Agreement interference effects of number in coreference processing in Brazilian Portuguese

Michele Alves*

Abstract. Our aim is to investigate how agreement cues and Principle B influence coreference processing in Brazilian Portuguese. According to Badecker & Straub (2002), all focused entities that feature-match the pronouns are initially considered as possible antecedents; and that the structural constraints would quickly select the adequate antecedent among those options. Taken this into account, our hypothesis was that the agreement cues are crucial for coreference processing in a language with rich morphology such as Brazilian Portuguese. Thus we expected to find a strong influence of number cues, even those displayed in attractors, which are candidates that feature-match the pronouns, but cannot be considered structurally acceptable antecedents due to Principle B structural constraints.

An eye-tracking experiment and an off-line grammaticality judgment experiment were conducted with native speakers of Brazilian Portuguese. It seems that our on-line results support Badecker and Straub (2002) and that our initial hypothesis was proved true; however only at early and after processing stages. We also provided a comparison between singular and plural agreement features showing that memory retrieval is more sensitive to marked types of agreement cues like plural. In addition, it should be mentioned that it was observed intrusion effects caused by the presence of plural attractors in both ungrammatical and grammatical sentences, which might be evidence in favor of the existence of content-based memory retrieval. Moreover, the results of the answers to the comprehension questions in the eye-tracking experiment as well as the off-line grammaticality judgment indicate that the presence of plural attractors create illusions of grammaticality and ungrammaticality, while long distance between the structurally acceptable antecedent and the pronoun can cause semantic illusions as well.

Keywords. coreference processing; number features; Brazilian Portuguese

1. Introduction. According to Lewis, Vasishth & van Dyke (2006), in order to process language in real time, previous interpreted information must be kept at least momentarily in our memory so that integration with novel upcoming material can take place rapidly. Taking this consideration, one important question in the literature is how prior linguistic material can be retrieved from memory and which factors can influence or interfere in this process. Since memory retrieval needs to be incredibly fast and efficient, it is hard to believe that our memory works in a serial search. Studies on lexical retrieval have shown that our memory activates linguistic items in parallel through association; therefore, all candidates that are associated with the target are kept activated in memory until one of the items is retrieved (cf. Marslen-Wilson, 1987).

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Syntactic dependencies can be comprehended and processed thanks to our memory, which works in a content-addressable fashion (McElree, 2000; McElree et al, 2003; van Dyke and McElree, 2006). In other words, it is a subset of grammatical cues generated by the target that activates in parallel the stored items in memory that match the content of these cues. However, memory can be constrained by similarity-based interference and decay factors (Lewis & Vasishth, 2005; Lewis, Vasishth & van Dyke, 2006). The former occurs when the similarity between the items and the retrieval cues increase, reducing the strength of association between the cue and the target as a greater number of items will be associated. Consequently, failure rates increase, and distractors, that is, candidates that partial-match the cues, can sometimes be retrieved. On the other hand, decay occurs, for example, when the linear distance between the dependent items is increased and the distant item gets decayed over time, which makes its retrieval more difficult to be happening.

The retrieval cues can be composed by, among others, structural, morphological, semantic, and contextual information. The present paper will be focused on discussing only two of them: the structural and morphological. One of the linguistic dependencies that enable us to examine the roles of the structural and the morphological cues in memory retrieval is binding. From the point of view of structural cues, conforming to Principle A (Chomsky, 1981), reflexives and their antecedents must be bound within the same domain, that is, in the same small clause; on the contrary, Principle B (Chomsky, 1981) posits that pronouns and their antecedents must not be bound in the same local domain. However, from the perspective of the morphological cues, pronouns and reflexives must simply agree with their antecedents in gender, number, and person.

Several studies proposed to discuss the relationship between the structural constraints and the agreement cues in memory retrieval. In the following section, some of these studies that focused on reflexive and pronominal binding will be briefly addressed.

2. Structural constraints *versus* agreement cues in binding. The relationship between the structural constraints and the agreement cues in the time-course of binding processing is very controversial in the literature. Considering the studies on reflexive binding, on one hand, Nicol & Swinney (1989), Sturt (2003), Xiang et al (2009); Phillips et al (2011); Dillon et al (2013) pointed out that memory cannot be initially influenced by distractors, that is, candidates that feature-match the anaphors but cannot be retrieved as antecedents according to Principle A. In other words, it seems that the structural constraints of Principle A are quite solid and invulnerable to failure. On the other hand, Badecker & Straub (2002) and Patil et al (2016) argue that the agreement features play a very important role at early processing measures, so that structurally unacceptable candidates can be considered as potential antecedents.

The studies on pronominal binding are also contradictory; on one hand, Nicol and Swinney (1989) and Clifton et al (1997) claim that the initial candidate set is only composed by the candidates that respect Principle B structural constraints; and on the other hand, Badecker & Straub (2002) and Kennison (2003) argue that both structurally acceptable and unacceptable candidates that feature-match the pronouns are initially considered as antecedents since the agreement features rather than the structural constraints are the decisive factor at early processing phases. Finally, Chow et al (2014) defend that both the structural constraints and the agreement features are equally important since the beginning of pronominal resolution. However, they could not find robust interference effects of structurally unacceptable candidates in coreference processing.

Among all the studies mentioned above, one of the most influential ones is Badecker and Straub (2002). After analyzing the results of a series of self-paced reading experiments,

Badecker & Straub (2002)'s finding is that binding structural constraints do not function as initial filters in processing since the initial candidate set can include structurally unacceptable antecedents. Besides the shorter reading times caused by structurally unacceptable antecedents in ungrammatical sentences (facilitatory interference), which the authors called the *no-antecedent* effect, they also found longer reading times when a structurally unacceptable antecedent agreed in gender with both the pronoun and the structurally acceptable antecedent (inhibitory interference), which they called the *multiple-match* effect. The authors support the *interactive-parallel-constraint* model, defending the idea that initially the antecedent candidates are the ones that coincide with the salient discourse entities that match the pronouns in number and gender, and that only at a later processing phase, the structural constraints would operate quickly and effectively in selecting from among the options available.

