005.

FRANCHETTO, B. "Prosody and Recursion in Kuikuro: DPs vs PPs". In: AMARAL, Luiz; MAIA, Marcus; NEVINS, Andrew; ROEPER, Tom (Org.). *Recursion Across Domains*. Cambridge, UK: Cambridge University Press, 2018: 314-333.

FRAZIER, L. *On Comprehending Sentences: Syntactic Parsing Strategies*. Doctoral Dissertation, University of Connecticut, 1979.

FRAZIER, L.; CLIFTON C. Construal. Cambridge, MA: MIT Press.

FRAZIER, L.; FODOR. J.D. 'The Sausage Machine: a New Two-Stage Parsing Model". *Cognition*, v. 6, p. 291-235, 1978.

FRAZIER, L.; RAYNER, K. "Making and Correcting Errors During Sentence Comprehension: Eye Movements and the Analysis of Structurally Ambiguous Sentences". *Cognitive Psychology*, v. 14, p. 178-210, 1982.

FRAZIER, L.; Rayner, K. "Parameterizing The Language Processing System: Left- Vs. Right Branching Within and Across Languages". *In:* HAWKINS, J. (Ed.). *Explaining Language Universals*. Blackwell: Oxford, 1988, p. 247-279.

FRENCK-MESTRE, C.; PYNTE, J. "Resolving Syntactic Ambiguities: Cross-Linguistic Differences?" In: Devincenzi, V.; LOMBARDO, M. (Eds.). *Cross-Linguistic Perspectives On Language Processing*. Dordrecht: Kluwer Academic Press, 2000: 119-148.

FRIEDERICI, A.D.; HAHNE, A.; SADDY, D. "Distinct Neurophysiological Patterns Reflecting Aspects of Syntactic Complexity and Syntactic Repair". J. *Psycholinguist. Res*. v. 31, n. 1, p. 45–63, 2002.

GIBSON, E. "Linguistic Complexity: Locality of Syntactic Dependencies". *Cognition*, v. 68, p. 1-76, 1998.

GIBSON, E.; PEARLMUTTER, N. "Constraints On Sentence Comprehension". *Trends in Cognitive Science*, v. 2, p. 262-268, 1996.

GIBSON , E.; PEARLMUTTER, N; CANSECO-GONZALES, E.; HICKOK, G. "Recency Preference In the Human Sentence Processing Mechanism". *Cognition* v. 59, p. 23- 59, 1996.

GILBOY, E.; SOPENA, J.-M.; CLIFTON, C.; FRAZIER, L. Argument Structure and Association Preferences In Spanish and English Complex Nps". *Cognition*, v. 54, p. 131-167, 1995.

HEMFORTH, B.; FERNANDEZ, S.; CLIFTON, C.; FRAZIER, L.; KONIECZNY, L.; WALTER, M. "Relative Clause Attachment In German, English, Spanish and French: Effects of Position and Length". *Lingua*, v. 8, 2015.

HOLLEBRANDSE, B. "The Importance of Second-Order Embedding and Its Implications for Cross-Linguistic Research". *In*: AMARAL, Luiz; MAIA, Marcus; NEVINS, Andrew; ROEPER, Tom (Org.). Recursion Across Domains. 1ed.Cambridge, UK: Cambridge University Press, 2018: 35-47.

KAAN, E.; SWAAB, T. "Repair, Revision, and Complexity in Syntactic Analysis: An Electrophysiological Differentiation". *Journal of Cognitive Neuroscience*, v. 15, p. 98-110, 2003.

KIMBALL, J. "Seven Principles of Surface Structure Parsing In Natural Language". *Cognition*, v. 2, p. 15-47, 1973.

LINGUA, Elsevier, v. 166, p. 43-64, 2015. DOI: https://doi.org/10.1016/j.

KITAGAWA, Y.; FODOR, J. D. "Prosodic Influence on Syntactic Judgments". In: FANSELOW, G; FERY, R.; VOGEL, R.; SCHLESEWSKY, M. (Ed.) *Gradience in Grammar*: Generative Perspectives. Oxford: Oxford University Press, 2006.

LIVERSEDGE, S. P.; PATERSON, K. B.; CLAYES, E. L. 2002. "The Influence of Only On Syntactic Processing of 'Long' Relative Clause Sentences". *Quarterly Journal of Experimental Psychology*, v. 55A, p. 225-240.

MAIA, M. A. R.; FRANÇA, Aniela Improta; GESUALDI, A ; LAJE, A.; SILVA, C. O. ; SOTO, Marije ; GOMES, J. 2018. "The Processing of PP Embedding and Coordination in Karajá and in Portuguese". *In*: AMARAL, Luiz; MAIA, Marcus;

NEVINS, Andrew; ROEPER, Tom (Org.). *Recursion Across Domains*. Cambridge, UK: Cambridge University Press, 2018, p. 334-356.

MAZUKA, R. Lust, B.. "On Parameter Setting and Parsing: Predictions for Cross-Linguistic Differences In Adult and Child Processing". *In*: FRAZIER, L.; VILLIERS, J. de (Eds.). *Language Processing and Language Acquisition*. Dordrecht: Kluwer, 1990, 234pp.

PAPADOPOULOU, D.; CLAHSEN, H. "Parsing Strategies In L1 And L2 Sentence Processing: a Study of Relative Clause Attachment In Greek". *Studies in Second Language Acquisition*, v. 25, p. 501–528, 2003.

PEARLMUTTER, N. J.; MACDONALD, M. C. "Individual Differences and Probabilistic Constraints In Syntactic Ambiguity Resolution". *Journal of Memory and Language*, v. 34, p. 521-542, 1995.

Pérez-Léroux, A., Castilla-Earls, A., Béjar, S., Massam, D., Peterson, T. "Strong Continuity and Children's Development of DP Recursion". In: AMARAL, Luiz; MAIA, Marcus; NEVIS, Andrew; ROEPER, Tom. (Org.). *Recursion Across Domains*. 1.ª Ed., V. 1. Cambridge, UK: Cambridge University Press, 2018: 296-313.

PHILLIPS, C. *Order and Structure*. Ph.D. Thesis, MIT, 1996.

ROEPER, T.;  OSEKI, Y. 2018. "Recursion in the Acquisition Path for Hierarchical Syntactic Structure". *In*: AMARAL, Luiz; MAIA, Marcus; NEVIS, Andrew; ROEPER, Tom. (Org.). *Recursion Across Domains*. 1.ª Ed., V. 1. Cambridge, UK: Cambridge University Press, 2018: 267-278.

SEVCENCO, A.; ROEPER, T.; PEARSON, B. (2015). "The Acquisition of Recursive Locative PPs and Relative Clauses in Child English". Paper Presented at GALA 2015.

TERUNUMA, A.; NAKATO, T. "Recursive Possessives in Child Japanese". *In*: AMARAL, Luiz; MAIA, Marcus; NEVIS, Andrew; ROEPER, Tom (Org.). *Recursion Across Domains*. 1.ª Ed., V. 1. Cambridge, UK: Cambridge University Press, 2018:  187-210.

ZAGAR, D.; PYNTE, J.; RATIVEAU, S (1997). "Evidence for Early-closure Attachment on First-pass Reading Times in French". *Quarterly Journal of Experimental Psychology*, 50A(2): 421-38.