

Working Memory and Theories of Syntactic Complexity

Ling 895

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“I don’t see any principled way to distinguish linguistics from neurolinguistics any more than one can distinguish chemistry from physical chemistry in principle. These may be useful distinctions for temporary purposes, but one looks forward to erosion of such boundaries as understanding progresses. My own view has always been that the part of the study of language relevant here is in principle part of human biology: ‘biolinguistics’, as some have called it”

Noam Chomsky, interview with Brigitte Stemmer, *Brain and Language* 68, 393-401 (1999)

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Working Memory and Theories of Syntactic Complexity¹

Introduction

This work examines the processing of different types of relative sentences and conjoined sentences with the aim of understanding the processes that underlie the comprehension of these sentences. To do this, different techniques from psycholinguistics (Rapid Serial Visual Presentation and eye-tracking) and cognitive neuroscience (Electroencephalography) are employed.

One of the aims of psycholinguistics and neurolinguistics is to understand which processes underlie our ability to understand a sentence. Much of the literature in the field of sentence processing deals with ambiguous sentences, seeking to establish the processing strategies that we make use of when parsing a sentence. In contrast, unambiguous sentences have received less attention in the literature. In this work, the parsing of unambiguous sentences – relative clauses and conjoined sentences – is examined in order to establish the processes responsible for understanding these sentences and their differences in complexity.

Acquisition, neuropsychological and psycholinguistic data show that object relative sentences (e.g. 2) are more difficult to be parsed than subject relatives (e.g. 1) and that relative sentences (e.g. 1 and 2) are more difficult to be parsed than conjoined sentences (3):

(1) The man that is pinching the woman is talking to the child.

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- (2) The man that the woman is pinching is talking to the child.
- (3) The man is pinching the woman and is talking to the child.

In this paper, these facts are examined in English and Brazilian Portuguese and some of the explanations for these findings are discussed. Another type of relative sentences – subject (e.g. 4) and object (e.g. 5) right branching relative clauses – is also investigated in order to examine the interaction between type of embedding (center-embedded X right branching) and type of relative (subject X object):

- (4) The child is talking to the man that is pinching the woman.
- (5) The child is talking to the man that the woman is pinching.

Relative and conjoined sentences are examined in Brazilian Portuguese (BP) and English using the Rapid Serial Visual Presentation technique. Two other experiments using different techniques – eye tracking and Event Related Potentials (ERP) are proposed in this paper as future work. The use of three different techniques to study the same phenomenon contributes to better understanding of the processes underlying the differences in processing relative and conjoined sentences.

Section 1 of this paper outlines some working memory explanations for the differences exemplified above. Section 2 reviews the relevant psycholinguistics and brain imaging experiments on relative clauses in order to compare these results with the working memory theories discussed in section 1. Section 3 introduces the RSVP technique and discusses one experiment (Miyake et al. (1994)) that uses RSVP to test syntactic complexity. It also introduces our RSVP experiment. The results of this RSVP experiment are presented in section 4 for Brazilian Portuguese and in section 5 for English. An explanation of the cross-linguistic RSVP results is offered in section 6. This section also offers a tentative proposal for a syntactic working memory based on Phillips (1996) and Weinberg (1999). Section 7 proposes two different experiments to test relative

clauses: an eye-tracking experiment and an EEG/ERP experiment. Section 8 presents the final conclusions. Appendix 1 presents the stimuli used in the RSVP experiment. The same stimuli will be used in the eye-tracking and EEG/ERP experiments.

Section 1 - Working Memory explanations for processing complexity

Several experiments using different techniques have found that object relative sentences as in (2) are more difficult to parse than subject relative clauses as in (1) (e.g. Ford (1983), Gibson (1998), Holmes and O'Regan (1983), King and Just (1991), Ni et al. (1996)). Some of the tentative explanations for this difference rely on working memory proposals. This section presents the proposals put forth by King and Just (1991), Caplan (1999) and Gibson (1998).

1.1 - King and Just (1991) The main idea motivating King, Just and colleagues is that language as well as other cognitive systems utilize a general, non-specialized working memory device for information storage and processing. This means that individual differences in working memory capacity measured by memory span tests (e.g. Reading Span test, Daneman & Carpenter 1983) influence syntactic processing. Populations with less working memory capacity for language should have greater difficulty in processing complex sentences than populations with a large working memory capacity for language.

King and Just examined the processing of center-embedded relative clauses in populations with different working memory capacity for language to explore their proposal.² In this paper, their explanation for the processing difference between object and subject center embedded clauses is examined.

² King and Just results are examined in section 2. The idea that working memory is a general device and that syntactic processing can be influenced by individual differences in working memory capacity for language is not discussed in this paper. King and Just's general working memory proposal and the results of their experiment are extensively discussed in Caplan and Waters (1999) and in Ni et al. (1996).

Following their proposal, center-embedded relative clauses (e.g. 6 and 7) make several demands on working memory:

- (6) The man that is pinching the woman is talking to the child.
- (7) The man that the woman is pinching is talking to the child.

One demand is linked to the fact that there is an embedded clause that interrupts the main clause. This means that the information presented before the embedded clause has to be maintained in working memory or reactivated after the embedded clause has been processed.

Another demand that increases the complexity of these sentences is that thematic roles have to be assigned properly to the noun phrases in the relative clause. In examples (6) and (7) above, the proper agent or patient thematic role has to be assigned to the noun phrase head of the relative clause “the man”. Following King and Just, this assignment increases the difficulty of the relative clause compared to the main clause.

The third demand in working memory differentiates object relative clauses from subject relative clauses in terms of complexity. Following these authors, the assignment of two different thematic roles to the same noun phrase in object relative clauses taxes working memory capacity. In sentence (7) the noun phrase “the man” receives the thematic role agent in the main clause and patient in the relative clause. In a subject relative clause like (6), the NP “the man” receives the thematic role of agent in both clauses. This makes object relative clauses more difficult to comprehend and process than subject relative clauses³.

Therefore, following King and Just’s proposal, center-embedded relative clauses should be more difficult than conjoined sentences because there is an

³ Ni et al. (1996) point out that if the assignment of two different thematic roles in object relatives increases the processing difficulty of these sentences, then subject right branching relatives (e.g. 4) should create similar difficulties. Conversely, object right branching relatives (e.g. 5) should pose no problem. In this context, object center embedded relative clauses and subject right branching relative clauses should cause more processing problems than subject center embedded relative clauses and object right branching relative clauses. This pattern was not found in Ni et al. experiment as discussed in section 2 of this paper.

embedded clause interrupting the main clause in relative sentences. They would also predict that right branching clauses should be easier than center-embedded clauses since in right branching clauses the main clause is not interrupted. Finally, when comparing subject right branching relative clauses (e.g. 8) and conjoined sentences (e.g. 9), subject right branching relative clauses should be more difficult to process than conjoined sentences:

- (8) The man is pinching the woman that is talking to the child.
- (9) The man is pinching the woman and is talking to the child.

In this case, the difficulty does not stem from an interruption in the main clause since there is no interruption to differentiate the complexity of these sentences. Difficulty increases because the object NP in the main clause in a subject right branching relative clause receives patient role in the main clause and agent role in the relative clause. In contrast, in a coordinated sentence, the coordinated NP receives in both clauses the agent role.

To summarize, following King and Just, center-embedded relative clauses are more difficult to process than conjoined sentences and object relatives are more difficult than subject relatives. By their first criterion (interruption of the main clause), right branching relatives should be easier than center-embedded relative clauses. By their third criterion (different thematic roles to a single NP), subject right branching relatives should be more difficult than conjoined sentences. All these ideas are examined in the RSVP experiment (section 3) and in the results presented in section 4 and 5.

Theories of Working Memory	Predictions of Degree of Difficulty
King and Just (1991)	1) Object relatives > subject relatives 2) Center embedded > right branching 3) Subject right branching > conjoined

1.2 – Caplan and Waters (1999) Caplan and Waters defend the position that there is a specialized working memory for syntactic processing that does not interfere with other cognitive systems contrary to King, Just and colleagues' suggestion.

In their view, the verbal working memory system is composed of sub-systems dedicated to different verbal tasks. Thus, there is a sub-system responsible for “interpretive processing” (sentence interpretation) and another sub-system responsible for “post-interpretive processing” like “storing information in long-term semantic memory, reasoning, planning actions and other functions” (Caplan and Waters 1999, p.78). This means that the sub-system responsible for sentence interpretation is separated from the “post-interpretive” sub-system that can be measured by standard tests of working memory. Thus, any individual difference in working memory capacity for language should not interfere with the processing of complex sentences.

They show compelling experimental results in this direction. In this paper, the characterization of complex sentences utilized by Caplan and Waters is the central focus. For these authors what make object relatives more complex than subject relatives is the fact that in object relatives there is a NP that has been moved “creating a nonstandard order of thematic roles” (Caplan and Waters 1999, p. 84).

Following Chomsky's (1986) Government and Binding framework, in a sentence like (10) the NP “the man” has moved from the position where it receives patient thematic role in the relative clause to the subject position of the main clause:

(10) The man_i that_i the woman is pinching _i is talking to the child.

This produces a nonstandard order of thematic roles where the NP receiving patient thematic role (the man) appears before the NP receiving agent thematic role (the woman) in the relative clause. This does not happen in a subject relative like (11) where the NP “the man”, before moving, receives agent

thematic role creating a canonical order of thematic roles in the relative clause – agent followed by patient:

(11) The man_i that_i \bar{c}_i is pinching the woman is talking to the child.

Caplan and Waters (1995) and Waters, Caplan and Rochon (1995) emphasize this point when comparing their suggestion with other complexity metrics. For example, Caplan and Waters (1995), when discussing Miyake et al.'s (1994) complexity metric, claim that “an appropriate measure of syntactic complexity is the comparison of sentences with canonical and non-canonical orders of thematic roles, that are matched for length and number of propositions” (Caplan and Waters 1995, p.640).

Thus, following these authors, complexity increases when the canonical order of thematic roles is not the standard one and the number of propositions is the same⁴. This means that differences in complexity are expected between subject versus object center-embedded and right branching relatives. Subject relatives are easier to process than object relatives in both types of relative clauses because of the standard order of thematic roles presented in subject relatives.

Differences in processing conjoined sentences versus object right branching and center-embedded relatives should also be expected. In a conjoined sentence the order of thematic roles is standard, contrary to object relatives that present a non-standard order. Thus, conjoined sentences should be easier to process than both types of object relatives (center-embedded and right-branching). Nevertheless, conjoined and subject right branching relatives should be equally difficult since both present a standard order of thematic roles. Section

⁴ Note that, although these authors establish their complexity metric following Chomsky's (1986) GB Theory, there is nothing in the GB system that predicts an increasing in sentence complexity because a NP has moved leaving a trace in object position. In this sense, Caplan and Waters complexity metric is based on an assumption that “canonical order” is less complex than “non-canonical orders”. No grammatical principle is governing this assumption.

4 and 5 present the RSVP results in order to examine Caplan and Water's predictions.

Theories of Working Memory	Predictions of Degree of Difficulty
King and Just (1991)	1) Object relatives > subject relatives 2) Center embedded > right branching 3) Subject right branching > conjoined
Caplan and Waters (1999)	1) Object relatives > subject relatives 3) Conjoined = subject right branching 4) Object relatives (right and center-embedded) > conjoined

1.3 - Gibson (1998) Gibson (1998) proposes that the complexity difference found between subject and object relative clauses should be explained by the quantity of computational resources involved in the processing of these structures. The availability of computational resources is influenced by two components of sentence comprehension: “(1) a memory cost component which dictates what quantity of computational resources are required to store a partial input sentence and (2) an integration cost component which dictates what quantity of computational resources need to be spent on integrating new words into the structures built so far” (Gibson 1998 p. 8).

Both components are influenced by the notion of locality. When storing a partial input sentence, the longer a predicted syntactic category is maintained in memory, the greater is the cost for keeping this category in memory. When integrating new words into the structure, “the greater the distance between an incoming word and the head or dependent to which it attaches, the greater the integration cost” (Gibson 1998, p.8).

Locality is established in terms of new discourse referents. Processing a NP that is new in the discourse or a tensed verb that denotes a discourse event increases integration cost.

Gibson assumes that when parsing a sentence there is a limited pool of computational resources units available to keep a representation active. Integrating a word into a representation requires a certain amount of computational resources. If the distance between the elements being integrated is longer, more computational resources will be needed to compute this integration. Therefore, long distance integrations require more computational resources. This assumption will be crucial to explain the difference between object and subject relatives.

To illustrate the idea of a memory cost component, we use the same structure presented by Gibson - an object relative sentence:

(12) The man who the woman is pinching is talking to the child.

Gibson claims that when processing the second "the" in the sentence above there are "four obligatory syntactic predictions": "(1) a verb for the matrix clause, (2) a verb for the embedded clause, (3) a subject noun for the embedded clause and (4) an empty category NP for the wh-pronoun 'who' " (Gibson 1998, p.14). These predictions have to be maintained in mind while the new discourse referent "the woman" is processed. Computational resources are required to keep these predictions activated while parsing the new discourse referent. This means that "the memory cost for a predicted category is increased when a new discourse referent is processed" (Gibson 1998, p.18)

Integration cost, as mentioned above, also increases while new discourse referents are processed. When comparing object and subject relative clauses, the integration cost to process object relative clauses is bigger than the integration cost necessary to process subject relative clauses. So more computational resources are needed to process object relatives, making these sentences more difficult to parse than subject relative sentences. Integration and memory cost are computed in terms of energy units.

In example (12), the integration cost to process the NP "man" is 0 because after the determiner "the" was processed, no new discourse referent has been

processed. The integration cost to process “who” and “the woman” is also 0 for the same reason.

The verb “is pinching” involves two different integration costs. First, the verb is attached as the verb for the clause initiated by the NP “the woman”. This attachment results in the verb assigning agent thematic role to the NP “the woman”. This integration cost utilizes 1 energy unit because after the NP “the woman” was processed, one new discourse referent “is pinching” has been processed.

The second integration cost concerns the attachment of an empty category as object of the verb “is pinching” and the co-indexation of this empty category with the pronoun “who”. Since there are two new discourse referents between the pronoun “who” and the empty category – “the woman” and “is pinching” – the integration cost in this case utilizes 2 energy units. So the total cost of integrating the verb “is pinching” is 1+2 energy units.

The verb “is talking” is integrated as the main verb of the NP “the man”. This integration costs 3 energy units since the distance between the verb and the NP “the man” encompasses three new discourse referents – “the woman”, “is pinching” and “is talking”.

Next, the integration of the determiner “the” requires 0 energy units and the integration of the NP “child” requires a total of 0+1 energy unit. The NP “child” is first integrated to the determiner “the” at the cost of 0 energy unit and then it is integrated as the object of the verb “is talking”. This integration costs 1 energy unit because one new discourse referent has been processed - “the child”- since the verb “is talking” was processed. The total integration cost for sentence (12) is summarized below:

- (13) The man who the woman is pinching is talking to the child.
 (0) (0) (0) (0) (1)+(2) (3) (0) (0)+(1)

Following this distance based integration metric, the integration cost of a subject relative clause is smaller than the integration cost of an object relative clause. Below, the example of a subject relative is repeated to illustrate this point:

(14) The man who is pinching the woman is talking to the child.