In a nutshell, the majority of the studies in the literature claim that reflexives are insensitive to structurally unacceptable antecedent candidates and that antecedent retrieval is only influenced by structural constraints, although Badecker & Straub (2002), Parker (2014) and Patil et al (2016) showed clear results that contradict this view. On the other hand, the influence of agreement features in pronominal binding still needs more investigation since there is not so much research on it as on reflexives. Phillips, Wagers & Lau (2011) explain that the apparent online fallibility of Principle B, as Badecker & Straub (2002) and Kennison (2003) showed, might be a consequence of Principle B looseness, since it only posits that the pronoun antecedent must not be local, which is not as restrictive as Principle A. Thus the agreement features may be useful in pronominal antecedent retrieval.

> The recognition of a pronoun must initiate a retrospective search for an antecedent. Since the structural relation between a pronoun and its antecedent is almost free, it is natural do assume that a pronoun initiates a cue-based search for an antecedent that shares its person, number, and gender features, and hence it wouldn't be surprising for this search to detect nouns that match those cues, even when they violate Principle B (PHILLIPS, WAGERS & LAU, p. 171, 2011)

The use of morphological cues in memory retrieval may vary not only depending on the syntactic dependency, but also across different languages. Lago (2015) highlighted the fact that agreement morphology is functionally more important in Spanish than, for example, in English. Because the word order in Spanish is sort of free, the morphological cues are more reliable than the positional information in this language. The author found out that, compared to English, Spanish comprehenders displayed a larger slowdown when there was an agreement violation between subjects and verbs, which might indicate that Spanish speakers rely more on morphological cues as they may struggle more to process a sentence with agreement problems.

Taken the fact that the use of agreement cues may be more fruitful in pronominal binding and in languages with rich morphology like Spanish, the present work aims to investigate how pronouns retrieve antecedents in Brazilian Portuguese, which is also a language with rich morphology. Therefore, we will not only fill a gap in the literature providing one more piece of evidence to the puzzle involving the use of agreement features is pronominal binding, which lacks more investigation, but we will also check whether languages with rich morphology tend to rely more on agreement features in syntactic dependencies resolution.

3. Experiments. It is relevant to mention that the two experiments that will be presented in this paper are similar to the ones in Alves (2016), which investigated the use of gender cues in pronominal antecedent retrieval in Brazilian Portuguese. Taken together, Alves (2016) and the present research are part of bigger project that aims to investigate the influence of agreement features in coreference processing in Brazilian Portuguese. This way, one can find some points in common between both papers.

The first experiment that will be reported here is an eye-tracking study, and its main purpose is to investigate how and when the structural constraints of Principle B and the number agreement cues influence the way nominal antecedents are retrieved from memory. Unlike the first experiment, which focused on the on-line processing, the second experiment is an off-line grammaticality judgment, and its purpose is to check whether the structural constraints of Principle B and the agreement cues influence the grammaticality judgment of the sentences on the same way it may influence the on-line processing.

We assume that since overt and redundant agreement marks are often available in languages with rich morphology, speakers will tend to strongly rely on them in order to resolve a variety of linguistic dependencies such as coreference. This way, our general hypothesis is that the agreement cues rather than the structural constraints of Principle B would play a major role in memory retrieval in a language with morphology richness such as Brazilian Portuguese. Taken this into consideration, we expect to find a robust influence of agreement cues throughout coreference processing in Brazilian Portuguese. For this reason, we expect to find a strong similarity-based interference effects caused by structurally unacceptable antecedent candidates that would function like distractors in our memory. In this paper, this kind of candidates will also be called *attractors* due to its local relation and feature-similarity with the pronouns.

The influence of attractors is also sensitive to the kind of feature, which is known as the *mismatch asymmetry*. It seems that structurally unacceptable candidates with marked features are more influential than structurally unacceptable candidates with unmarked features; and, since plural is morphologically marked in English, distractors with this kind of feature influence processing more than distractors in the singular (cf. among others Bock and Miller, 1991 and Wagers et al, 2009 for subject-verb agreement; Dillon, 2013 for reflexives). Based on this, we also expect to find more influence in coreference processing of attractors in the plural than in the singular. We hypothesize that memory is not that abstract as it may be sensitive to different types of agreement cues. Consequently, we expect that salient and marked cues such as plural would be retrieved from memory more easily than singular. Staub (2009) claims that plural nouns are effective attractors not because of its morphology (morpheme –s) or notional plurarity, but because of its grammatical number. Plural is marked in opposition to singular, which is the *default*, unmarked, automatic and dominant gender.

Finally as memory can be affected by decay, we are also interested in examining the effects of linear distance in coreference processing. Previous studies found that long linear distance can bring costs to binding processing (cf. among others, Schweppe, 2013; Chow et al, 2014). Thus our last hypothesis is that attractors would have stronger interference in coreference when the structurally acceptable candidate is linearly far from the pronouns.

3.1 Eye-tracking experiment.

3.1.1 PARTICIPANTS. Twenty-nine native speakers of Brazilian Portuguese with normal or corrected-to-normal vision participated as volunteers in the experiment. They were undergraduate students of the Federal University of Rio de Janeiro (UFRJ) and were randomly invited to participate in the study, and, as compensation for their work, they receiving three hours of *Cultural-Scientific Activities* (*Atividades-Científico-Culturais Discentes*, AACC), which is mandatory for their graduation. All participants were naive in relation to the object of study of the experiment and signed a consent form which stated that the task they would perform would not bring any risks to their health and that the results would be eventually published. It should be noted that of the twenty-nine participants, five

were excluded from our analysis as they had less than 80% of their eyes movements recorded. Therefore, the experiment was analyzed using data from twenty-four participants, more specifically sixteen female and eight male with a mean age of 22.6 years.