In a subject relative clause, as in an object relative clause, the cost to process the NP “man” and the pronoun “who” is 0 since no new discourse referent has been processed after these words have been processed. The verb “is pinching” requires 0+1 energy unit to be integrated. Zero (0) energy units corresponds to the attachment of a gap in the subject position of the embedded clause since it crosses no new discourse referents. One (1) energy unit corresponds to the attachment of the verb “is pinching” to its subject “the man” given that it crosses one new discourse referent. The determiner “the” is then integrated at a cost of 0 energy units. The NP “woman” is first integrated to the determiner “the” at a cost of 0 energy units and as the object of the verb “is pinching” at a cost of 1 energy unit since there is one new discourse referent – “the woman” – that has been processed after the verb has been processed. So the total cost of integrating “woman” is 0+1 energy unit.

Integrating “is talking” and “to the child” requires the same energy units – 3 and 0+1 respectively – as in the object relative for the same reasons presented above. The total cost of processing a subject relative is summarized below:

(15) The man who is pinching the woman is talking to the child.
 (0) (0) (0)+(1) (0) (0)+(1) (3) (0) (0)+(1)

Comparison between the energy cost of subject relatives and object relatives reveals that the attachment of the embedded verb (“is pinching”) in an object relative costs more than its attachment in a subject relative. Gibson’s theory predicts then that reading times at this point of the relative clause will be longer in object relatives than in subject relatives. He also predicts that in both

relative sentences reading times will be long at the matrix verb because the integration cost at this point is 3 energy units.⁵

Therefore, following Gibson's theory, object relatives are more difficult to parse than subject relatives because the integrations occurring between the first NP and the matrix verb require more computational resources in an object relative than in a subject relative.

Gibson's locality theory explains the difference between subject and object center-embedded relative clauses. But what would be the predictions if his theory is extended to conjoined sentences (16) and to right branching relative clauses (17 and 18)?

(16) The child is talking to the man and is pinching the woman.

(17) The child is talking to the man that is pinching the woman.

(18) The child is talking to the man that the woman is pinching.

Following Gibson's theory, conjoined sentences should present an increase in integration cost at the region of the second verb ("is pinching" in example 16) because to integrate it as another verb of the NP "the child" two new discourse referents ("is talking" and "the man") are crossed. The integration cost of a conjoined sentence should be:

(19) The child is talking to the man and is pinching the woman.

(0) (0) (1) (0) (0)+(1) (2) (0) (0)+(1)

This means that reading times are expected to be long at the second verb of the conjoined sentence.

⁵Gibson compares his predictions and the results of two self-paced word-by-word reading experiment (King and Just (1991) and Gibson and Ko (1998)). In these experiments, reading times were longer in the regions predicted by Gibson's distance based integration metric. Thus, in an object relative, reading times increased when the two verbs (embedded and matrix) were processed and in a subject relative, reading times increased when the matrix verb was processed. Nevertheless, comparison of Gibson's proposal and Ni et al. (1996) results do not show up as Gibson would predict (section 2 for details).

By the same reasoning, right branching sentences should be easier than center-embedded sentences since the integration cost of the matrix verb in these cases is smaller than in center embedded sentences. The integration of the matrix verb “is talking” in (17) and (18) costs 1 energy unit because there is just one new discourse referent (“is talking”) between the verb and the subject NP “the child”. The other integration costs will be similar to the ones found in a center-embedded clause. Below, the integration costs of a subject right branching relative (20) and an object right branching (21) are presented:

- (20) The child is talking to the man that is pinching the woman.
 (0) (0) (1) (0) (1) (0) (0)+(1) (0) (0)+(1)
- (21) The child is talking to the man that the woman is pinching.
 (0) (0) (1) (0) (1) (0) (0) (0) (1)+(2)

Object right branching relatives should be more difficult than subject right branching relatives for the same reason found with center-embedded clauses, namely there is a NP intervening between the NP (“the man”) and the verb (“is pinching”) in object relatives. Nevertheless, right branching clauses should be easier than center-embedded clauses because the integration cost of the matrix verb in right branching clauses requires less computational resources than the integration of the matrix verb in center-embedded clauses. On-line experiments with right branching sentences should show an increase in reading times only at the point of processing the embedded verb (“is pinching”) in an object relative clause. The other regions should be processed fast.

As summarized in this section, there are different explanations for the difference in complexity found during the processing of relative clauses. These different explanations make different predictions when the data is extended to another type of relative clause – right branching relatives - and to conjoined sentences (see table 1):

Table 1 – Summary of Predictions

Theories of Working Memory	Predictions of Degree of Difficulty
King and Just (1991)	1) Object relatives > subject relatives 2) Center embedded > right branching 3) Subject right branching > conjoined
Caplan and Waters (1999)	1) Object relatives > subject relatives 3) Conjoined = subject right branching 4) Object relatives (right and center-embedded) > conjoined
Gibson (1998)	1) Object > subject relative clauses. 2) Center-embedded > right branching. 3) Conjoined > subject right branching.

These predictions are tested in the RSVP experiment. The next section discusses some on-line experiments that examined relative clauses.

Section 2 – Experiments with relative sentences

In this section, some experiments that tested relative clauses are examined. The aim is to summarize psycholinguistic and brain imaging findings about relative clauses in order to compare these results to the predictions outlined by the working memory theories discussed in section 1.

The papers discussed in this section make precise claims about the regions in the relative clause that show processing difficulty. The results of these experiments are compared to Gibson’s locality metric and King and Just’s working memory proposal in order to examine if experiments using different techniques found increasing difficulty in the same regions proposed by Gibson as having high integration cost and by King and Just as having increased processing demands. This comparison is important to evaluate the complexity metrics discussed in section 1. Caplan and Waters proposal is not discussed in

this section because their working memory model does not make any claims about the regions in the sentence that should exhibit increased difficulty⁶.

As discussed in section 1, Gibson's locality metric predicts that the embedded verb in object relative clauses has higher integration cost than the embedded verb in subject relative clauses. Another region of high integration cost is the matrix verb in both types of relative clause:

Subject:

(22) The man who is pinching the woman is talking to the child.

(0) (0) (0)+(1) (0) (0)+(1) (3) (0) (0)+(1)

Object:

(23) The man who the woman is pinching is talking to the child.

(0) (0) (0) (0) (1)+(2) (3) (0) (0)+(1)

King and Just predict increased processing demands in the same regions proposed by Gibson. King and Just claim that the embedded verb in object relatives increases processing demands because at this point two thematic roles must be assigned: the patient thematic role must be assigned to the first NP (the man in 23) and the agent thematic role must be assigned to the other NP ("the woman" in 23). Processing demands are also increased at the region of the matrix verb in object relatives because an agent must be found for the matrix verb and the NP receiving the agent role (the man in 23) is not the same that receives the agent role in the embedded verb. Thus, following King and Kutas, object relatives should show increased reading times at the embedded verb and at the matrix verb. Following Gibson, object relative clauses should show increased reading times at the embedded verb and both relative clauses should show increased reading times at the matrix verb.

⁶ Nevertheless, Caplan and Waters (1998, p.80) mention that there is evidence showing that in object relatives "increased load occurs at the verb of the embedded clause and/or the main verb". In the RSVP experiment presented in section (3), Caplan and Waters' proposal is examined.

This section is organized by the type of technique employed in the experiment so that the results of several methodologies are also compared.

2.1 – Self-paced word-by-word reading experiments: King and Just (1991), Gibson and Ko (in prep.)

King and Just (1991), as discussed in section 1, propose that object relatives are harder to process than subject relatives because object relatives increase working memory demands. To test their working memory predictions, they examined subject and object center-embedded relative clauses in an experiment that used self-paced word-by-word reading paradigm. This technique presents sentences word-by-word using a subject-paced moving window paradigm. This means that the subjects controlled word presentation. The subjects read the sentences and also had to remember the final word of each sentence in a series of three sentences.

The results of their experiment show the pattern predicted by King and Just: reading times were significantly longer at the embedded verb and at the matrix verb in object relatives compared to subject relatives.

The finding that the embedded verb yielded long reading times in object relatives supports Gibson's metric too. But the fact that the matrix verb yielded longer reading times in object relatives than in subject relatives does not corroborate Gibson's predictions since the matrix verb in both relative clauses has the same integration cost (3 units). Gibson (1998, p. 24), nevertheless, claims that this difference follows from his metric "because integration cost is dependent on the complexity of the intervening integrations. Thus, reading times at the matrix verb in the object-extracted RC are slower than in the subject-extracted RC because the integrations intervening between the subject NP and matrix verb are more complex in the object extraction."

Since Gibson assumes a limited pool of computational resource units, it makes sense to claim that the integration cost of the matrix verb is dependent on the complexity of the intervening integrations. Integrations with high energy cost

use more resources units and by consequence limit the computational resource units available, slowing the integration cost of subsequent words⁷.

Gibson (1998, p. 23) remarks that the task in King and Just's experiment was difficult since it involved reading and memory. Gibson and Ko (in prep) tested relative clauses in an experiment where there was no additional memory task. The technique used in Gibson and Ko's experiment is the same as in King and Just – self-paced word-by word paradigm. The results of this experiment confirmed Gibson's predictions. Reading times were slow at the region of the embedded and matrix verbs in object relatives. In subject relatives, reading times increased only in the region of the matrix verb. Figure 4 in Gibson (1998, p. 23) illustrates the comparison between reading times as predicted in Gibson's model and the results found in Gibson and Ko's experiment. This figure shows a difference in reading times between the matrix verb in subject (390ms.) and object (425ms.) relative clauses. Object relative clauses also showed an increasing in reading times at the region of the embedded verb (embedded verb: object: 450ms., subject: 355ms.). Reading times were fast in subject relatives than in object relatives. It is not mentioned if these differences in reading times are significant. As pointed out above, Gibson claims that his metric can explain this difference too.

2.2 - Continuous Lexical Decision task experiment: Ford, M. (1983)

In this paper, the processing of subject and object center-embedded relative clauses is examined using "Continuous Lexical Decision task". This technique measures reaction time for each word of a sentence while subjects are deciding about whether a string of letters is a word or not. The idea is that "any extra processing load due to parsing complexity at the location of the word" should appear in the reaction time measurement.

⁷It is important to examine if this dependence of an integration cost on the complexity of intervening integrations occurs in other cases too.

Object relative clauses were harder to process than their subject counterpart at three locations in the sentences. In the object clause, reaction time were significant longer in the relative clause verb (attacked), in the main clause verb (admitted) and in the main clause determiner (the):

(24) The reporter that the senator attacked admitted the error.

Following the author “parsing complexity is increased at the gap in object relatives and remains increased for the next couple of words” (Ford, 1983 p.210).

Thus, assigning the head to the gap is more difficulty in an object relative sentence than in a subject relative sentence. Although the author is not aiming to explain this complexity difference, she points out that the difficulty could be related to the fact that in object relatives there is more parsed material between the head of the relative clause and the gap than in a subject relative. When the parser encounters the gap and has to assign a phrase to this gap, the amount of parsed material between the gap and the head could make a difference for the parser. This idea is, in some sense, revisited in Gibson’s work. In Gibson’s proposal the amount of intervening constituents between the gap and the head is the reason of working memory load with object relative clauses.

2.2.1 – Comparison of Ford’s results and theories of Working Memory.

Ford’s finding that the relative clause verb had long reading times matches Gibson’s and King and Just’s predictions. Gibson’s metric proposes that the relative clause verb has high integration cost in object relative clauses and King and Just determine increased processing demands in the embedded verb in object relatives. Ford also found that the matrix verb had long reading times in object relative clauses. This is expected in King and Just proposal and can also be explained by Gibson’s metric as showed in section 2.1.

The finding that the main clause determiner (the) had long reading times is not expected in Gibson's metric and in King and Just's proposal but it is possible that this long reading time is just a consequence of the type of task used in the experiment and does not really reflect an integration cost. Thus, Ford's experiment corroborates King and Just predictions and Gibson's predictions – long reading times in the region of the relative clause verb in object relatives and long reading times at the matrix clause verb in object relative clauses.

2.3 - Eye-tracking experiments

2.3.1 - Holmes and O'Regan (1981)

Holmes and O'Regan used an eye-tracking system to test subject (25) and object (26) center-embedded relative clauses in French:

(25) L'auteur qui connaît l'éditeur a rencontré mon ami.

(26) L'auteur que l'éditeur connaît a rencontré mon ami.

They also tested a stylistic variant of object relative clauses which has the same surface structure of a subject relative clause:

(27) L'auteur que connaît l'éditeur a rencontré mon ami.

They divided the sentences in 5 zones:

1 Q 3 4 5

(28) Je crois que /le sauvage/ qui/ va attaquer/ le chasseur/ monte sur un cheval noir

(29) Je crois que /le sauvage / que/ le chasseur/ va attaquer/ monte...

(30) Je crois que/ le sauvage/ que/ va attaquer/ le chasseur/monte...

Eye movement data were classified as “initial fixations” and “relooks”. Initial fixations measured the total time the subject spent examining a zone. Relooks measured the number of trials a subject reentered a zone.

For “initial eye fixations”, zone 1 and zone Q did not show any difference. At zone 3, subject relatives and transposed object relatives showed the same pattern. For these two sentences the verb was fixated to some extent longer than the NP of normal object relatives. For zone 4 the verb of normal object relatives was fixated longer than the NP of subject and transposed object relatives. For these zones the average time spent examining the verb was significantly longer than the time examining the NP. Zone 5 did not show any significant difference in fixation time. Fig. 2 from Holmes and O’Regan (1983, p. 424) shows the mean initial inspection times as a function of structure and zone. Examination of this figure reveals that the average fixation time at zone 5 was around 400ms. This average fixation was smaller than the average fixation for zone 3 (around 460ms) and zone 4 (around 440 for normal object relatives and 420 for subject and transposed object relatives). Zone Q did not receive long fixations (280ms.). Nevertheless, if length differences among the words are subtracted, zone Q was fixated much longer than the other zones. Figure 2 also shows that normal object relatives had long fixations (440ms) at zone 3 and 4 (NP plus verb) and subject and transposed relatives had long fixations (460ms) at regions 3 (the verb) but not at regions 4 (420 ms at the NP). Zone 1 exhibited a mean fixation of 440ms. for all types of sentences.

When “relooks” were examined, subject relatives received a significantly lower probability of relooking than object relatives and between the two types of object relative, there was no significant difference. Zone 1, Q and zone 3 received less relooking in subject relatives compared to both object relatives. Transposed object relatives received more relookings at zone Q and zone 3 and normal object relatives received more relookings at zone 1 and zone 5. Zone Q received several relookings compared to its length.

2.3.1.1 – Comparison between Holmes and O’Regan’s results and Theories of Working Memory

For initial eye fixations, Holmes and O’Regan found that, at region 3, the verb in subject and transposed object relative clauses were fixated a bit longer than the NP in normal object relative clauses. This is expected in Gibson’s metric since the integration cost of the verb is one and the integration cost of the NP is zero at this point. Thus, a small difference at this point is coherent with Gibson’s predictions. King and Just do not expect any significant difference at this region.

For region 4 they found that the verb in normal object relatives received longer fixations than the NP in both subject and transposed object relative clauses. This is expected in King and Just’s metric since at the region of the verb two thematic roles must be assigned. This is also expected in Gibson’s metric since the integration cost of the verb in an object relative clause is three units while the integration cost of the NP in subject relative clauses is 1 unit. But comparison between the integration of the verb in all types of relatives (fig 2, p.424), reveals that the verb in object relative clauses was not fixated longer than the verb in subject relative clauses (object: 440ms, subject 460ms) as Gibson’s metric and King and Just proposal predict.