3.1.2 DESIGN AND MATERIALS. The independent variables of the experiment were: *grammaticality of the sentence*, which is directly related to Principle B structural constraints, (grammatical or ungrammatical), the *presence of attractor* (presence or absence), the *linear distance* between the structurally antecedent and the pronoun (short or long) and the *attractor number* (singular or plural). Therefore, our experimental design was 2 x 2 x 2 x 2 with sixteen conditions.

Each of the four lists, which were elaborated using a Latin Square, was pseudo-randomized and composed by sixteen experimental sentences and thirty-two fillers. Of the sixteen experimental sentences, half was short and half long. Of the eight short sentences, four had attractors in the singular and four had attractors in the plural. The same division was made for the eight long sentences. The filler questions were balanced between yes and no answers.

The experiment was composed by two on-line and one off-line dependent variables. The on-line dependent variables were the First and Total Fixation Durations at the pronoun areas. The First Fixation Duration measures how long it takes to read the pronouns when they are first encountered, whereas the Total Fixation Duration corresponds to the sum of all the eye fixations at the pronoun areas. Finally, the off-line dependent variable corresponds to the answers to the comprehension questions, which purpose was to check whether the readers were semantically retrieving the structurally acceptable antecedent candidate or not.

One can find a sample of the materials used in the experiment below[2]:

(1)

a. Long ungrammatical sentence with plural attractor
O geógrafo$_{[sg]}$ trouxe$_{[sg]}$ muitos mapas e as rotas marítimas para ensinar os marinheiros$_{[pl]}$ que seguem$_{[pl]}$ **eles$_{[pl]}$** nas expedições.
"The$_{[sg]}$ geographer$_{[sg]}$ brought$_{[sg]}$ a lot of maps and the sea-routes to teach the$_{[pl]}$ sailors$_{[pl]}$ who follow$_{[pl]}$ **them$_{[pl]}$** in the expeditions."

b. Long ungrammatical sentence without plural attractor
Os geógrafos$_{[pl]}$ trouxeram$_{[pl]}$ muitos mapas e as rotas marítimas para ensinar os marinheiros$_{[pl]}$ que seguem$_{[pl]}$ **ele$_{[sg]}$** nas expedições.
"The$_{[pl]}$ geographers$_{[pl]}$ brought$_{[pl]}$ a lot of maps and the sea-routes to teach the$_{[pl]}$ sailors$_{[pl]}$ who follow$_{[pl]}$ **him$_{[sg]}$** in the expeditions."

c. Long grammatical sentence with plural attractor
Os geógrafos$_{[pl]}$ trouxeram$_{[pl]}$ muitos mapas e as rotas marítimas para ensinar os marinheiros$_{[pl]}$ que seguem$_{[pl]}$ **eles$_{[pl]}$** nas expedições.
"The$_{[pl]}$ geographers$_{[pl]}$ brought$_{[pl]}$ a lot of maps and the sea-routes to teach the$_{[pl]}$ sailors$_{[pl]}$ who follow$_{[pl]}$ **them$_{[pl]}$** in the expeditions."

d. Long grammatical sentence without plural attractor
O geógrafo$_{[sg]}$ trouxe$_{[sg]}$ muitos mapas e as rotas marítimas para ensinar os marinheiros$_{[pl]}$ que seguem$_{[pl]}$ **ele$_{[sg]}$** nas expedições.
"The$_{[sg]}$ geographer$_{[sg]}$ brought$_{[sg]}$ a lot of maps and the sea-routes to teach the$_{[pl]}$ sailors$_{[pl]}$ who follow$_{[pl]}$ **him$_{[sg]}$** in the expeditions."

e. Comprehension question
O geógrafo é acompanhado nas expedições?

[2] It is relevant to mention that the conditions called *without attractor* are those in which the noun that occupies the attractor position does not gender-match the pronoun.

"Is the geographer followed in the expeditions?"

3.1.3 PROCEDURE. The experiment was conducted at the laboratory of experimental research (LAPEX) at the Federal University of Rio de Janeiro (UFRJ) in Rio de Janeiro, Brazil. The eye-tracker used in this experiment was *Tobii Studio™ TX 300*, which requires an initial individual calibration in the beginning of the procedure for the eye-tracker to be able to monitor the participant's pupils during the reading task. The participants were instructed to seat comfortable and were given written and oral task instructions. After that, calibration process would start followed by a short practice with filler sentences so that the experimenter would check whether the participants understood the task and were performing it at a natural speed. Ultimately, the experimenter would leave the participants alone in a quiet room without any distractions. Each sentence of the experiment would appear at once on the computer screen, and after reading them, the participants would press the space bar to answer a comprehension question about the sentence that was just read by fixating their eyes in one of the options - "Yes" or "No". Each participant performed randomly one of the four lists of the experiment. The duration of the experiment was of twenty minutes approximately.

3.1.4 RESULTS. Data was extracted using *Tobii Fixation Filter*, which is the default fixation algorithm in *Tobii Studio™ 2.X version 2.2*. It should be noted that our data did not have any outliers trimming or transformation and was analyzed at R[3] statistics software, using *plotrix*[4], *lmer Test*[5], and *gplots2*[6] packages.