Zone 5 did not show any difference in eye fixations and received less fixations compared to zone 3 and 4. This is not expected in King and Just and Gibson’s metric. Since zone 5 contains the matrix verb that has three units integration cost, the fixations in this zone should be longer than the fixations in zone 3. Thus, Holmes and O’Regan found the inverse pattern predicted by Gibson and King and Just. Also Gibson and King and Just do not predict long fixations at zone Q since the integration of the relative pronoun costs zero. Holmes and O’Regan found that zone Q received longer fixations than the other zones relative to its length.

“Relookings” showed a pattern predicted by Gibson and King and Just with subject relative clauses receiving less relookings than object relative clauses.

2.3.2 - Ni, Shankweiler and Crain (1996)

Ni et al. (1996) used the eye-tracking technique to test subject/object center-embedded relative clauses and subject/object right branching relative clauses in high and low span readers measured by Daneman & Carpenter (1980) memory span test. The sentences were divided in five regions:

- 1 2 3 4 5
- (31) The doctor/ who cited the memo/ sued/ the hospital/ last week.
- (32) The doctor/ who the memo cited/ sued/ the hospital/ last week .
- 1 2 3 4 5
- (33) The hospital/ sued/ the doctor/ who cited the memo/ last week.
- (34) The hospital sued the doctor who the memo cited last week.

Two measures were computed: first-pass reading and regressive eye-movements. First-pass reading “comprises the total duration of all fixations on a given region of a sentence” and incidence of regressive eye-movements “is calculated as the percent of first-pass eye fixation that are immediately followed by a backward glance to a region previously visited” (Ni, Shankweiler and Crain 1996, p.9).

For first-pass reading, when examining the reading time at the relative clause in center embedded and right branching clauses, no effect of place of relative clause (right versus center embedding) was found, but an effect of type of relative clause (object versus subject) was found. Object relative clauses had longer reading times than subject relative clauses in both right and center embedded relative clauses. This difference in reading times between object and subject relative clauses was found with low-span and high-span subjects.

In a fine grained analysis of first pass reading times, specific locations in the relative clause were examined in order to find out where the increased reading times were occurring. The relative clauses were divided in three regions:

1 2 3

(35) Subject relatives: ... who/ cited/ the memo

(36) Object relatives: ... who/ the memo/ cited

Object relative clauses displayed longer reading times at region 2 than subject relative clauses. The NP in object relative clauses had more fixations than the verb in subject relative clauses⁸. Length could have contributed to this difference since the NP has two words and the verb consisted in just one word. When length effect was eliminated, the difference between object and subjects relatives was still significant. When comparing reading times for the NP in all sentences, longer reading times were found for object relatives (region 2) than subject relatives (region 3). Reading times at the verb in all sentences did not show significant results, although the verb in object center embedded clauses had much longer reading times (355ms) than the verb in subject center-embedded clauses (315ms).

When the authors examined regressive eye movements with these relative sentences they found that object relatives showed significantly more regressive eye movements than subject relatives. Again there was no significant difference between low-span and high-span subjects with respect of eye regression. Both groups regressed more from object relatives than from subject relatives. Low-span readers, nevertheless, were found to regress more than high-span subjects.

The region of the verb produced significant more regression in object relatives than in subject relatives. More regressions from the verb occurred in right branching relative clauses than in center-embedded sentences. The region of the NP showed significant more regressions in objects relatives than in subject relatives. Thus, object relative clauses yielded more regressions than subject relative clauses at the verb and at the NP.

⁸Note that this is exactly the opposite pattern found in Holmes and O'Regan. At this region they found that the verb in subject relatives had more fixations than the NP in object relatives.

2.3.2.1 – Comparison between Ni et al. results and Theories of Working Memory

Ni et al. discuss the results found in King and Just (1991). As mentioned in section 1, King and Just found that object center-embedded relative clauses are more difficult to process than subject center-embedded relative clauses. They claim that this difficulty is a consequence of the fact that in object relatives one head NP of the relative clause plays two different thematic roles – the agent role in the main clause and the patient role in the relative clause. This produces increased memory demands and as a consequence object relatives are more difficult than subject relatives.

As Ni et al. observed, if assignment of two different thematic roles in object relatives is the reason for the processing difficulty, then right branching subject relatives should pose the same problem (“the senator attacked the reporter that admitted the error”) and right branching object relatives should pose no problem (“the senator attacked the reporter that he disliked”). The prediction, then, is that center embedded object and right branching subject relative clauses should be harder to process than center embedded subject and right branching object relative clauses. The Ni et al. results do not support King and Just’s proposal. They found that object relatives are harder to process independent of the place of embedding (right versus center)⁹.

When examining reading times at the relative clause in right and center embedded clauses, Ni et al. did not find an effect of place of relative clause (right versus center embedding) but found an effect of type of relative clause (object versus subject). Object relative clauses had longer reading times than subject relative clauses in both right and center embedded relative clauses. This is consistent with Gibson’s predictions since integration cost at the relative clause is

⁹ Also King and Just’s proposal is not compatible with Hakes et al. (1976) and with the English results of the RSVP experiment presented in section (5) of this paper. In both experiments right branching and center-embedded relative clauses were tested and King and Just’s pattern was not found. In both experiments object relatives were harder to process independent of type of embedding.

the same for right and center-embedded clauses. What differs in these sentences is the integration cost between object and subject relative clauses. Gibson predicts longer reading times for object relative clauses compared to subject relative clauses. Ni et al. found exactly this pattern. As just mentioned, this finding is not compatible with King and Just's predictions.

When examining reading times inside the relative clause, Ni et al. do not find the pattern predicted by Gibson and King and Just. The locality-based metric predicts that reading times in object relative clauses should be fast in the region of the NP and long in the region of the embedded verb. In subject relative clauses, reading times should be fast in both the embedded verb and NP. King and Just expect longer reading times at the embedded verb in object relatives compared to subject relatives.

Ni et al. found that at region 2 (e.g. 35 and 36) the NP inside the object relative clause ("the memo") received longer fixations than the verb inside the subject relative clause ("cited"). This finding does not match Gibson's predictions. In Gibson's metric, the NP inside the object relative clause has zero unit integration cost and the verb inside the subject relative clause has one unit integration cost. King and Just also do not predict this pattern. For them long reading times occur only in the region of the embedded verb in object relatives.

Also subjects took longer to read the NP in object relative clauses compared to the NP in subject relative clause. Again this is not expected in Gibson's metric since the integration cost of the NP is 0 energy units in the object relative clause and 1 energy unit in the subject relative clause. So the expectation was that reading time for the NP should be similarly fast in both constructions. The same is true for King and Just proposal.

As discussed in section 1.3, Gibson's complexity metric consists of two components: an integration cost component and a memory cost component. The memory cost component is responsible for storing partial input sentences and is also affected by locality. This means that when storing a partial input sentence the longer a predicted syntactic category is maintained in memory, the greater is

the cost for keeping this category in memory. In an object relative clause as mentioned in section 1.3, at the point of processing the second “the” there are four obligatory syntactic predictions that have to be kept in mind while “the” is processed: "(1) a verb for the matrix clause, (2) a verb for the embedded clause, (3) a subject noun for the embedded clause and (4) an empty category NP for the wh-pronoun 'who' " (Gibson 1998, p.14), totalizing a memory cost of $3M(0)$ ¹⁰:

(37) The man who the woman is pinching is talking to the child.

At the next word, “woman”, the predictions for the embedded verb and the empty category site increase 1 unit because a new discourse referent (the woman) has been processed, increasing the distance between the point at which the predictions were made and their possible realization. At this point the total memory cost is $2M(1)$. This is the point where memory cost is higher in an object relative clause.

In a subject relative the higher memory cost is $2M(0)$ at the point of processing the relative pronoun corresponding to (1) a verb for the matrix clause, (2) a verb for the embedded clause and (3) an empty category NP for the wh-pronoun 'who'. This is less than the memory cost of an object relative clause.

The memory cost associated with the point of processing the noun “senator” in an object relative clause can maybe explain the long reading time at this region found in Ni et al. results. In this case, the region in the sentence that exhibits the highest memory cost would show long reading times. Nevertheless, it is not clear in Gibson (1998) how memory and integration costs combine and show up in reading times experiments. Gibson (1998, p. 34), when examining double center-embedded relative clauses, suggests that the point of maximal *integration cost* is the point predicted to show longest reading times. In this case, points of high memory cost do not show up as points of long reading times. If this is true, the long reading times found in the region of the NP in object relatives do

¹⁰ Although there are four syntactic predictions, the total memory cost at this point is 3 because Gibson considers the memory cost of the matrix verb cost free.

not match Gibson's predictions. Gibson (1998, p.64), however, when examining ambiguity resolution, shows that points of high memory cost correspond to regions of long reading times. This suggests that points of high memory cost can correspond to regions of the sentence with long reading times¹¹. In this case, the long reading times in the region of the NP in object relative clauses observed in Ni et al.'s results can be accounted by Gibson's metric.

Summarizing, it is not clear if the long reading times found in the region of the embedded NP in object relative clauses can follow from Gibson's metric. The relation between memory cost and integration cost needs to be clarified so that it is possible to compare the long reading times found at the region of the NP in object relatives to Gibson's complexity metric.

For the embedded verb, Ni et al. found longer reading time for the verb in object center embedded relative clauses (355ms) compared to subject center embedded relatives (315ms). They do not mention if this difference was significant. This is expected in King and Just proposal. This is also expected in Gibson's metric since the integration cost of the embedded verb requires three energy units in object relative clauses and one energy unit in subject relative clauses. But Ni et al. did not find the same pattern with right branching relative clauses. With subject right branching clauses, the fixation time of the embedded verb was around 325ms and with object right branching 320ms. Gibson's theory would predict the same pattern for both types of relative sentences - right branching and center-embedded relatives - since the integration cost of the embedded verb is the same in both types (1+2 in the object relative and 0+1 in the subject relative).

¹¹ Moreover, Gibson (1998, p.20) states that " integration times at points of higher memory cost will be increased relative to integration times at points of lower memory cost". This means that long reading times should be found in regions of high memory cost. Thus, in an object relative clause, long reading times should be expected in the region of the embedded NP as Ni et al. found. But, then, in the case of double embedded clauses discussed in Gibson (1998), long reading times should also be found in the regions of high memory cost. Gibson does not mention any long reading times at these points.

Since Ni et al. claim that no difference was found between right branching and center-embedded relative clauses, we assume that the total reading time between these two types of relative clause did not show any significant difference. As mentioned before, King and Just would predict long reading times with object center embedded relative clauses and subject right branching relative clauses. Gibson's metric would predict shorter reading times for right branching relative clauses. Remember that if Gibson's metric is extended to right branching relatives as discussed in section 1, the integration cost in right-branching relatives is smaller than in center-embedded relative clauses. The integration of the main verb costs one energy unit in right branching relatives and three energy units in center embedded relatives. Thus, Gibson's prediction is not confirmed in this case¹².

When examining reading times in all regions of the sentence in Ni et al. experiment (figure 2, p.10), the first subject NP has the same reading time (300ms) as the matrix verb (350ms) contrary to King and Just and Gibson's expectations. King and Just expect longer reading times for the matrix verb in object relatives than subject relatives. Following Gibson's theory, the integration cost of the first NP is 0 energy unit in all types of relative clauses and the integration cost of the matrix verb is 3 energy units in both subject and object center embedded sentences. This means that an increase in reading times in the region of the matrix verb should be expected in Ni et al. experiment. This does not occur.

Ni et al. also examined the incidence of regressive eye movements when subjects were reading relative sentences. They found that more regressions occurred with object relatives compared to subject relatives. Moreover, they found that more regressions occurred in the region of the embedded verb in object relatives than in subject relatives. This finding is compatible with King and

¹² Nevertheless, in section 6, an explanation is offered for the lack of easiness with right branching relatives in English. If this explanation is correct, Gibson's metric do not present problems in this case.

Just and also with Gibson's metric, since the integration of the embedded verb is more costly in object than in subject relatives.

But they also found more regressions at the NP in object relatives compared to subject relatives. A result that contrasts with King and Just since no increased processing demand is expected in the NP. This finding also contrasts with Gibson's expectations since the integration cost of the NP is similar in both object and subject relative sentences. Maybe the high memory cost at the point of processing the NP in object relatives is influencing regression at this point in the sentence.

To summarize, the two eye-tracking experiments examined here (Holmes and O' Regan and Ni et al.) did not show any long fixation at the region of the matrix verb. This finding contrasts with King and Just and Gibson's predictions. In Ni et al. experiment, the verb inside the relative clause showed longer fixations in object center-embedded relative clauses than in subject center-embedded relative clauses as would be expected in King and Just and Gibson's metric. Surprisingly, Holmes and O'Regan did not find longer fixations in the verb in object relatives than in subject relatives. Ni et al. found long reading times at the NP inside the object relative clause contrary to King and Just and Gibson's integration cost prediction.

2.4 – Event Related Potential (ERP) experiment

2.4.1 – King and Kutas (1995)

King and Kutas recorded ERPs to subject and object center-embedded relative clauses in High and Low capacity readers (as measured by the reading span test, Daneman & Carpenter (1980):

(38) The reporter who harshly attacked the senator admitted the error.

(39) The reporter who the senator harshly attacked admitted the error.

In the experiment words were presented for 200ms with 500ms stimulus-onset asynchrony. Subjects had to read the sentences and answer to a true-false comprehension question in less than half of the sentences. Subjects were also told to favor accuracy over speed in their responses.

To acquire multiword ERPs, relative clauses were divided in the following regions:

1 2 3 4

Object: the reporter who/the senator/harshly attacked/ admitted the error.

Subject: the reporter who/harshly attacked/ the senator/admitted the error.

Their main results are summarized here. For region 2 (Object: the senator, subject: harshly attacked) there was a significant effect of Electrodes, with more absolute negativity over posterior electrodes sites. There was also a significant Electrodes X Sentence Type interaction with object relative clauses showing more frontal negativity compared to subject relative clauses.

In region 3 (Object: harshly attacked, Subject: the senator) they did not find the interaction between Electrode X Sentence Type showed in region 2. In region 4 (main verb plus NP), ERPs to object relative clauses showed more negativity than ERPs to subject relative clauses, producing a main effect of Sentence Type.

Single word ERPs in region 2 (the definite article in object relatives and the adverb in subject relatives), showed a more anterior negativity for the article compared to the adverb.

Region 3 (adverb in object relatives and article in subject relatives), by contrast, did not show the same anterior negativity for the article exhibited in region 2. The article in subject relatives showed only a small frontal negativity and a positivity at posterior sites. King and Kutas interpret this ERP difference in the region of the article as a result of working memory load. Object relatives require more working memory load at the region of the article whereas subject relatives do not require the same working memory load. ERPs in the region of the article are then more pronounced in object relatives.

Region 3 also comprises the verb in object relative clauses and the noun in subject relative clauses. For these words, a reliable interaction between Sentence Type and Electrode Site was found where the verb in object relative clauses showed greater negativity than the NP in subject relative clauses.

They also found that Poor comprehenders displayed greater left anterior negativity for object relatives than did Good comprehenders. The authors considered this fact a support for the interpretation of the LAN (left anterior negativity) as an effect of processing load. Left Anterior Negativity (LAN) effects have been reported in several ERP studies. This negativity, as the name indicates, has a frontal maximum and is usually larger over the left than the right hemisphere. Its latency is between 300ms and 500ms. post-stimulus. As Brown and Hagoort (1999, p. 285) noticed, there is no agreement about the LAN interpretation. LAN effects have been reported to violations of word category (e.g. the appearance of a verb after an article and an adjective) (Friederici et al. 1996), to number, case, gender and tense mismatches (Müntz et al. 1993) and to verbal working memory load (Kluender and Kutas 1993). In this context, the fact that LAN effects were larger for object relatives in Poor comprehenders than in Good comprehenders, led King and Kutas support the working memory interpretation of LAN.

Region 4 (the main verb in both sentences) showed a three way interaction of Sentence Type, Electrode Site and Hemisphere where the main verb in object relatives exhibited greater left anterior negativity than the main verb in subject relatives. When compared to control sentences, main verbs in both object and subject relatives showed greater left negativity than control fillers suggesting that “reactivation” of the noun phrase that is the subject of the main verb requires working memory.

2.4.1.2 – Comparison of King and Kutas’ results to Theories of Working Memory

King and Kutas’ results showed that object relative clauses exhibit greater left anterior negativity than subject relative clauses. This is coherent with all working memory theories discussed in section 1 of this paper since all of these theories predict that object relatives are more difficult to process than subject relatives. The ERP difference would be the neural correlate of this difficulty in processing object relatives.

King and Kutas found that at region 2 the first noun phrase inside the object relative clause (the senator) showed more frontal negativity than the adverb in subject relatives. This is not expected in King and Just’s proposal. The regions of increased processing demand are the ones containing the embedded and matrix verbs in object relatives. Gibson’s metric does not predict this difference either since at region 2 the integration cost for the NP would be zero. Gibson does not predict any difference in integration cost between subject and object relative clauses at this point of the sentence. But as discussed in section 1.3.2.1, the high memory cost exhibited at the point of processing this NP could be the reason for the frontal negativity found in the ERP analysis.

At region 3 an anterior negativity in the verb (attacked) in object relative clauses compared to the NP (the senator) in subject relative clauses was found. This finding is expected in Gibson’s metric since the integration cost at the verb in an object relative clause is high (1+2) while the integration cost of the NP in a subject relative clause is smaller (0+1). This difference is also expected in King and Just’s proposal.

King and Kutas found that in both types of relative clauses the main verb in region 4 showed greater negativity than control fillers. This is expected in King and Just’s proposal. This finding is also expected in Gibson’s proposal since there is a high integration cost at this point in both types of relative clauses. King and Kutas also found that the main verb in object relative clauses showed greater anterior negativity than the main verb in subject relative clauses. This

finding matches King and Just's proposal since the matrix verb in object relatives creates more processing demands than the matrix verb in subject relatives. This finding also follows from Gibson's proposal. Although, the main verb has the same integration cost (three units) in both types of relative clause, a difference can be expected at this point because integration cost is dependent on the complexity of the intervening integrations. Thus, the fact that object relative clauses showed greater negativity at the main verb than subject relative clauses could follow from Gibson's metric.

2.5 - General discussion

Several experiments examining subject and object relative clauses with different techniques found that object relatives are more difficult to process than subject relatives. However, the regions in the relative clauses that exhibit great difficulty to process present some differences among different techniques.

All experiments examined here with the exception of Holmes and O'Regan found longer reading times at the embedded verb in object relatives than in subject relatives.

The experiments using Continuous Lexical Decision Task (Ford 1983), Self-paced word-by-word reading paradigm (King and Just 1991 and Gibson and Ko in preparation) and ERPs methodology found that the matrix verb in object relative clauses displayed long reading times. The experiments using eye-tracking did not find difficulty in processing the matrix verb in both types of relative clauses. The long reading times in the matrix verb in object relatives could be explained as an artifact of the experimental techniques. Eye-tracking methodology is more sensitive than Continuous Lexical Decision Task and Self-paced word-by-word reading paradigm because it does not allow multiple task interference (e.g. press a button, lexical judgments) while the subject is reading the sentence. But this cannot explain the discrepancy in results because the experiment that used ERP methodology also found the difference in the matrix verb. ERPs have a temporal resolution of milliseconds and do not allow

interference while subjects are reading the sentences. Maybe in the ERP experiment examined here, the stimulus-onset asynchrony (500ms) allowed some extra-linguistic interference. Thus, it is not clear why eye tracking experiments did not find long reading times at the matrix verb in relative clauses.

In this paper, we propose an eye-tracking experiment and an ERP experiment that use the same stimuli so that it is possible to compare the regions that showed increased difficulty with the same stimuli.

The lack of difficulty in the region of the matrix verb found with eye-tracking technique is not compatible with King and Just and Gibson's metric. When differences were found in the region of the matrix verb, longer reading times were displayed in object relatives compared to subject relatives. King and Just and Gibson's metric predict these differences in reading times.

Moreover, Ni et al. and King and Kutas experiments found long reading times at the embedded NP in object relative clauses while the other experiments discussed here did not show any increase in reading times at this point. This increasing in reading times at the embedded NP in object relatives is not expected in King and Just and in Gibson's integration cost metric. Nevertheless, Gibson's metric can account for this long reading time if regions of high memory cost are correlated to regions of long reading times in psycholinguistics experiments. But as discussed in this section the relation between memory cost and integration cost and how they show up in reading times experiments is not so clear in Gibson (1998).

Thus, it is not clear the role that the NP in object relative clauses and the matrix verb in both constructions are playing in the processing of relative clauses. One way to help to solve this problem is to use the same stimuli while testing with different techniques.

Section 3 – Rapid Serial Visual Presentation (RSVP) experiment

Rapid Serial Visual Presentation is a technique first used by Forster (1970) in which words of a sentence are presented rapidly and consecutively in

the same spot on a computer screen. Since the words are presented rapidly, the RSVP technique “is intended to push the subjects to the limit of their reading capability so as to impede the normal subject’s capacity to organize the input string” (Ni. (1988), p.72). Forster (1970) presented approximately 16 words per second (62.5 msec) in an experiment where subjects had to write down as many words of a sentence as possible. He found that complex sentences (center-embedded) were recalled poorer than simpler sentences (active sentences).

Since RSVP presents words rapidly, syntactic processing is affected. For this reason, in the sentence processing literature, RSVP has been used with the aim to compare RSVP results to aphasic data in order to establish the kind of deficit involved in aphasia (see, for example, Miyake et al. (1994), Ni. (1988), Caplan and Waters (1995) and Martin (1995) critique of Miyake (1994) and Miyake’s (1995) response).

RSVP has not been used often in sentence processing experiments. In this paper, RSVP is used because we want to exploit the effects of “stressing” the parser while subjects read different types of relative sentences and conjoined sentences. It is also worth comparing these results to results of other experiments that used different techniques during the processing of relative sentences and to the theories of working memory discussed in section 1. In section 3.1, Miyake et al.’s experiment is discussed because they tested the same types of sentences that we tested. Section 3.2 presents the RSVP experiment we used to test relative and conjoined sentences in English and Brazilian Portuguese.

3.1 - Miyake, Carpenter and Just (1994)

Miyake et al. propose that the comprehension problems found in aphasic patients with certain types of construction are the result of reductions in working memory resources.

For them working memory comprises the site “both for executing various language processes and for storing intermediate and/or final products of the

computation” (Miyake et al. 1994, p. 673). So storage and language processing computations are mediated by the same supply of working memory resources and compete for resources when the demand is high (e.g. processing object relative sentences).

Following these authors, working memory can be influenced by sentence complexity so that complex sentences tax working memory capacity. As mentioned in section 1, Just & Carpenter propose that center embedded relative clauses tax working memory because “the embedded clause interrupts the constituents in the main clause, and the initial noun phrase must be maintained in working memory while the comprehender is processing the embedded clause” (Miyake et al. 1994, p. 673).

Object relative clauses are still more demanding than subject relative clauses because the thematic roles inside the relative clause are assigned in a non-canonical order where the agent role comes after the patient role and/or the NP in subject position receives the agent thematic role in the main clause and the patient role in the relative clause (the reporter that the senator attacked admitted the error).

For Miyake et al., aphasics and normal individuals vary in working memory capacity and aphasics when processing language have less working memory capacity than normal subjects. This reduction in working memory capacity in aphasics causes problems in syntactic comprehension since aphasics fail “to meet the real-time processing constraints due to resource limitation” (Miyake et al. 1994 p.687).

One way to test their prediction, following these authors, is to make normal adults perform like aphasic patients. This can be done by imposing temporal constraints in sentence processing; more precisely, by making processing more difficult to normal subjects.

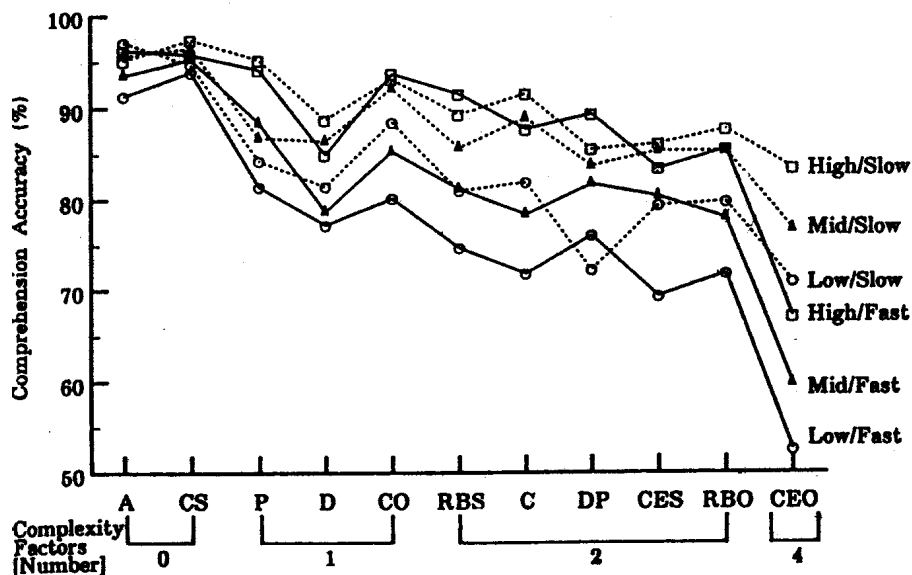
Miyake et al. used RSVP technique to impose temporal constraints in the processing system and test their prediction. They presented 11 different types of sentences to normal adults with different working memory capacities (measured

by the Reading Span test (Daneman and Carpenter 1980)) at two different rapid rates – 200 msec. per word and 120 msec. per word.

Subjects were asked to answer a yes/no question after reading the sentences to make sure that they understood the sentences (e.g. did the actor kick the comedian? After the sentence: the comedian that the actor kicked ignored the pianist).

Their predictions are: “1) normal adults should show similar effects of syntactic complexity as do aphasic patients”, 2) “normal adults should show effects of severity”: performance should be poor with more rapid presentation and with subjects with smaller working memory capacity and performance should be better with less rapid presentation and with subjects with larger memory capacity, 3) “this severity” dimension should interact with the syntactic complexity of the sentences”.

They found that more complex sentences were comprehended less accurately. Also high-span subjects performed better, in general, than low and mid-span subjects. And finally, subjects performed better in the slow condition than in the fast condition as figure 4 from Miyake et al. repeated below show:



Based on these results, the authors concluded that normal subjects performed similar to aphasic subjects as described in Caplan et al. (1985) and that their data supports their hypothesis that reduced resources is the major source for the syntactic comprehension failure with aphasics.

These results and its conclusions are extensively discussed in Caplan and Waters (1995) and Martin (1995). In this paper, some points that deserve attention are discussed.

First of all, for more complex sentences – with 2 and 4 complexity factors¹³, there are differences in performance that are not discussed by Miyake et al. For example, if right branching subject relatives (RBS), conjoined (C), center-embedded subject relatives (CES) and right branching object (RBO) relatives have 2 complexity factors as described by Caplan et al. (1985), why should the performance with these sentences vary as showed in figure 4 above? In other words, inside the 2 complexity factor group there are variations in performance that are not discussed or analyzed.¹⁴

In general, examination of Miyake's et al. results shows no pattern within subject group. Below, some common patterns between the 2 and 4 complexity factor sentences (RBS, C, CES, RBO, CEO) are discussed. For example, it is examined if subject right-branching clauses (RBO) are more difficult than conjoined sentences (C). Also, it is examined if object relatives are more difficult than subject relatives, a fact replicated several times in the literature. And finally it is examined if right branching sentences are more difficult than center-embedded sentences. The results are presented below:

¹³ In Caplan et al. (1985), the factors that contribute to increase the difficulty of sentences are: "1) three (as opposed to two) thematic roles for a single verb, 2) two (as opposed to one) verbs in a single sentence, 3) non-canonical (as opposed to canonical) order of thematic roles, 4) the maintenance of the first noun phrase is necessary while another set of thematic roles is computed, 5) there is a noun that plays two different thematic roles in different clauses.

¹⁴ Caplan and Waters (1995) make a similar point in their review of Miyake's et al. results. They discuss the difference between sentence type and syntactic complexity and point to the fact that the metric Miyake et al. use is not necessarily a reflection of syntactic complexity since in this metric there are facts primarily syntactic and others non-syntactic. They suggest that "an appropriate measure of syntactic complexity is the comparison of sentences with canonical and non-canonical orders of thematic roles, that matched for length and number of propositions". (op.cit p. 640). So for example it is worth to compare RBS and RBO or CES and CEO.

Low-fast: RBS better than Conj, RB better than Center-embedded, subject better than object

Mid-fast: RBS better than Conj., no difference between RB and Center-embedded (subject relative), subject better than object

High-fast: RBS better than conj, RB better than Center-embedded, subject better than object.

Low-slow: Conj better than RBS, very subtle difference between RB and Center-embedded, very subtle difference between subject and object

Mid-slow: Conj better than RBS, no difference between RB and Center-embedded, no difference between subject/object RB

High-slow: Conj better than RBS, RB better than Center-embedded, subject a little bit better than object.

It is surprising to find that there is no pattern among the groups when these differences are examined more closely. Sometimes right branching clauses (RB) are better than center embedded clauses, sometimes not. When RB clauses are better, the authors do not specify if the difference is significant. Subjects with the same amount of working memory perform different in the 2 conditions (e.g. mid fast X mid slow performance with Conj and RBS). Why should the subjects present this difference?

Careful examination of the graphic, demonstrate that RBS have better performance than conjoined in 3 conditions (low-fast, mid-fast, high-fast). Is this difference in performance significant? Why is this difference encountered if both sentences have the same length and are equally complex (2 factors complexity)?

Also, it has to be explained why the difference found with RBS and conjoined sentences is not replicated with the slow rate. For the slow rate, RBS are better than conjoined.

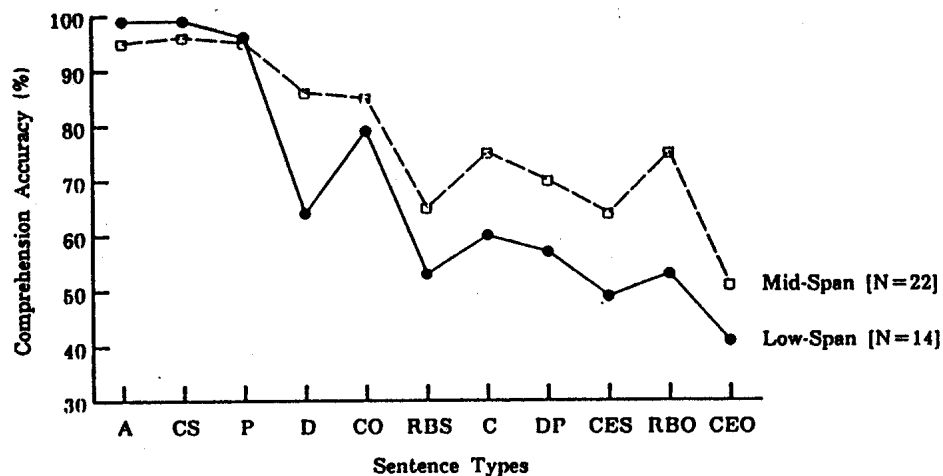
Miyake's et al. (1995) claim - as an answer to Caplan and Waters (1995) comments - that the metric that they used is correct because it "includes various factors likely to affect demand on computational and storage resources". But how

do these “various factors” interact? Why there is no pattern among different sentences types and why similarly complex sentences have different performance accuracy if they are similarly complex?