Means as well as standard errors of First Fixation Duration at the pronoun area were reported for each condition in Table 1:

	Short sentences with attractors in the singular	Short sentences with attractors in the plural	Long sentences with attractors in the singular	Long sentences with attractors in the plural
Ungrammatical sentence with attractor	283 (27)	306 (33)	331 (29)	263 (17)
Ungrammatical sentence without attractor	258 (30)	317 (35)	309 (26)	352 (43)
Grammatical sentence with attractor	278 (24)	268 (10)	307 (43)	261 (10)
Grammatical sentence without attractor	260 (16)	297 (21)	286 (28)	303 (22)

Table 1: First Fixation Duration means and standard errors in milliseconds for each experimental condition

[3] R Core Team (2016). R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria (https://www.r-project.org/)
[4] Lemon, J. (2006) Plotrix: a package in the red light district of R. R-News, 6(4): 8-12.
[5] Alexandra Kuznetsova, Per Bruun Brockhoff and Rune Haubo Bojesen Christensen (2015). lmerTest: Tests in Linear Mixed Effects Models. R package version 2.0-29 (https://CRAN.R-project.org/package=lmerTest)
[6] Gregory R. Warnes, Ben Bolker, Lodewijk Bonebakker, Robert Gentleman, Wolfgang Huber Andy Liaw, Thomas Lumley, Martin Maechler, Arni Magnusson, Steffen Moeller, Marc Schwartz and Bill Venables (2015). gplots: Various R Programming Tools for Plotting Data. R package version 2.16.0.
(https://CRAN.R-project.org/package=gplots)

A linear mixed-effect model was created with the help of *lmerTest* package. Its fixed effects were: *grammaticality of the sentence*, *presence of attractor*, and *type of attractor*, while its random effects were: *participants* and *items*. And by using the *anova* function, we found a significant effect of the interaction between *presence of attractor* and *attractor number* in our First Fixation Duration model: F(1,0.014)=4.61, p=0.037.

To figure out which pair of conditions were significantly different, bar plots with 95% confidence intervals were created with the help of *gplots* package. Figure 1, 2, and 3 illustrate how attractors in the singular and in the plural affected the First Fixation Duration at the pronoun area in ungrammatical and grammatical sentences.

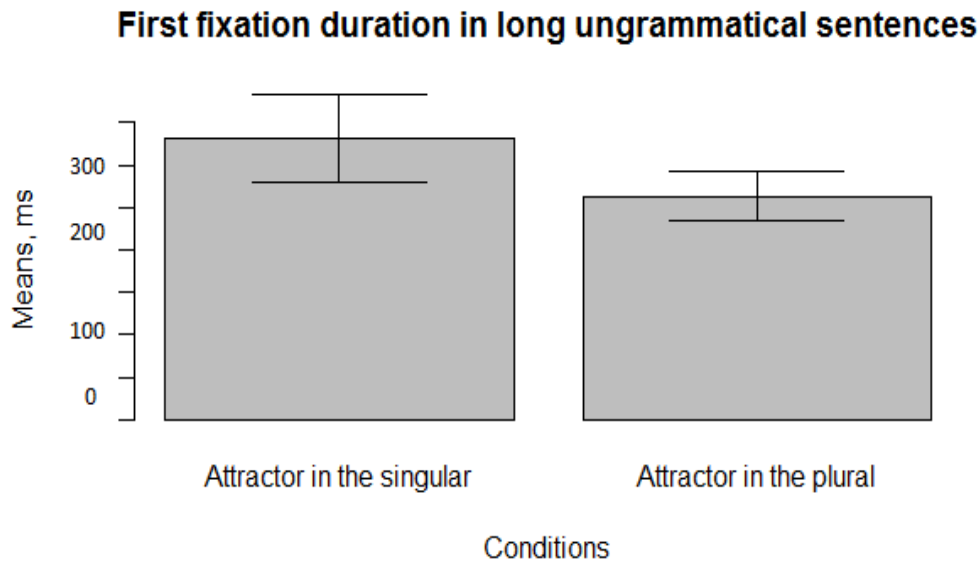

Figure 1. Barplot with 95% confidence intervals showing First Fixation Duration at the pronoun area in ungrammatical sentences with attractors in the singular and in the plural

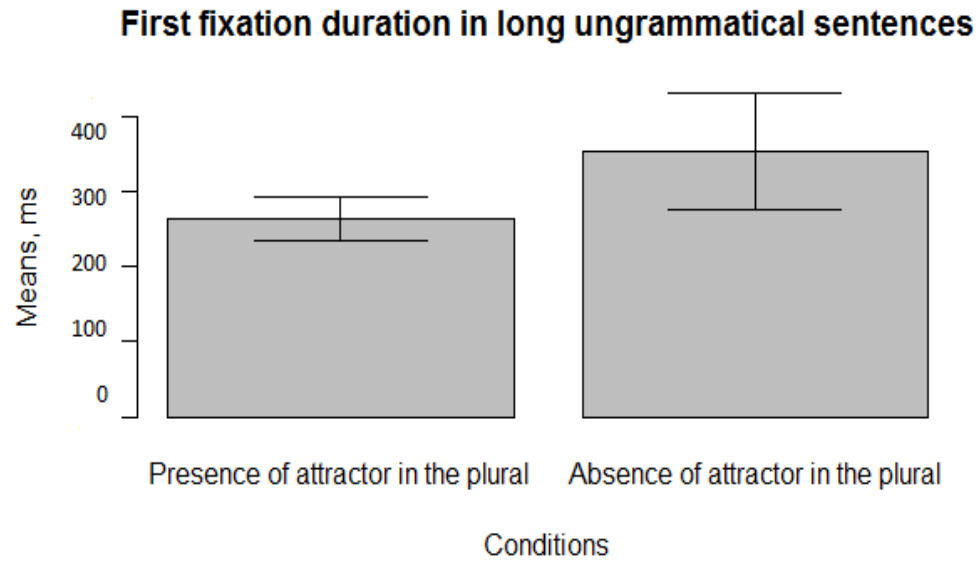

Figure 2. Barplot with 95% confidence intervals showing First Fixation Duration at the pronoun area in ungrammatical sentences with and without attractors in the plural