It seems that this complexity factor proposal can account for the data in general but there are within group variations that are not accounted for by this complexity factor proposal. More fine-grained criteria are needed to understand and explain these differences within group.

In a second experiment using RSVP, the authors tested low and mid span readers with the same sentences presented in experiment 1 with only one rate – 160msec. For this experiment the subjects after reading the sentences should draw a diagram that depicts the relationships among the participants in a sentence. For a subject center embedded relative clause, like “the lawyer that kicked the writer pushed the doctor” the diagram should depict who did what to whom.

Their results are presented in the graphic below from Myiake et al. 1995 p. 697 figure 6:



If these results are compared to the results in experiment 1, it is possible to observe that they differ in different aspects. First of all, the performance with the more complex sentences (2 and 4 complexity factor) is worse in this experiment with a slower rate (160ms) compared to the fast condition in

experiment 1 (120ms). Does this mean that in experiment 1 subjects did not understand the sentences and that the comprehension accuracy that they used is not adequate?

Second, conjoined sentences are better than RBS sentences in this experiment for mid and slow span subjects contrary to experiment 1 where at the fast rate RBS were better than conjoined. Why should this occur since in both experiments comprehension accuracy is tested?

Also in this experiment, for the mid-span subjects, performance with RBO is better than RBS performance, contrary to experiment 1 where RBS showed better performance than RBO and contrary to general expectation since object relatives have been described as more difficult than subject relatives in other experiments. With low span subjects, RBO seems to have the same comprehension accuracy as RBS, again contrary to general expectation.

Although the authors wanted to depict performance differences with the sentences so that subjects could be classified into different subgroups like in Caplan's (1985) experiment, it should be expected that subjects with the same amount of working memory should perform, in general, similar to experiment 1.

These results differentiations between the two experiments deserve to be explained since both experiments measure comprehension accuracy. What is clear from this comparison is that there is no pattern among the sentences – sometimes one type is more difficult, sometimes not. Also, it has to be explained why sentences that are ostensibly equally complex present differences in comprehension. To do this, a more fine-grained experiment is required. A more fine-grained RSVP experiment is proposed in the next section.

3.2 - Experiment using RSVP

In the present RSVP experiment, subjects were shown subject and object center embedded relative clauses, subject and object right branching relative clauses and conjoined sentences:

- a) The man that _ is pinching the woman is talking to the child right now.
- b) The man that the woman is pinching _ is talking to the child right now.
- c) The child is talking to the man that _ is pinching the woman right now.
- d) The child is talking to the man that the woman is pinching _ right now.
- e) The child is talking to the man and _ is pinching the woman right now.

The subjects were asked to sit in front of a Power Macintosh 8600/200 computer. The distance between the monitor and the subject's eyes was approximately 27 inches. Subjects received instructions about the experiment. They were told that they would read sentences on the computer screen, word-by-word and that the word presentation would be fast. After sentence presentation, they would have to judge if the sentence was grammatical (good) by pressing a key in the computer keyboard. They were asked to answer as fast and as accurate as possible. During the experiment, lights were turned out. Only a lamp was on so that they could see the keyboard.

Each word of the sentence was presented on the computer screen for 200 ms with 0 ms inter-word interval. This rate was chosen based on Poeppel et al.'s (in preparation) results showing that subjects perform well in an experiment with comparable sentence structures. The purpose of using this rate is to make subjects perform above chance and at the same time create difficulties for the normal processing of the sentences.

After all the words of the sentence were presented, the subject had to judge if the sentence was grammatical or not. Ungrammatical sentences were sentences missing constituents (e.g. the child is talking to that is pinching the woman) or sentences with too many constituents (e.g. the clown is pushing the woman that the thief is kicking the woman). Reaction times and number of errors are measured in all the sentences.

Subjects read 100 sentences: 20 critical trials and 80 fillers. Each critical trial was composed of 5 types of sentences ((a) subject and (b) object center embedded relative clauses, (c) subject and (d) object right branching relative clauses and (e) conjoined sentences). The critical trials were divided in 5 lists so

that subject number 1 would read sentences 1a, 2b, 3c, 4d, 5e, 6a..., subject number 2 would read 1b, 2c, 3d, etc. Each subject read 4 examples of each sentence type. The fillers and critical trials were randomized.

Right branching relative clauses were included in order to examine if their complexity matches the predictions the theories discussed in section 1 make to these sentences. It is important to know, for example, if right branching relatives are easier to process than center-embedded relatives as King and Just's proposal would predict.

Moreover, it is worth examining if complexity is modulated only by the type of relative (subject versus object) or also by the type of embedding (right versus center embedding). This investigation helps to shed lights into the processes that underlie the difficulty with object relative clauses.

Also, the difference between relative clauses and conjoined sentences is minimized by comparing conjoined sentences with subject right branching clauses:

(40) The child is talking to the man_i that _i is pinching the woman.

(41) The child is talking to the man and _i is pinching the woman.

As the examples above shown, the difference between subject right branching relatives and conjoined sentences is only the presence of the relative pronoun in the first case and the conjunction in the second case. This is different from other experiments (e.g. Just et al. 1996) where conjoined sentences were compared to center-embedded clauses. It is important to know if in this situation conjoined sentences are still easier to process than relative clauses.

In subject right branching relative clauses (e.g. 40), the NP "the man" is interpreted as the subject of the relative sentence. To do this, this NP needs to be stored and rehearsed in working memory until the point it finds the gap position to which it should be attached. At this point, the NP is reactivated and interpreted as the subject of the relative sentence. When reactivating the NP, the parser does not need to scan a huge piece of structure while looking for the NP

that should be linked to the gap. The position occupied by the NP is close to the gap position.

However, in conjoined sentences (e.g. 41), to interpret the NP “the child” as the subject of the second matrix clause, the parser has to scan all the first clause to find the NP that should occupy the subject position of the second matrix clause. Thus, reactivation of the NP in the conjoined sentence obliges the parser to cross some amount of structure (various phrases) until it finds the NP that should be linked to the subject position of the second clause. This means that the structure has to be maintained in working memory until the parser finds the NP “the child”.

Thus, the expectation is that when comparing conjoined and subject right branching relatives, conjoined sentences should not be easier than relative clauses because the parser has to scan much more structure in a conjoined sentence compared to a subject right branching relative clause. This obliges a conjoined structure to be kept longer in working memory than a subject right branching relative clause.¹⁵

This hypothesis is similar to Gibson’s locality based theory in the sense that the amount of material intervening between the gap and the head of the gap taxes working memory and is also similar to Ford’s (1983) proposal that intervening material could be the reason of processing difficulties of object relatives compared to subject relatives. In this case, these ideas are just extended to compare conjoined and subject right branching relative clauses.

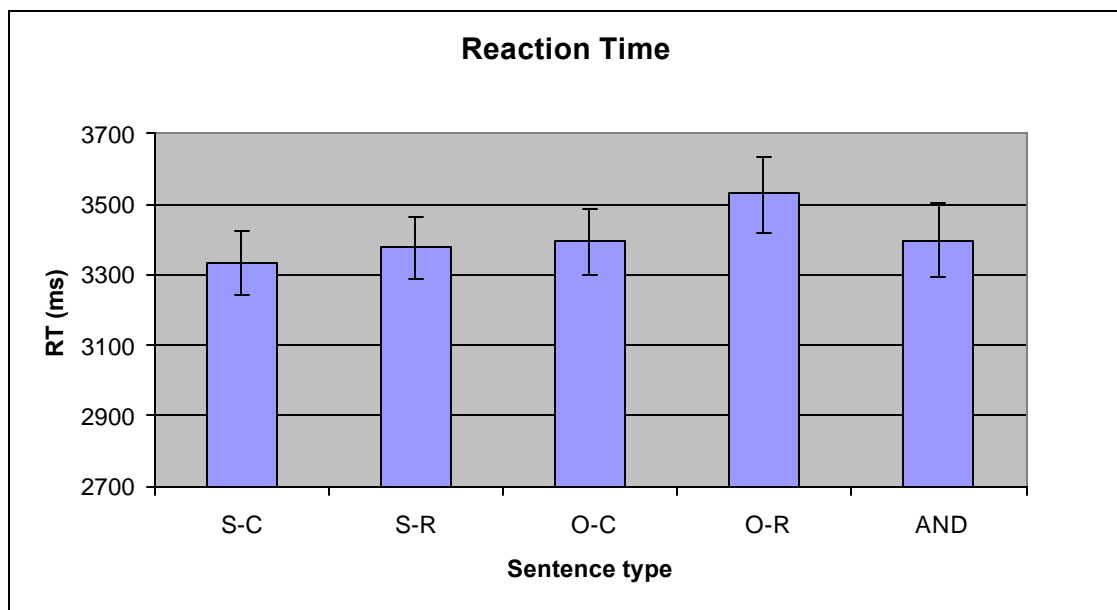
Section 4 - Brazilian Portuguese Results

Sixteen Brazilian Portuguese native speakers (age ranging from 22 to 37; 15 right-handed; 6 women; no vision problems) participated in the experiment. Reaction time and number of comprehension errors were measured while subjects were judging if the sentences were grammatical or not.

¹⁵ In section 6, another syntactic metric is proposed to explain these differences.

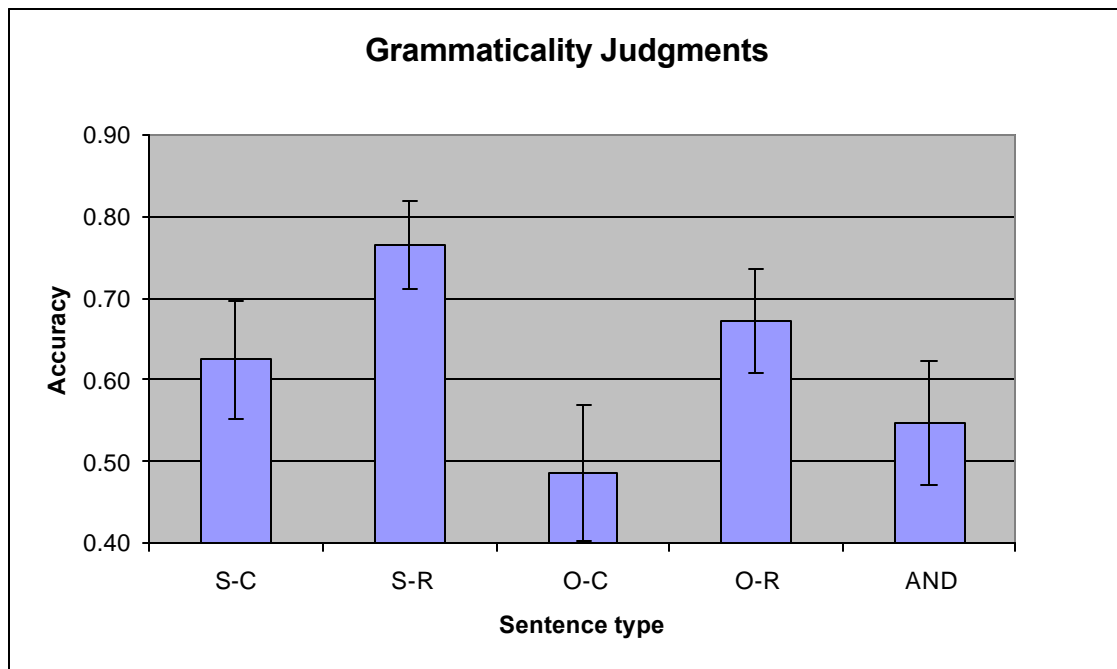
Reaction time revealed no significant effect of sentence type as shown by the analysis of variance: ($F(4,75)=0.57, p=0.69$). There was a (non-significant) trend for right-branching object relatives (O-R) being longer as shown in figure 1 (S-C: subject center-embedded clauses, S-R: subject right branching clauses, O-C: object center-embedded clauses, O-R: object right branching clauses and AND: conjoined sentences):

Figure 1 – Reaction Time in Brazilian Portuguese



The analysis of variance of grammaticality judgment performance shows a marginally significant effect of sentence type $F(4,75)=2.38, p=0.058$. In particular, whereas center-embedded clauses and conjoined sentences yielded performance near chance levels (0.63, 0.48 and 0.54 respectively), right-branching relative clauses were associated with better performance (0.67 and 0.77):

Figure 2 – Grammaticality Judgments in Brazilian Portuguese



Subject center-embedded relatives (S-C:0.63) were more difficult than subject right branching relatives (S-R:0.77), the planned comparison showing a marginally significant effect of sentence type ($p=0.06$). Object center-embedded relatives (O-C: 0.48) were also more difficult than object right branching relatives (O-R: 0.67), ($p=0.04$).

These results show that center-embedded relative clauses were more difficult to process than right branching relative clauses in Brazilian Portuguese. We call this the center-embedding effect.

When comparing subject (S-C:0.63) versus object (O-C: 0.48) center-embedded relative clauses and subject (S-R:0.77) versus object (O-R:0.67) right-branching relative clauses, no significant effect was found. Nevertheless, there is a tendency for object relatives to be more difficult than subject relatives. An increase in the number of subjects could reveal a significant result in these cases.

When comparing subject right branching relatives and conjoined sentences, conjoined sentences (0.54) were more difficult than subject right branching relative clauses (0.77) ($p=0.025$). This is exactly what is expected if the distance (number of phrases) between the gap and the head taxes working memory and increases complexity in these cases. This finding is very important when comparing different working memory theories, as discussed in section 6.

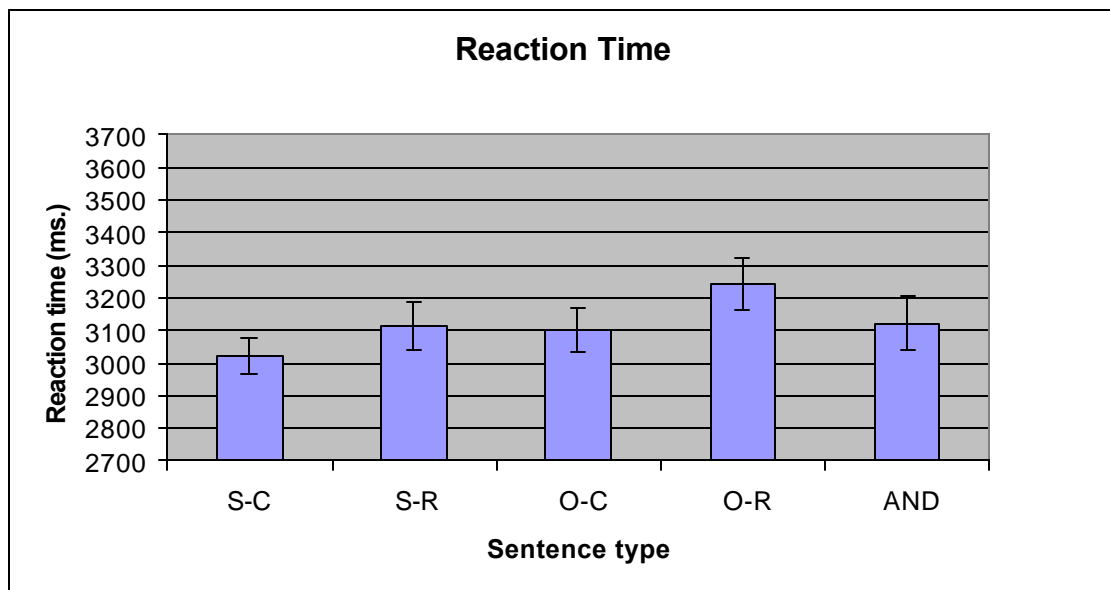
To summarize, in Brazilian Portuguese, center-embedded relatives were more difficult than right branching relatives. There is a tendency for object relatives to be more difficult than subject relatives and finally conjoined sentences were more difficult than subject right branching relative clauses.