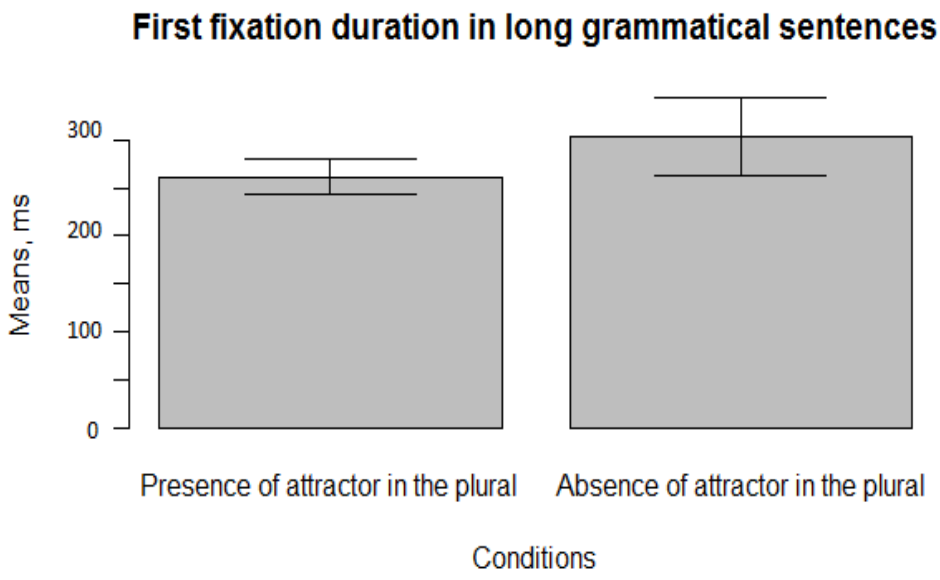

Figure 3. Barplot with 95% confidence intervals showing First Fixation Duration at the pronoun area in grammatical sentences with attractors in the singular and in the plural

Table 2 contains means along with standard errors of Total Fixation Duration at the pronoun area for each condition:

	Short sentences with attractors in the singular	Short sentences with attractors in the plural	Long sentences with attractors in the singular	Long sentences with attractors in the plural
Ungrammatical sentence with attractor	449 (48)	507 (60)	599 (77)	493 (44)
Ungrammatical sentence without attractor	439 (53)	451 (60)	670 (21)	667 (123)
Grammatical sentence with attractor	450 (41)	376 (37)	439 (81)	367 (27)
Grammatical sentence without attractor	506 (70)	465 (62)	473 (53)	472 (59)

Table 2: Total Fixation Duration means and standard errors in milliseconds for each experimental condition

A linear mixed-effect model was also created with the help of *lmerTest* package. Its fixed and random effects were the same of the First Fixation Duration model. And by using the *anova* function, we only found a slight trend towards significance for *grammaticality of the sentence* in our Total Fixation Duration model: $F(1,0.125) = 2.8$, $p=0.10$. However, when we performed the repeated ANOVA test considering the participants as error, we found a statistically significant main effect of *grammaticality of the sentence*: $F(1,23) = 3.97$, $p=0.047$. We think that there must be some unknown factor in our items that negatively affected our linear mixed-effect model for the Total Fixation Duration.

To figure out which pair of conditions were significantly different, bar plots with 95% confidence intervals were created with the help of *gplotS* package. Figures 4 and 5 show how attractors in the plural affect the Total Fixation Duration at the pronoun area.

As one can see in Figure 4 and 5, reading times at the pronoun area in grammatical sentences are faster than in ungrammatical sentences in spite of the presence of plural attractors (T-tests, p=0.036 and p=0.010 respectively).

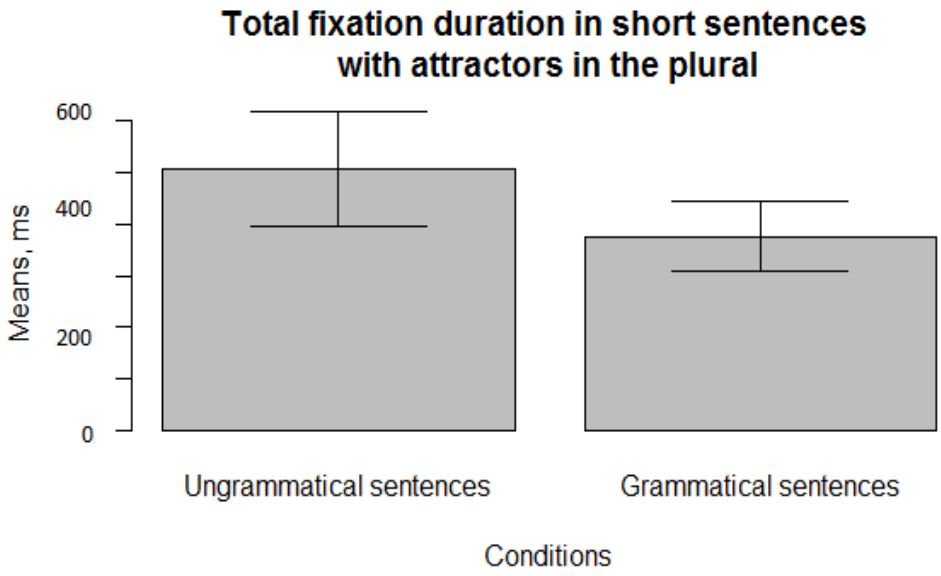

Figure 4. Barplot with 95% confidence intervals showing Total Fixation Duration at the pronoun area in short ungrammatical and grammatical sentences with attractors in the plural

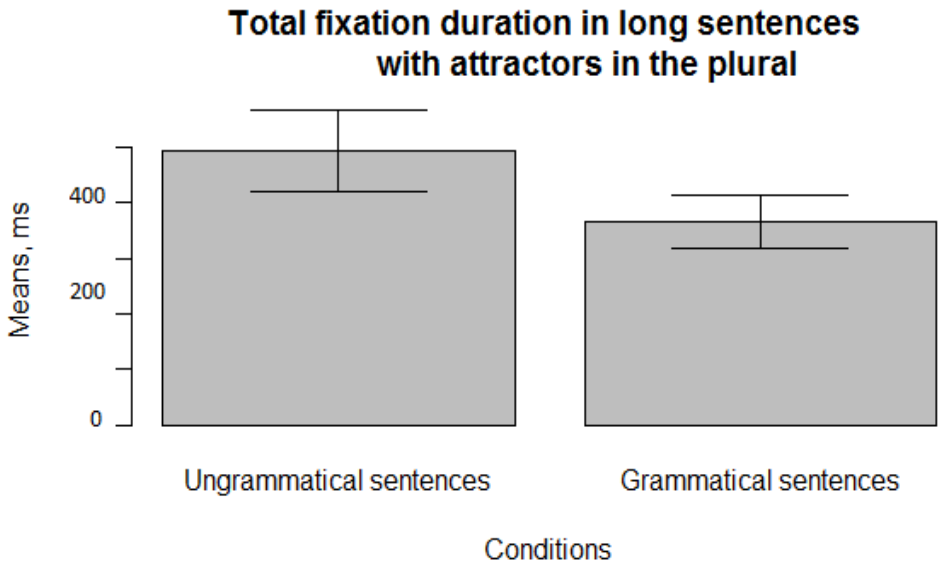

Figure 4. Barplot with 95% confidence intervals showing Total Fixation Duration at the pronoun area in long ungrammatical and grammatical sentences with attractors in the plural

Finally, the comprehension questions in the end of each experimental sentence were used to check whether the readers were semantically retrieving the structurally acceptable antecedent candidate. Consequently, if this is the case, their answer to the questions as in (1e) would be

"yes". The off-line results of the comprehension questions (two sided Fisher Test with simulated p-value based on 2e+05 replicates, $p<0.0014$) can be seen in Table 3:

The answers to the comprehension questions show that the presence of attractors can interfere in the comprehension of coreference. By looking at the first two rows of Table 3, one can note that the participants tried hard to retrieve the structurally acceptable antecedent in ungrammatical sentences, therefore, they seem to ignore the fact that the structurally acceptable antecedents were not agreeing in number with the pronouns.

	Short sentences with attractors in the singular	Short sentences with attractors in the plural	Long sentences with attractors in the singular	Long sentences with attractors in the plural
Ungrammatical sentence with attractor	96%	74%	80%	77%
Ungrammatical sentence without attractor	83%	88%	75%	92%
Grammatical sentence with attractor	83%	88%	63%	80%
Grammatical sentence without attractor	96%	96%	91%	96%

Table 3: Yes-Anwers to the comprehension questions in percentage

3.1.5 DISCUSSION. As mentioned before, there was a statistically significant effect in the eye-tracking experiment for the interaction between the factors *presence of attractor* and *attractor number* in First Fixation Duration, and a main effect for *grammaticalitly* in Total Fixation Duration. In other words, our results indicate that initially gender agreement features play a very important role in how pronouns retrieve their antecedents from memory and that the structural constraints of Principle B seem to only affect this process at later processing phases. Therefore the present research found evidence in favor of the *interactive-parallel-constraint* (Badecker & Straub, 2002), which states that the initial antecedent candidate set is composed by the focused entities that feature-match the pronoun, and that only later, the binding structural constraints would help the parser choosing the antecedent from among those options. Because the structural constraints are only taken into account at late processing, structurally unacceptable candidates (attractors) can be initially considered as potential antecedents.

It is relevant to say that unlike Badecker & Straub (2002), our research provided evidence that memory retrieval is also sensitive to different types of number agreement features. The pairwise comparison tests between the conditions in First Fixation Duration showed that plural attractors are responsible for greater influence in memory retrieval than attractors in the singular. More specifically, in ungrammatical sentences, that is, when there was a feature-mismatch between the structurally acceptable antecedent and the pronoun, coreference processing was faster in the presence of plural attractors than in the presence of singular attractors. One reason for that may lie on the fact that plural number is salient and marked. It seems that memory can be so strongly influenced by plural, that attractors carrying this type

of number may be retrieved by memory as antecedents in spite of the fact they violate Principle B structural constraints.

In addition, the facilitatory effect in First Fixation Duration was observed when both ungrammatical and grammatical sentences with plural attractors were compared to the same sentences without attractors. In ungrammatical sentences, the same facilitatory effect was also found by Badecker & Straub (2002), and was called the *no-antecedent effect*. As there is not a feature-match between the structurally acceptable candidates and the pronouns in ungrammatical sentences, attractors turn out to be retrieved as antecedents as an attempt of the parser to rescue the sentences. Interestingly, not all attractors can be retrieved by memory equally, as plural attractors may be considered better "rescuers" than singular attractors. In grammatical sentences, on the other hand, in Badecker & Straub (2002)'s work, instead of facilitatory, the presence of attractors was responsible for inhibitory effects, that is, the presence of attractors caused slower coreference presence. The *multiple-match effect*, as the authors called, was considered to be a competition between two antecedents. In this case, the parser would have problems to choose the correct antecedent. However, our results were opposite to the *multiple-match effect* found by Badecker & Straub (2002), that is, rather than slower, the presence of plural attractors was responsible for faster coreference processing. Dillon et al (2013) highlighted that inhibitory effects are not necessarily evidence of the similarity-based interference effects in memory.

> However, the inhibitory interference effects of this sort are not necessarily due to retrieval interference. For example, a feature-overwriting process that degrades the memory chunks when their representations overlap in feature content would predict similar patterns of difficulty, without requiring the use of non-structural cues to retrieval. Thus the strongest evidence that comprehenders use non-structural cues to retrieval, and thereby genuinely retrieve illicit antecedents during online comprehension is the presence of a facilitatory intrusion effect (DILLON, p.101, 2013)

Based on that, the intrusion effects (facilitatory effects) found in our eye-tracking experiment in both ungrammatical and grammatical sentences can be clearly considered evidence that antecedents are retrieved through a content-based memory. In other words, illicit antecedents (attractors) can cause interference effects in memory due to the fact that they partial match the content cues of the pronouns, leading memory to retrieve them as the antecedents.