Section 5 - English Results

Thirty-six English native speakers (age ranging from 20 to 41; 30 right-handed; 21 women; no vision problems) participated in the experiment.

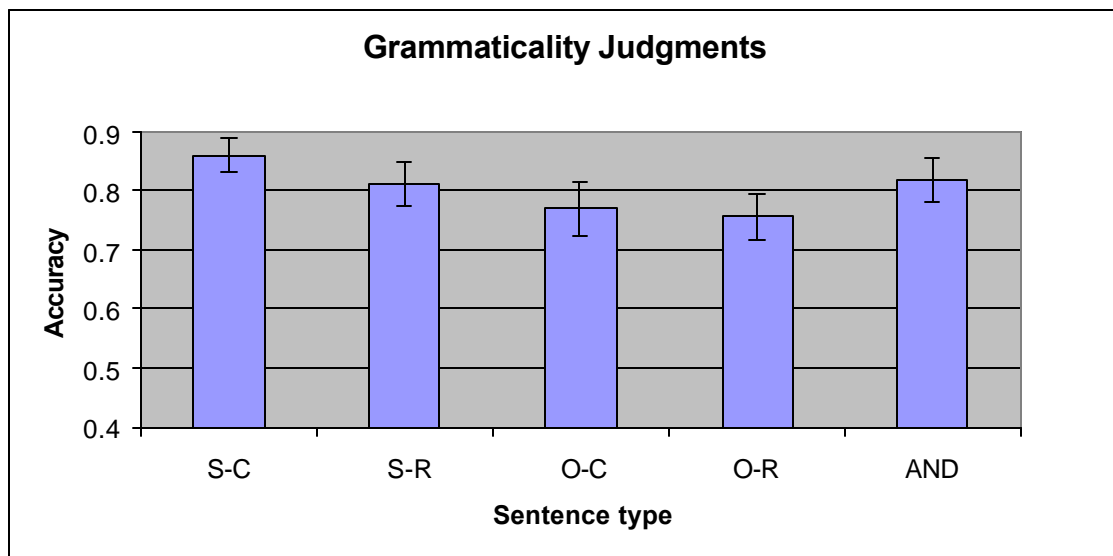
As in the Brazilian Portuguese data, reaction times showed no significant effect of sentence type: $F(4,175)=1.19, p=0.3$:

Figure 3 – Reaction time in English



The grammaticality judgment analysis showed significant results. The omnibus ANOVA did not show a significant effect of sentence type ($F(4,175)=1.21, p=0.3$). Planned comparisons revealed significant sub-effects, however:

Figure 4 –Grammaticality Judgments in English



Contrary to Brazilian Portuguese, there was no center-embedding effect in English. Subject center-embedded relative clauses were not more difficult than subject right branching relative clauses ($p=0.1$). Neither were object center-embedded clauses more difficult than object right branching relative clauses ($p=1.6$).

When comparing subject center-embedded relatives (S-C:0.86) with object center-embedded relatives (O-C:0.77), a significant effect on sentence type was found ($p=0.04$). When comparing subject right branching relatives (S-R:0.81) with object right branching relatives (O-R:0.75), no significant effect on sentence type was found ($p=0.1$), although there is a clear tendency for object right branching relatives to be more difficult than subject right branching relatives.

Subject right branching relative sentences were also compared to conjoined sentences ($p=0.4$). As predicted in section 2, conjoined sentences were not easier than right branching relative clauses. In this case both types presented the same performance (0.81).

Thus, in English, object relatives are more difficult than subject relatives independent of the type of embedding (right versus center), contrary to Brazilian Portuguese. In both languages, conjoined sentences were not easier than subject right branching clauses. In English the difficulty was similar (0.81) and in BP conjoined sentences were, in fact, more difficult than subject right branching relative clauses.

The next section discusses and compares these results with the predictions outlined in section 1.

Section 6 - Discussion

The RSVP results in both languages showed a tendency for object relatives to be more difficult than subject relatives. In BP, object relatives had worse performance than subject relatives. Although a significant effect was not found, it is clear that object relatives presented more difficulties than subject relatives. In English, object center-embedded relatives showed significantly worse performance than subject center-embedded relatives and object right branching relatives showed a tendency to be worse than subject right branching relatives.

These results are compatible with the literature. Several experiments using different techniques found that object relatives were harder to process than subject relatives (Ford (1983), Frauenfelder et al. (1980), Gibson (1998), Hakes et al. (1976), Holmes and O'Regan (1983), King and Just (1991), Ni et al. (1996), Wanner & Maratsos (1978)). All the theories discussed in section 1 would predict these differences (Caplan & Waters (1999), Gibson (1998) and King and Just (1991)).

One surprising result was the finding that center embedded clauses are harder to process than right branching clauses in Brazilian Portuguese. In the RSVP results, there is a clear cross-linguistic difference between BP and English. In English, the type of embedding (center or right) did not contribute to increase the difficulty in processing relative sentences as in BP. This finding has to be explained. A tentative explanation for this difference is offered in this section.

King, Just and colleagues would expect right branching relatives to be easier than center-embedded relatives because of their complexity metric. Interruption of the main clause is one of the factors responsible for increasing the complexity between center-embedded relatives and conjoined sentences. Since right branching relatives do not interrupt the main clause, right branching relatives are expected to be easier than center-embedded relatives, other things being equal. This expectation was found in BP. Nevertheless, the King and Just proposal cannot account for our English results, in which no difference was found. King and Just would also predict, as Ni et al. noticed, more difficulty to process object center-embedded relatives and subject right branching relatives compared to subject center-embedded and object right branching relatives. This is due to the fact that in object center-embedded and subject right branching relatives the same NP has different thematic roles in the main clause and in the embedded clause. This pattern of difficulty is not found in either language.

Caplan and Waters' proposal cannot account for the RSVP results either. For them, complexity increases when the canonical order of thematic roles is not respected. This explains the difference between subject and object relatives, but does not explain the differences obtained in BP. For Caplan and Waters, there should be no difference between right branching and center-embedded sentences since when comparing a subject center-embedded relative with a subject right branching relative the order of thematic roles is identical. The same is true when comparing object center-embedded relatives with object right branching relatives.

Gibson's theory predicts that right branching relatives are easier than center-embedded relatives because the integration cost of right branching relatives is smaller than the integration cost of center embedded relatives (see section 1.3). This expectation was found in BP; but then Gibson's proposal does not account for the English results.

6.1 – Preliminary explanation for the cross-linguistic difference

At first sight, no working memory theory discussed in section 1 is able to account for the RSVP data in BP and English. To explain the cross-linguistic differences found in the RSVP experiment, syntactic differences between English and BP are examined. A preliminary explanation for the cross-linguistic differences is proposed based on facts about extraposition from relative clauses in both languages.

English allows extraposition from a relative clause as illustrated in (42) while BP does not allow this kind of extraposition as illustrated in (43):

(42) Any girl_i could break the table easily that_i takes karate lessons.
(Frazier 1996, p. 98)

(43) *Qualquer menina_i poderia quebrar a mesa facilmente que_i faz aulas de karate.

In (42) the relative clause is extraposed, modifying the NP "any girl". This is not possible in BP as (43), a translation of the English example shows. This suggests that, in English, when the pronoun "that" is encountered in a right branching relative clause, the relative clause can modify the NP in object position of the main clause or the NP in subject position of the main clause. Thus, in English, a right branching relative is ambiguous at the point of processing the pronoun "that":

(44) The child is talking to the man that is pinching the woman.

In (44), when the relative pronoun “that” is encountered, it can be attached to the object NP “the man” or to the NP “the child”. Therefore, the sentence is ambiguous at this point. The ambiguity remains until the end of the sentence when the reader/hearer is sure that the relative clause modifies the object NP “the man”. Since there are no semantic or pragmatic reasons for choosing high attachment (extraposition) of the relative clause, the low attachment is preferred. This preference for low attachment can be explained using Gibson’s locality metric. Other approaches (Frazier and Clifton 1996, Phillips 1996 and Weinberg 1999) are also able to explain this preference. Phillips’ and Weinberg’s ideas are discussed in this section. In Gibson’s metric, the distance between the NP “the man” and the gap in (44) is smaller than the distance between the NP “the child” and the gap in (44). Thus, an object attachment is preferred over a subject attachment (extraposition) in English.

The attachment ambiguity of right branching relative clauses in English increases the complexity of these sentences and suggests that a temporarily parallel processing should be possible in these cases. The computation of the attachment ambiguity increases the working memory cost of right branching relatives in English.

If Gibson’s metric is adopted, when comparing right branching relative clauses and center-embedded relative clauses, right branching relatives are easier to process than center-embedded relatives. But, this pattern does not occur in English. We propose that right branching relative clauses are not easier than center-embedded relative clauses in English because right branching relatives have their complexity increased due to their attachment ambiguity. Thus, ambiguity increases the difficulty to parse right branching relatives in English and as a consequence center-embedded relative clauses are not more difficult to parse than right branching relative clauses as should be expected if Gibson’s metric is adopted.¹⁶

¹⁶ Ambiguity can be suppressed in right branching relatives if the plural tense is used: “the children are talking to the man that is pinching the woman” (Colin Phillips personal

In BP, relative clauses cannot be extraposed. Sentence (43) is ungrammatical in BP. BP does not allow attachment of the relative clause to the subject in (43). The relative clause has to be attached to the object in BP. Thus, when parsing a right branching relative clause there is no ambiguity at the point where the pronoun is parsed. The relative clause is attached to the object NP and just one structure is computed. Since there is no ambiguity, the difficulty in processing right branching relative clauses in BP does not increase as in English. Therefore, center-embedded relative clauses are more difficult than right branching relative clauses as expected if Gibson's metric is adopted.

If the possibility of extraposition increases the complexity of right branching relative clauses, it is expected that languages that allow extraposition will not display differences between right and center-embedded relative clauses. In contrast, languages that do not allow extraposition will exhibit less difficulty to process right branching than center embedded relatives. The only study (MacWhinney and Pleh 1988) that examined center-embedded and right branching relatives clauses in languages other than English is examined here.

MacWhinney and Pleh (1988) investigated subject/object right branching and center embedded relative clauses in Hungarian. They examined relative clauses in both canonical (SVO and SOV) and non-canonical orders (VSO, OSV, OVS, VOS). Subjects read sentences on a TV screen and then answered a comprehension question about the sentence. With non-canonical orders, right branching relatives showed less decision errors than center-embedded relatives. With canonical orders, center embedded relatives showed less decision errors than right branching relatives. In terms of reaction times, right branching relatives were usually faster than center embedded relatives. Nevertheless, right branching relatives presented a slow-down in reading times in SVO sentences. So right branching relatives were easier than center-embedded relatives with

communication). In these cases, at the point of processing the verb, it is clear that the relative modifies the NP "the man". Thus, it is expected that in these cases right branching relatives do not have their complexity increased and should be easier to process than center embedded relatives.

non-canonical orders. With canonical orders, center embedded relatives were slightly better than right branching relatives.

Hungarian allows extraposition of the relative clause and in this case, as MacWhinney and Pleh report, there is no difference between a right branching relative and an extraposed relative clause when the order is SVO and VSO. In other words, with SVO and VSO word orders, right branching relative clauses and extraposed relative clauses are ambiguous. Note that a right branching relative is not easier than a center embedded relative with SVO word order. With VSO, as shown in MacWhinney and Pleh's (1988, p. 128) Figure 2, the percent of comprehension errors is almost the same (around 15%) for both types of relative clauses. This is exactly the pattern predicted above. In languages that allow extraposition, right branching relatives should not be easy to process since the ambiguity increases the complexity of right branching relatives. In Hungarian, extraposed relative clauses and right branching relatives are ambiguous with respect to SVO and VSO word orders. In these cases, right branching relatives are not easier than center embedded relatives.

Languages that do not allow extraposition should exhibit less difficulty in processing right branching relatives than center embedded relatives. This happens with non-canonical word orders in Hungarian. With non-canonical word orders right branching relatives are easier than center embedded relatives. Hence, Hungarian confirms the predictions mentioned above. Extraposition from a relative clause creates ambiguity and increases the difficulty in processing right branching relatives. In this case right branching and center embedded relatives are expected to have similar performance. When extraposition is not allowed, there is no ambiguity and center embedded relatives are expected to be more difficult than right branching relatives to process.¹⁷

If the cross-linguistic difference found in the RSVP experiment is a consequence of the possibility of extraposition of relative clauses in English, then King and Just first working memory demand (interruption of the main clause) and

¹⁷ More cross-linguistic studies with right branching and center embedded relative clauses are required to confirm this proposal.

Gibson's metric capture these results since both predict that right branching relative clauses are easier than center-embedded relative clauses. Nevertheless, as discussed above, one of King and Just's working memory demands predicts that object center embedded and subject right branching relatives should be more difficult than subject center embedded and object right branching relatives. This pattern is not found in both languages, so King and Just's complexity metric does not account for the RSVP results.

In the RSVP experiment, subject right branching relatives were also compared to conjoined sentences. Conjoined sentences were not easier than subject right branching relatives. In BP conjoined sentences were significantly harder than subject right branching relatives. This is important, since in general it has been claimed that relative clauses are more difficult to process than conjoined sentences. These results show that the generalization is not absolute. Not all types of relative clauses are more difficult than conjoined sentences¹⁸. Quite the contrary, relative clauses can be easier than conjoined sentences as is the case in BP.

King and Just's proposal would not account for this finding. For them, a subject right branching should be more difficult than a conjoined sentence because the NP in object position in the main clause in a subject right branching clause receives two different thematic roles, Patient in the main clause and Agent in the relative clause, as discussed in section 1.1. Thus, following their metric, subject right branching are harder than conjoined sentences. This prediction was not found in English where both types showed similar performance (0.81) and either in BP where conjoined were harder than subject right branching. King, Just and colleagues cannot explain these findings.

Caplan and Waters would not expect the difference found in BP either. Since both types of sentence have the same number of propositions and

¹⁸ In this RSVP experiment, no significant difference was found between relative sentences and conjoined sentences, besides the one in BP. So, using RSVP, no type of relative sentence was significantly harder than conjoined sentences. Caplan and Waters (1995) predict that object relatives are harder than conjoined sentences to process. This prediction was not found in the RSVP results.

canonical order of thematic roles, they are equally complex and should be equally hard. This was found in English. In BP, however, conjoined sentences were difficult to process. Caplan and Water's complexity metric does not predict this finding.

Gibson's proposal accounts for BP facts. The integration cost of a conjoined sentence is bigger than the integration cost of a subject right branching relative sentence (see section 1.3). But Gibson apparently cannot account for the lack of difference in processing these sentences in English.

If right branching relative clauses have their complexity increased because of the ambiguity at the point where the relative pronoun is parsed, then the absence of difficulty between right branching relative clauses and conjoined sentences in English is explained. Right branching relative clauses should be easier than conjoined sentences since the distance between the gap and the head is smaller in subject right branching relative clauses than in conjoined sentences. This difference does not occur in English because right branching relative clauses are difficult in English in consequence of the possibility of extraposition from the relative clause. In this case only Gibson's metric accounts for the RSVP results.

Thus, King and Just's proposal is not able to account for the RSVP data. They predict that conjoined sentences should be easier than subject right branching relative clauses. This prediction was not found in both languages. Also, one of their complexity criteria predicts that object center embedded and subject right branching relatives should be more difficulty than subject center embedded and object right branching relatives. Again this was not found in both languages. Caplan's proposal cannot explain two BP findings: right branching being easier than center-embedded clauses and conjoined being harder than subject right branching clauses. Gibson's proposal explains the RSVP results. The English findings that do not correspond to Gibson's predictions - the lack of easiness in processing right branching relatives compared to center embedded relatives and the lack of difficulty in processing conjoined sentences are

explained by the ambiguity in parsing right branching relative clauses in English. Ambiguity increases the complexity of right branching relatives in English and by consequence these sentences are hard to process. Thus, in English, right branching relatives are as difficult to process as center embedded relatives and conjoined sentences.¹⁹

Gibson's metric is, then, the more adequate complexity metric to account for the RSVP results if, as proposed here, the possibility of extraposition from a relative clause increases the complexity of right branching relatives in English.

Nevertheless, as examined in section 2, it is important to clarify the relation between the two components (integration and memory costs) of Gibson's metric and the way these components show up as correlates of complexity in behavioral and brain imaging experiments. More precisely it is important to confirm if Gibson's metric predicts long reading times in the region of the embedded NP in object relative clauses as found in Ni et al.'s experiment and in King and Kutas' experiment. Also, it is important to clarify the status of the matrix verb as a point of difficulty in parsing relative clauses, since eye-tracking experiments (Holmes and O'Regan and Ni et al.) did not find long reading times at this point while subjects were reading relative clauses. In Gibson's complexity metric, the region of the matrix verb is a point of high integration cost in relative clauses processing.

6.2 - A Tentative Syntactic Working Memory Metric

In this section, a tentative working memory metric is proposed based on Phillips' and Weinberg's parser proposals. This metric uses the same principles used in syntax and thus is a syntactic working memory integrated with the principles of the grammar.

¹⁹ Other cross-linguistic studies as well as the use of different methodologies (behavioral techniques and brain imaging techniques) are expected to confirm these findings and to shed light into this intriguing aspect of sentence processing.

Gibson's metric does not pursue a more syntactic view of working memory (as do Caplan and Waters). Gibson follows King and Just in proposing a single resource pool for storage and integration of linguistic units. Moreover, although the memory cost and integration cost components make predictions about syntactic requirements, locality is measured by counting new discourse referents. In this sense, Gibson's metric is hybrid in that it makes assumptions about syntactic requirements of linguistic units and at the same time uses semantic/pragmatic notions to measure locality.

It is worth examining if it is possible to account for the facts that Gibson's metric account using principles of grammar, or in other words, it is important to explore the possibility that working memory respects the principles of grammar. In the domain of parsing, two proposals (Phillips 1996 and Weinberg 1999) have already tried to show that ambiguity resolution can be explained using the same principles that guide syntax. Phillips' proposal maintains that there is no difference between the parser and the grammar. In both proposals the notion of locality is very important as in Gibson's metric to explain the preference for association of the final word in cases like (45) to the most recent word:

(45) John said Bill left yesterday.

The preference for local attachment in (45) is explained by Phillips using a principle called Branch Right:

Branch Right (Phillips 1996 p. 111)

Metric: select the attachment that uses the shortest path(s) from the last item in the input to the current input item.

Reference set: all attachments of a new item that are compatible with a given interpretation.

This principle predicts a preference for right branching structures in the sense that it requires "the paths through the phrase marker from one terminal

node to the next terminal node to be as short as possible” (Phillips 1996, p. 111). The short path entails right branching structures and guarantees precedence/c-command correspondences.

Weinberg (1999) proposes a minimalist parser where minimalist economy conditions like Last Resort and Greed direct parsing preferences.²⁰ In this parser, precedence and dominance relations are also important. Weinberg follows Kayne’s (1994) suggestion that precedence information can be derived from dominance information and Uriagereka’s (1999) proposal that the relation between precedence and c-command can be maintained simple if the operation Spell-Out is allowed to apply many times in the derivation. Weinberg assumes that “Spell-out applies whenever two categories cannot be joined together by the Merge Operation” (Weinberg 1999, p.287). Economy conditions determine a preference for derivations that use few operations. Thus, economy conditions establish a preference for derivations with few Spell-outs so that “the system spells out or linearizes only when it cannot otherwise establish a chain of precedence” (Weinberg 1999, p.288).

Weinberg’s parsing algorithm “applies left to right and evaluates ambiguities with respect to economy conditions” (Weinberg 1999, p.288). Her system follows the minimalist theory in that items are inserted or moved in the derivation to check features. Material spelled-out is linearized and the syntactic structure is removed so that it is not anymore available for reanalysis from a preferred to a dispreferred reading. To illustrate these assumptions, example (45) is discussed again:

(46) John said Bill left yesterday.

As discussed before, in example (46), there is a preference for attachment of the adverb to the embedded verb and not for attachment of the adverb to the

²⁰ Last Resort: Operations do not apply unless required to satisfy a constraint. The minimal number of operations is applied to satisfy the constraint. Greed: “The operation cannot apply to α to enable some different element β to satisfy its properties... Benefiting other elements is not allowed”. (Chomsky 1995, p. 201). (From Weinberg 1999, p.285)

matrix verb. Weinberg accounts for this with economy conditions. Attachment of the adverb as a complement of the embedded verb requires no Spell-out. The adverb is just merged under “left”. Attachment of the adverb as an adjunct of the matrix verb requires Spell out of the material that will not c-command the adjunct (Bill left). Spell-out is subject to economy conditions so that a derivation that uses more Spell-outs is dispreferred when compared to a derivation that uses few Spell-outs. Thus, in this case, lower attachment involves fewer Spell-out operations and is preferred to the matrix attachment that requires more Spell-out operations. Economy conditions, then, explains the preference for low attachment of the adjunct.

Right branching structures are, in general, preferred because no Spell-out operation is applied since these structures guarantee that the element that precedes a category also dominates it. This preference follows from independently motivated grammatical principles. The same principles that govern the grammar also govern the parser. Economy conditions dictates which derivation is more economical, hence optimal in the grammar and also in the parser.

If grammatical principles also shape working memory, it should be expected that structures that use more Spell out operations should cost more than structures that use few Spell out operations. The interruption of the one-to-one relation between precedence and domination is expensive for working memory. In the case of relative clauses, this entails that when comparing right branching relatives and center-embedded relatives, right branching relatives should be less expensive than center-embedded relatives since right branching structures involve less Spell-out operations. This difference can also be accounted for by Phillips’ Branch Right principle. Right branching relatives produce short paths and guarantee precedence/c-command correspondences. Thus, they are less expensive than center-embedded relatives.

When comparing right branching relatives with conjoined sentences, right branching relatives should be easier than conjoined sentences because the

derivation of conjoined sentences involve more Spell-out operations than the derivation of right branching relatives.

This preference for right branching structures, nevertheless, cannot explain the difficulty in processing object relative clauses compared to subject relative clauses. We propose one tentative explanation for this difference using Weinberg's ideas. As Weinberg proposes, the parser prefers to assign case and θ -features whenever it is possible. Thus, an ambiguous sentence as (47) where the NP "his sister" can be attached as a direct object or a complement subject, has a preferred reading as direct object:

(47) The man believed his sister to be a genius.

This preference occurs because attachment as a direct object allows the NP to check case and θ -features with the preceding verb. Attachment as a complement subject allows case and θ -features to be checked only when the θ -assigner (the head of the complement clause) has been processed. When the NP "his sister" is processed the head of the complement clause has not yet been processed, thus no features are assigned to the NP "his sister" if it is attached as the subject of the complement clause.

These ideas apply in a straightforward manner to relative clauses. In subject relative clauses when the embedded verb ("is pinching" in 48) is processed, case and θ -features can be assigned to the extracted NP. So the postulation of a gap in subject position allows case and θ -features to be assigned to the extracted NP:

(48) The child that _ is pinching the woman is talking to the man.

In object relative clauses, nevertheless, when the NP in subject position of the embedded verb is encountered, no case and θ -features can be assigned to the extracted NP (the child in 49) or to the subject of the embedded clause (the

woman in 49). Case and θ -features can be checked only when the embedded verb is processed:

(49) The child that the woman is pinching_ is talking to the man.

Subject relative clauses cost less than object relative clauses because case and θ -features are checked fast in subject relatives. Thus, it is possible to claim that there is a preference to optimize feature checking that is reflected in working memory.

The RSVP data can be explained using the kind of syntactic working memory suggested above. Right branching relatives are easier to process compared to center-embedded relatives because right branching relatives use less Spell-out operations than center-embedded relatives. The long reading times found at the matrix verb in psycholinguistic and EEG/ERP experiments would reflect the interruption of precedence/c-command relations. In the RSVP data, right branching relatives were easier than center-embedded relatives in BP. In English, this difference was not found because of the ambiguity created by the possibility of extraposition from a relative clause. Ambiguity increased the complexity of right branching relatives in English.

Right branching relatives are also easier to process than conjoined sentences because conjoined sentences involve more Spell –out operations than right branching relatives. This happens in the BP data. This does not happen in English because the complexity of right branching relatives is increased because of ambiguity.

Object relatives are more difficult to process than subject relatives because subject relatives allow the case and θ -features of the extracted NP to be checked faster than in object relative clauses. Thus, subject relatives allow optimization of feature checking. In the RSVP experiment object relatives are more difficult or tended to be more difficult to process than subject relatives in both languages.

The tentative proposal of a syntactic working memory that respects the principles of the grammar has to be examined in other contexts to see if it can account for the same data accounted for in Gibson (1998). The data examined in this paper can be explained by the syntactic working memory proposed in this section.

Section 7 – Experiment proposals

7.1 – Eye tracking experiment

The same stimuli used in the RSVP experiment will be used in an eye-tracking experiment. Adverbs are added at the end of the sentences following Crain's suggestion (Stephen Crain, personal communication). The insertion of the adverb is important because the eye-tracking program sometimes presents unreliable data at this point. With adverbs, no point of relative clauses and conjoined sentences will suffer this problem:

(50) The man that the woman is pinching is talking to the child right now.

The use of eye-tracking methodology will allow a better understanding of the RSVP data since eye-tracking provides on-line data about the regions of the sentences that present more difficulties to process while subjects are reading the sentences.

It will also be possible to compare these results with the experiments discussed in section 2. More precisely, it will be possible to evaluate if the regions usually found to exhibit long reading times, present long reading times in this experiment too (e.g. embedded verb in object relatives). It is also important to examine if the NP in subject position in the embedded clause in object relatives (e.g. the woman in 50) presents long reading times as in Ni et al. experiment. Another important issue is the difficulty to process matrix verbs. Only eye-tracking experiments did not find long reading times at this region of the

sentence (section 2 of this paper). King and Just, Gibson's metric as well as the syntactic working memory proposed in section 6 expect long reading times at this region of the sentence.

7.2 – EEG/ERP experiment

In this experiment, the brain imaging technique electroencephalography (EEG/ERP) is used. EEG/ERP was chosen because of its better temporal resolution (m.s.) compared to other brain imaging techniques (fMRI and PET). EEG/ERP will allow a precise temporal record of neuronal activity while subjects are processing relative clauses and conjoined sentences.

The same stimuli used in the RSVP and eye-tracking experiment will be used in this experiment. This experiment will allow comparison of its results to King and Kutas' (1995) results and also to the psycholinguistic results presented in section 2.

One version of this experiment presents relative clauses without context in the same way they were presented in the RSVP and eye-tracking experiments:

(51) The man that the woman is pinching is talking to the child.

Another version of this experiment introduces context to the relative clauses. A relative clause like (51) above will be presented after a picture is presented to the subject. This picture will contain a woman pinching a man that is talking to the child and also other men that are doing other activities (smoking a cigar, talking to each other, etc) so that the restrictive aspect of relative clauses is highlighted. It is important to know if context will facilitate processing of these sentences and to establish the neural correlate of the semantic/pragmatic information. Some subjects will be presented with pictures containing context as indicated above. Others will be presented with pictures that do not contain

context (just one man been pinched by a woman). The ERP difference (if any) in these two types of presentation will be examined.

Section 8 - Conclusions

This paper evaluates three working memory metrics (King and Just 1991, Caplan and Waters 1999, Gibson 1998) used to explain the differences in processing subject and object center-embedded relative clauses. Conjoined sentences and right branching relative clauses were also examined in order to evaluate the predictions these metrics make to these types of sentence. Several experiments that examined relative clauses using different techniques were discussed in order to compare the results of these experiments with the complexity metrics discussed in section 1. These experiments show some convergent results, such as longer reading times at the embedded verb in object relatives compared to subject relatives. Some experiments (Ni et al. and King and Kutas) also found long reading times at the subject NP inside the embedded clause in object relatives. Long reading times were also found in the matrix verb in both types of relative clauses. Eye-tracking experiments, nevertheless did not find long reading times at this point.

Relative clauses and conjoined sentences were tested using RSVP in Brazilian Portuguese and English. A cross-linguistic difference was found in this experiment. In BP and English object relatives were significantly more difficult or showed a tendency to be more difficulty than subject relatives corroborating the results in the literature. Nevertheless, right branching relatives were easier to process than center-embedded relatives in BP but not in English. Also, subject right branching relatives were easier to process than conjoined sentences in BP but not in English.

This cross-linguistic difference is accounted for by exploiting a syntactic difference between these languages: the possibility of extraposition from relative clauses. English allows extraposition from relative clauses contrary to BP. This

possibility of extraposition creates ambiguity in processing right branching relative clauses in English and increases the complexity of these sentences. As a result, right branching relatives are not easier to process than center embedded and conjoined sentences in English.

When the RSVP results are compared to the metrics discussed in section 1, Gibson (1998) is the only complexity metric that accounts for these results if the cross-linguistic difference is explained using “extraposition from relatives clauses”. Although Gibson’s metric is able to account for the RSVP data, a tentative syntactic working memory proposal is developed based on parsing proposals that respect the principles of the grammar. This tentative syntactic working memory is also able to account for the RSVP data with the advantage that it follows from independently motivated grammatical principles and is not a hybrid syntactic and semantic/pragmatic working memory as Gibson’s metric is. More work is needed to evaluate the predictions of this syntactic working memory.

An eye-tracking and an EEG/ERP experiment proposals are also presented in this paper. These experiments will test the same sentences tested in the RSVP experiment. The EEG/ERP experiment will also examine differences in processing relative clauses with and without context.

The findings of this work have direct consequences for other areas of research like neuropsychology. Works with aphasics have shown that Broca’s aphasics have problems to comprehend object center-embedded relatives, but no problems to comprehend subject center-embedded relatives (Caramazza & Zurif 1976, Grodzinsky 1990, 1999).

Based on these comprehension differences, Grodzinsky (1990, 1999), following the Government and Binding framework (Chomsky 1986), proposes that Broca’s aphasics have problems with sentences that involve movement, leaving a trace in the S-structure level. The trace deletion hypothesis states that in Broca’s aphasics “all traces are deleted from S-structure level”(Grodzinsky 1990 p. 83). Since in Broca’s aphasics traces are deleted, they are not able to understand “who did what to whom” in sentences containing relative clauses”:

(52) The girl_i who_i the boy is pushing t_i is tall.