On the other hand, the results of Total Fixation Duration only showed effects of grammaticality. For obvious reasons, coreference processing in grammatical sentences was processed faster than in ungrammatical sentences despite the presence of attractors. It seems that the structural cues of Principle B is the most important factor in memory retrieval at late processing stages.

Finally, it is relevant to say that *linear distance* effects showed significant effects in neither the First nor the Total Fixation Duration. Thus it seems that the decay effects of the structurally acceptable candidates in long linear sentences did not affect on-line coreference processing. The answers to the comprehension questions, which aimed to check whether the comprehenders were semantically retrieving the structurally acceptable candidate, were probably influenced by linear distance though. In sentences with singular attractors, the structurally acceptable antecedents tended to be semantically retrieved more often in sentences with short linear distance. On the other hand, the attractors rather than the structurally acceptable antecedents tended to be semantically retrieved in sentences with short linear distance. This way, it seems that decay effects resulted from long linear distance made the semantic retrieval of the structurally acceptable antecedent more difficult, which consequently increased the chances of the attractors being retrieved instead.

Curiously, in sentences with plural attractors, the linear distance did not seem to affect semantic retrieval that much. Maybe because the plural features displayed in the attractors bring already strong attraction effects regardless of the linear distance between the structurally acceptable antecedent and the pronoun. Moreover, it seems that in ungrammatical sentences, the context that facilitates the semantic retrieval of the structurally acceptable antecedent the most is the one with short sentences and singular attractors due to the lack of decay effects and salience of the attractor. In grammatical sentences, the context that brings more trouble for memory to retrieve the structurally acceptable antecedent is the one with long sentences and singular attractor. Thus although singular attractors are not too much influential in coreference processings, they can cause serious semantic problems when present in long sentences. One possible reason to justify that is that the singular number is the *default* number, that is, it is the number of most part of the nouns. The force of the plural attractors seems to be only stronger during processing, but it seems that they are not semantically retrieved as antecedent after processing.

It is worthy noting that the structurally acceptable antecedent tends to be retrieved as the semantically antecedent even with a feature-mismatch with the pronoun, which might mean that these ungrammatical sentences are actually not ungrammatical for the comprehenders. Therefore, one could wonder whether the comprehenders did not notice that feature-mismatch, or noticed it and ignored it, considering the sentence grammatical, which is usually called illusion of grammaticality. Finally, it seems that it was difficult for the participants to semantically retrieve the structurally acceptable antecedents in grammatical sentences, which may be evidence that both the structurally acceptable antecedents and the attractors were competing with each other to be semantically retrieved. In these cases, the attractors seems to be retrieved as antecedents, creating semantic illusions.

In order to check whether the presence of attractors caused were illusions of grammaticality and ungrammaticality we decided to conduct an off-line acceptability judgment experiment, which will be discussed in the following session.

3.2 The off-line acceptability judgment experiment

3.2.1 PARTICIPANTS. Forty native speakers of Brazilian Portuguese, undergraduate students of the Federal University of Rio de Janeiro (UFRJ) participated in the experiment. They were all volunteers and received one hour of *Cultural-Scientific Activities* (*Atividades-Científico-Culturais Discentes*, AACC) as compensation for their work. It is relevant to say none of these participants were the same of the eye-tracking experiment and that they were all naive in relation to our object of the study.

3.2.2 DESIGN AND MATERIALS. We conducted a Likert Scale task with the same sentences that were used in the eye-tracking experiment, thus the independent variables and the design were also the same. The dependent variable in this experiment is the rate that the participants gave to each sentence, which varied from one to five, *1* for very unnatural, *2* for natural, *3* for OK, *4* for natural and *5* for very natural.

3.2.3 PROCEDURE. The experiment was conducted in quiet classrooms at the Letters Faculty in the Federal University of Rio de Janeiro (UFRJ). The experimenter gave the participants oral instructions before handing them the handouts, which contained the materials with written instructions and proper spaces above each sentence for the participants to mark their answers.

3.2.4 RESULTS. Z-scores were calculated for each piece of data in order to minimize the subject variability in relation to the scale. The means of the Z-scores as well as their standard errors were reported in Table 4:

	Short sentences with attractors in the singular	Short sentences with attractors in the plural	Long sentences with attractors in the singular	Long sentences with attractors in the plural
Ungrammatical sentence with attractor	-0.37 (0.18)	0.28 (0.23)	0.30(0.18)	1.0 (0.24)
Ungrammatical sentence without attractor	-0.12 (0.14)	-0.23 (0.18)	0.62 (0.18)	0.61 (0.22)
Grammatical sentence with attractor	0.95 (0.20)	0.23 (0.21)	0.21 (0.19)	0.88 (0.25)
Grammatical sentence without attractor	0.65 (0.19)	0.88 (0.25)	0.75 (0.19)	0.80 (0.20)

Table 4: Z-scores means and standard error of the acceptability judgment experiment

A linear mixed-effect model was created with the same fixed and random effects of the eye-tracking experiment. And by using the *anova* function, we found a significant main effect of *grammaticality of the sentence* in our model: $F(1,1.49)=17.9$, $p<0.0001$; a main effect of *linear distance*: $F(1,1.49)=7.0$ $p=0.021$; a significant interaction between the factors *grammaticality of the sentence and linear distance:* $F(1,1.49)=15.2$, $p=0.0001$, and a quite strong trend for the interaction between the *grammaticality of the sentence,* the *attractor number* and the *linear distance*: $F(1,1.49)=3.66$, $p<0.056$.

The *grammaticality* factor was relevant, for example, when comparing the rates in ungrammatical and in grammatical short sentences with attractors in the singular. The grammatical sentences were rated more positively than the ungrammatical sentences with attractors (T-test, $p<0.0001$) or without attractors (T-test, $p=0.001$).

The *linear distance* influence was very robust in all comparisons. Ungrammatical sentences in general and grammatical sentences with plural attractors were rated more positively in long than in short sentences whereas the opposite happened for grammatical sentences with singular attractors (T-test, $p<0.01$). On the other hand, grammatical sentences without attractors do not seem to be influenced by distance factors.