In the GB framework, structures involving movement have their theta-role transmitted via the chain formed between the antecedent “the girl”, the relative pronoun “who” and the trace. In the example above, to understand that the NP “the girl” was pushed by the boy, the theta role assigned in Deep Structure before the NP has moved, needs to be reactivated via the chain. Since Broca’s aphasics have their traces deleted, they are not able to retrieve the theta role of the NP “the girl” at Surface Structure. As a consequence, they have problems to understand relative clauses.

But as noted by Grodzinsky, they do not have problems with subject relatives:

(53) The girl_i who_i t_i is pushing the boy is tall.

Grodzinsky’s explanation for this difference in comprehension follows from a cognitive strategy that he calls “Default Principle”:

“ Default Principle:

If a lexical NP has no theta-role (that is, it is in a nonthematic position), assign it the theta-role that is canonically associated with the position it occupies, unless this assignment is blocked. In this case assign it a role from the next lower level in the Thematic Hierarchy.” (Grodzinsky 1990, p.118)

Since aphasics have difficulties in comprehending sentences that contain traces, they use this cognitive strategy to help them “guess” a meaning for the sentences. This cognitive strategy assigns to the NP the theta role usually assigned to the position occupied by the NP. Since Agent canonically occupies the subject position, aphasics assign the theta role of Agent to NPs in subject position. In the case of subject relatives this strategy correctly compensates for trace deletion. They will assign to the NP occupying the subject position (“the girl” in 53) the Agent theta-role and they will perform above chance with subject relatives. With object relatives, the default principle is not able to compensate the

trace deletion. They assign to the NP in subject position the Agent role (the girl in 52). This assignment produces two NPs with Agent role: the NP in subject position in the matrix clause (the girl in 52) and the NP in subject position in the embedded clause (the boy in 52). Aphasics then guess “who is doing what to whom” in these cases, generating an at chance performance with object relatives.

Grodzinsky’s hypothesis accounts for Broca’s aphasics comprehension limitations. Nevertheless, as showed in this work, normal adults also have more difficulties in processing object relatives than subject relatives. A natural approach of these facts would be to suggest that aphasics and normal adults suffer the same difficulty with differences in degree. Specifically both populations have more difficulty to process object relatives because these sentences require more working memory than subject relatives²¹. In the aphasic population this difficulty is more accentuated in consequence of neurological problems.

In the working memory metric proposed in section 6.2, object relatives require more working memory since at the point of processing the second NP (“the boy” in 52) two NPs have to be stored with case and θ -features unchecked. Subject relatives do not offer the same difficulty since the case and θ -features of the NP “the girl” (in 53) are checked as soon as the verb is encountered. Aphasics would have problems with object relatives because they have to keep in their working memory two NPs with case and θ -features unchecked until they find the verb and are able to check the case and θ -features of the NPs.

This unified account is able to explain the processing difficulty with object relatives in normal adults and aphasics. Grodzinsky’s account, on the other hand, needs to justify the trace deletion hypothesis and explain the behavior of normal adults in processing object relatives.

As mentioned in the introduction, this paper presents on-going work that seeks to find evidences about the processes underlying the differences in

²¹ Other works have already proposed that the difficulty found with object relatives in aphasics is due to working memory limitations (Caplan & Waters 1999, Lukatela et al. 1995 and Miyake et al. 1994)

processing relative and conjoined sentences. To do this, different techniques from psycholinguistic and brain imaging will be used.

Appendix 1

This appendix presents the stimuli used in the RSVP experiment. For the eye-tracking experiment, adverbs were added at the end of the sentences. The stimuli presented below contain also the adverbs that will be used in the eye-tracking experiment.

Warm-up

Grammatical:

- 1) The dog is barking at the girl that _is hugging the boy tightly.
- 2) The man is kicking the girl that the boy is scaring _ at the party.
- 3) The thief is hitting the man and robbing the old lady at the same time.
- 4) Whom do you believe that the girl will go out with_ this Saturday?
- 5) Is the driver who is passing the taxi yelling to the policeman hurriedly?

Warm-up

Ungrammatical

- 1) The girl that is playing with the boy the girl is holding the ball.
- 2) The snake and the cow is pushing is pointing to the tiger.
- 3) Is the child who burning the matches is calling the babysitter?
- 4) The thief persuaded to give the money immediately during the match.
- 5) Who do you think that will criticize the senator during the interview?

Practice

Grammatical

- 1) The man that is playing with the child is holding the baby cautiously.
- 2) The monkey that the giraffe is pushing is pointing to the rabbit anxiously.

- 3) Is the boy who is burning the TV calling his mother in the kitchen?
- 4) The policeman persuaded the driver to pay the bill immediately.
- 5) Whom do you believe that the reporter will criticize during the conference?

Ungrammatical

- 1) The monkey is looking at the boy that the boy is combing the girl.
- 2) Is the man who passing the car is yelling to the woman?
- 3) The lawyer is hitting and jumping the woman the tall girl on the street.
- 4) Whom do you think that will go out with the beautiful young girl?
- 5) The fat lady that is kicking the boy the by that is leaving.

Stimuli

Grammatical

- 1) a) The child is talking to the man that _ is pinching the woman right now.
b) The child is talking to the man that the woman is pinching _ right now.
c) The man that _ is pinching the woman is talking to the child right now.
d) The man that the woman is pinching _ is talking to the child right now.
e) The child is talking to the man and _is pinching the woman right now.
- 2) a) The clown is pushing the woman that _ is kicking the thief again.
b) The clown is pushing the woman that the thief is kicking_ again.
c) The woman that _ is kicking the thief is pushing the clown again.
d) The woman that the thief is kicking_ is pushing the clown again.
e) The clown is pushing the woman and _is kicking the thief again.

- 3) a) The man is pointing to the policeman that _ is following the fireman secretly.
- b) The man is pointing to the policeman that the fireman is following_ secretly.
- c) The policeman that _ is following the fireman is pointing to the man secretly.
- d) The policeman that the fireman is following _ is pointing to the man secretly.
- e) The man is pointing to the policeman and _is following the fireman secretly.
- 4) a) The dog is looking at the boy that _ is biting the girl in anger.
- b) The dog is looking at the boy that the girl is biting _ in anger.
- c) The boy that _ is biting the girl is looking at the dog in anger.
- d) The boy that the girl is biting _ is looking at the dog in anger.
- e) The dog is looking at the boy and _ is biting the girl in anger.
- 5) a) The boy is robbing the woman that _is touching the man just now.
- b) The boy is robbing the woman that the man is touching _ just now.
- c) The woman that _ is touching the man is robbing the boy just now.
- d) The woman that the man is touching_ is robbing the boy just now.
- e) The boy is robbing the woman and _is touching the man just now.
- 6) a) The referee is shouting at the soccer player that _ is pushing the boxer rudely.
- b) The referee is shouting at the soccer player that the boxer is pushing_ rudely.

- c) The soccer player that _ is pushing the boxer is shouting at the referee rudely.
- d) The soccer player that the boxer is pushing_ is shouting at the referee rudely.
- e) The referee is shouting at the soccer player and _is pushing the boxer rudely.
- 7) a) The girl is talking to the woman that _ is drying the child at this moment.
- b) The girl is talking to the woman that the child is drying_ at this moment.
- c) The woman that _ is drying the child is talking to the girl at this moment.
- d) The woman that the child is drying_ is talking to the girl at this moment.
- e) The girl is talking to the woman and _ is drying the child at this moment.
- 8) a) The neighbor is looking at the woman that _ is visiting the priest once more.
- b) The neighbor is looking at the woman that the priest is visiting_ once more.
- c) The woman that _ is visiting the priest is looking at the neighbor once more.
- d) The woman that the priest is visiting_ is looking at the neighbor once more.
- e) The neighbor is looking at the woman and _ is visiting the priest once more.
- 9) a) The boy is pointing to the man that _ is striking the lion forcefully.
- b) The boy is pointing to the man that the lion is striking_ forcefully.
- c) The man that _ is striking the lion is pointing to the boy forcefully.

- d) The man that the lion is striking_ is pointing to the boy forcefully.
- e) The boy is pointing to the man and _ is striking the lion forcefully.
- 10) a) The woman is kissing the swimmer that _ is patting the referee tenderly.
- b) The woman is kissing the swimmer that the referee is patting_ tenderly.
- c) The swimmer that _ is patting the referee is kissing the woman tenderly.
- d) The swimmer that the referee is patting_ is kissing the woman tenderly.
- e) The woman is kissing the swimmer and _ is patting the referee tenderly.
- 11) a) The gorilla is pushing the elephant that _ is spraying the trainer wildly.
- b) The gorilla is pushing the elephant that the trainer is spraying_ wildly.
- c) The elephant that _ is spraying the trainer is pushing the gorilla wildly.
- d) The elephant that the trainer is spraying_ is pushing the gorilla wildly.
- e) The gorilla is pushing the elephant and _ is spraying the trainer wildly.
- 12) a) The woman is waving to the man that _is measuring the teenager one more time.
- b) The woman is waving to the man that the teenager is measuring_ one more time.
- c) The man that _is measuring the teenager is waving to the woman one more time.
- d) The man that the teenager is measuring_ is waving to the woman one more time.
- e) The woman is waving to the man and _is measuring the teenager one more time.
- 13)a) The clown is smiling at the woman that _ is carrying the man gently.

- b) The clown is smiling at the woman that the man is carrying_ gently.
- c) The woman that _ is carrying the man is smiling at the clown gently.
- d) The woman that the man is carrying_ is smiling at the clown gently.
- e) The clown is smiling at the woman and _ is carrying the man gently.
- 14)a) The monkey is looking at the dog that _is chasing the cat over and over.
- b) The monkey is looking at the dog that the cat is chasing_ over and over.
- c) The dog that _is chasing the cat is looking at the monkey over and over.
- d) The dog that the cat is chasing_ is looking at the monkey over and over.
- e) The monkey is looking at the dog and _is chasing the cat over and over.
- 15)a) The woman is talking to the nurse that _is washing the child attentively.
- b) The woman is talking to the nurse that the child is washing_ attentively.
- c) The nurse that _is washing the child is talking to the woman attentively.
- d) The nurse that the child is washing_ is talking to the woman attentively.
- e) The woman is talking to the nurse and _is washing the child attentively.
- 16)a) The man is touching the dancer that _is lifting the woman carefully.
- b) The man is touching the dancer that the woman is lifting_ carefully.
- c) The dancer that _is lifting the woman is touching the man carefully.
- d) The dancer that the woman is lifting_ is touching the man carefully.
- e) The man is touching the dancer and _is lifting the woman carefully.
- 17)a) The child is kicking the boy that _is kissing the girl violently.
- b) The child is kicking the boy that the girl is kissing_ violently.
- c) The boy that _is kissing the girl is kicking the child violently.
- d) The boy that the girl is kissing_ is kicking the child violently.

- e) The child is kicking the boy and _is kissing the girl violently.
- 18)a) The nurse is pointing to the doctor that _is feeding the man kindly.
 b) The nurse is pointing to the doctor that the man is feeding _ kindly.
 c) The doctor that _is feeding the man is pointing to the nurse kindly.
 d) The doctor that the man is feeding _ is pointing to the nurse kindly.
 e) The nurse is pointing to the doctor and _is feeding the man kindly.
- 19)a) The teacher is calling the boy that _is scratching the girl frantically.
 b) The teacher is calling the boy that the girl is scratching_ frantically.
 c) The boy that _is scratching the girl is calling the teacher frantically.
 d) The boy that the girl is scratching_ is calling the teacher frantically.
 e) The teacher is calling the boy and _is scratching the girl frantically.
- 20)a) The woman is hitting the boy that _is pulling the girl repeatedly.
 b) The woman is hitting the boy that the girl is pulling_ repeatedly.
 c) The boy that _is pulling the girl is hitting the woman repeatedly.
 d) The boy that the girl is pulling_ is hitting the woman repeatedly.
 e) The woman is hitting the boy and _is pulling the girl repeatedly.

Ungrammatical:

- 1) The boy is laughing at that _ is pinching the doll now.
- 2) The businessman is pushing the child that the lawyer is kicking the.
- 3) The woman the baby is following that is talking to the man again.
- 4) The monkey that _ is biting and the old lady is pointing to the snake.
- 5) The teenager is robbing that the boy and _is forgetting the woman.

- 6) The vampire that _ is pushing that the woman is shouting at the child.
- 7) I think nearly boys all enjoy playing in the mud after the rain.
- 8) The surgeons that operated on her were competent both.
- 9) The coach cannot remember the names of the players all.
- 10) Why did you ask me to peel these all apples last Friday?
- 11) The teacher yelled at the naughty children for spilling juice on rug the.
- 12) When the truck drove through the intersection the traffic light red was.
- 13) Morris informed us that the history course would probably difficult be.
- 14) Who could possibly think that those guys intelligent are?
- 15) When did they realize that the baby starving was?
- 16) They don't sell beer or hard liquor on Sundays is annoying.
- 17) There was nobody at the station to meet us was unforgivable.
- 18) In your opinion, is to help in the kitchen something Susan enjoys .
- 19) Who do they deny the claim that the burglar shot again?
- 20) Who does Marvin regret the fact that he insulted yesterday?

Fillers

Grammatical:

- 1) Whom do you think that the man will invite _to the party?
- 2) Whom do you believe the visitors will accept _in the hotel?
- 3) Whom do you imagine that the lady will see _in the theater?
- 4) What do you expect that the journalist will show _on Saturday?
- 5) Whom do you believe that the woman saw _ in the movie?

- 6) Whom do you think that the girl met _ in the gym?
- 7) Whom do you believe that the students will criticize_ in the review?
- 8) What do you expect that the scientist will discuss_ in the talk?
- 9) Whom do you imagine that the family will allow_ in the house?
- 10) Whom do you believe that the boy will dislike_ during vacations?
- 11)The man persuaded Mary to donate the book to the library.
- 12)The players obliged the coach to go on vacation this summer.
- 13)The priest helped the girl to look for a job in the neighborhood.
- 14)The salesman convinced the man to offer the jewelry to the woman.
- 15)The student suggested to the lover to buy flowers for the woman.
- 16) Is the Eskimo who is covering the furs speaking to the trader?
- 17)Is the doctor who is citing the memo suing the hospital again?
- 18)Is the senator who is criticizing the paper complaining to the chairman?
- 19)Is the worker who is replacing the machine thanking the boss?
- 20)Is the man who is warming the soup calling the child in the kitchen?

Ungrammatical:

- 1) Who do you think that _will call Mary to the meeting?
- 2) Who do you believe that _will receive the neighbors in the house?
- 3) Who do you agree that _ will meet the cable man in the basement?
- 4) Who do you expect that _ will introduce the Pope to the press?
- 5) Who do you accept that _ will destroy the enemy in the movie?
- 6) Who is Jill pleased about the fact that I apologized to?
- 7) Which famous movie star do they doubt our claim that we met?

- 8) Which of the governors did someone xerox Bob's letter to?
- 9) Which problem did the supervisor see Ted's report about?
- 10) Which scandal did they refuse to publish Mailer's new novel about?
- 11) The boss thinks nothing is whether he likes the job.
- 12) The plumber took what the time was to finish the job.
- 13) Tom and the children and there was a man carrying the golf clubs.
- 14) The awards ceremony but the marines marched along the road.
- 15) As they said, around the pond is supposed to improve the drainage.
- 16) What kind of sauce did Sam serve the pork chops and?
- 17) This is the fruit juice you should mix the rum and.
- 18) Is the employee who promoting the company is complaining to the boss?
- 19) Is the man who blackmailing the school is contacting the newspaper?
- 20) Is the reporter who describing the article is calling the editor?

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