The *attractor number* was decisive when comparing short sentences with singular and plural attractors. Ungrammatical sentences were rated more positively in sentences with plural attractors while grammatical sentences were rated more positively in sentences with singular attractors.

Although the factor *presence of attractor* was not significant in our model, the individual comparisons among the conditions showed that ungrammatical short sentences with plural attractors were rated more positively than sentences without attractors (T-test, $p=0.041$) and that short grammatical sentences with plural attractors and long grammatical sentence with singular attractors were rated more negatively in the presence of attractors (T-test, $p=0.02$).

3.2.5 DISCUSSION. It was observed that the off-line grammaticality judgment experiment presented a main effect of *grammaticality* and *linear distance* besides of the effect of the interaction between these two factors. As one can notice, the results of the off-line grammaticality judgment experiment are congruent with the results found in the eye-tracking experiment for Total Fixation Duration and for the answers to comprehension questions. In the case of the Total Fixation Duration, which measures late processing effects, we also found a main effect of *grammaticality*; and in the case of the answers to the comprehension questions, which occurred at a post-processing phase in our experiment, the *linear dista*nce was also considered a decisive factor. This way, it seems that the *grammaticality* and *linear distance* effects are proper of later processing stages.

Additionally, it seems that our suspicions regarding the fact the sentences with a feature-mismatch between the structurally acceptable antecedents and the pronouns were not considered to be ungrammatical by the comprehenders were correct. The results of the off-line grammaticality judgment experiment indicate that supposed ungrammatical sentences were treated as grammatical in sentences with long linear distance and with plural attractors. The former effect is a consequence of the decay caused by the long distance, that is, the feature-mismatch between the structurally acceptable antecedent and the pronoun tends to be taken for granted or ignored when there is a long distance between the structurally acceptable antecedent and the pronoun. The latter effect is a consequence of the similarity-based interference effects of attractors that display very salient features such as plural.

When it comes to grammatical sentences, it seems that it is the presence of plural attractors rather than the linear distance that is not responsible for leading the comprehenders to treat these sentences as ungrammatical, which would be considered an illusion of ungrammaticality. It is relevant to say that illusions of ungrammaticality are quite rare in the literature. Wagers et al (2009) argue in favor of the grammatical asymmetry as illusions of grammaticality, but not of ungrammaticality can occur in processing. According to the authors, the similarity-based interference effects only occur in ungrammatical sentences, generating illusions of grammaticality. On the other hand, since there is a perfect feature-match between the structurally acceptable antecedent and the pronoun, there is no intrusion of distractors, and no illusion of ungrammaticality. One explanation of this difference between our research and Wagers et al (2009) may be related to the fact that the differently from subject-verb agreement, in pronominal coreference, there is no expectation, no predictions, made by the comprehenders regarding the agreement features displayed in the pronoun. Probably, in the subject-verb relation, once the NPs (noun phrases) are encountered, predictions are automatically made, which may diminish the interference from distractors, especially in grammatical sentences.

4. General Discussion

This research aimed to understand how pronouns retrieve their nominal antecedents in memory in Brazilian Portuguese. Our hypothesis was that because Brazilian Portuguese is a language with rich morphology, the agreement cues would play a more important role than structural constraints in coreference processing. However, our results indicate that the agreement cues only play a role in early processing stages, while the structural constraints cues are delayed until late processing stages, which is congruent with Badecker & Straub (2002) and the *interactive-constructive hypothesis*.

Thus it seems that initially memory activates in parallel all antecedent candidates that feature-match the content cues of the pronouns (*Content Addressable Memory*, CAM), and that Principle B cues seem to filter these candidates until one of them is retrieved. Because the structural constraints are not taken into account at early processing stages, attractors, that is,

antecedent candidates that are structurally unacceptable according to Principle B, but that feature-matches the pronoun can be initially retrieved as the correct antecedents. Our results showed that the memory in more influenced by attractors in the plural than by attractors in the singular. Therefore, as we hypothesize, memory is not that abstract as one may think as different types of agreement cues may have different levels of activation in memory. Plural attractors rather than singular attractors were responsible for intrusion effects, that is, they facilitated coreference processing in both ungrammatical and grammatical sentences. One possible reason for that lies in the fact that plural is a marked number in English, which makes it more salient in memory than singular.

It should be noted that besides the similarity-based interference effects caused by attractors, coreference can also be influenced by decay effects in memory when, for example, there is a long linear distance between the structurally acceptable antecedent and the pronoun. Therefore, we also hypothesized that in these cases the interference effects of attractors would be stronger since the structurally acceptable antecedent would be more difficult to retrieve. Our hypothesis was partly proven true as our on-line results did not show any sensitiveness to linear distance factors; however, our off-line results indicate that long linear distance between the structural acceptable antecedent and the pronoun can result in difficulties not only to semantically retrieve the structural acceptable antecedents, but also to detect a feature-mismatch on them.

It is important to mention that our research found grammatical illusions during or after coreference processing. The on-line illusion of grammaticality was detected when supposed ungrammatical sentences were processed as grammatical in the presence of plural attractors. On the other hand, the off-line illusion of grammaticality was found not only when structurally acceptable antecedents were semantically retrieved despite the fact that they feature-mismatched the pronoun, but also when supposed ungrammatical sentences were rated as if there were grammatical in long distance sentences. Moreover, it was observed that ungrammatical sentences were rated as grammatical in the presence of plural attractors or in long linear distance sentences, which can be considered an illusion of ungrammaticality. Finally, in grammatical sentences, we also found semantic illusions when singular attractors were semantically retrieved instead of the structurally acceptable antecedent. Thus the illusions are created by memory retrieval problems, which appears to be caused not only by similarity-based interference effects due to the presence of plural attractors, but also by decay effects due to the long linear distance between structurally acceptable candidates and pronouns.

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