RETRIEVAL PROCESSES IN SUBJECT-VERB AGREEMENT COMPUTATION

by

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Presented to the Faculty of the Graduate School of

The University of Texas at Arlington in Partial Fulfillment

of the Requirements

for the Degree of

DOCTOR OF PHILOSOPHY

THE UNIVERSITY OF TEXAS AT ARLINGTON

August 2017

ABSTRACT

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An important question in psycholinguistics is how subject-verb agreement is computed. One recent proposal is that memory retrieval processes play a key role in subject-verb agreement during sentence comprehension (Wagers et al., 2009). This model holds that when an agreeing verb (e.g., *praise-s/-∅; was/were*) is encountered, a search is initiated through the memory representation of the sentence for a noun phrase (NP) with matching agreement features. When a controlling subject with matching features is available, the search ends successfully. However, in instances of a mismatch with this subject, the mechanism may (incorrectly) satisfy the agreement requirements of the verb with a grammatically inaccessible NP. This dissertation details several self-paced reading and eye-tracking experiments investigating the factors involved in triggering and modulating these retrieval processes. More specifically, these experiments examine the verbal cues that initiate retrieval-based agreement operations as well as their time course and the grammatical cues that might influence these processes.

One finding that has been taken to support the memory retrieval model is the "illusion of grammaticality" in sentences like **The musicians that the reviewer praise so highly won a prestigious award.* Under this proposal, this illusion occurs because the plural relative clause (RC) head (*musicians*) is able to satisfy the agreement requirements of the RC verb (*praise*). This study looks into the cues that initiate retrieval processes in three self-paced reading experiments examining whether long-distance agreement attraction is observed across verbal agreement targets. The results of these experiments indicate that long-distance attraction effects occur regardless of the form of the agreeing verb, suggesting that this effect reflects core properties of subject-verb agreement processing. Second, this study uses eye tracking to investigate the time course of long-distance agreement attraction in order to determine whether the attractor element influences early agreement processing or late processing, after ungrammaticality has been indexed. The results of this experiment show that these attraction effects are evident across first-pass reading measures, indicating that these effects relate to the earliest stages of subject-verb agreement processing. Finally, this dissertation examines the extent to which agreement attraction is influenced by structural cues – specifically, whether the structural position of the attractor NP, either as a syntactic subject or object, affects its viability as a controller for the verb. The results indicate that agreement attraction effects are sensitive to structural information on the attractor noun. Specifically, they appear to show that the agreement processor ignores the features of an attractor noun which has already been encoded as the subject for a verb in a previous clause.

ACKNOWLEDGEMENTS

First, a word of thanks to my committee. Jeffrey Witzel, my dissertation supervisor, has been a model teacher and mentor. Thank you for the time you have invested into editing papers, abstracts, and presentations. Your feedback has helped me develop both academically and professionally. Thank you for your detailed questions about my analyses and thank you for your patience as I worked my way forward to completion. Many of the claims in this dissertation grew out of comments and suggestions you made in our meetings. Naoko Witzel, thank you for your probing questions on the implications of my claims and your attention to detail on the presentation of my analysis. Your comments and suggestions have helped me develop my research since this project was just a qualifying paper. I can still remember my first graduate syntax course, taught by Joey Sabbagh. I can trace my love for syntax back to that course. Thank you, Joey, for your guidance and instruction during my early years in the program and your continued feedback and support as I merged my passion for syntax with language processing.

Beyond my committee, every professor I have had at UT Arlington has been a part of shaping my academic development and my work on this dissertation. In particular I wish to thank our department chair, Laurel Smith Stvan. Your guidance and support throughout my doctoral career has been indispensable. You have helped me develop both as a teacher and a scholar.

To my fellow students in the Psycholinguistics Lab, thank you for your attentive ears and thoughtful minds in lab meetings. In particular, I would like to thank Iya Khelm Price, Daniel Amy, Juliet Huynh, Kristen Fleckenstein, and Darcey Browning. Your comments have helped me develop clearer analyses and stronger arguments.

I gratefully acknowledge funding from the College of Liberal Arts at UT Arlington (Summer Dissertation Fellowship). In addition, the Department of Linguistics and TESOL has employed me as an Enhanced Graduate Teaching Assistant for all six of my years here. Lastly, both the College of Liberal Arts and the Department of Linguistics and TESOL have provided travel funding, allowing me the opportunity to present my research at academic conferences. Portions of this research project have been presented at the 2013 UTA Student Conference in Linguistics and TESOL, as well as the CUNY Conference on Human Sentence Processing in 2014 and 2015.

And now to my family. Thanks to my parents for life, education, and faith. You chose to invest your time into my education from the very start. You have modeled diligence and hard work since my very first memory, all the while fostering a loving home. You helped me develop a critical mind and supported my passion for linguistics (even if some of the terms I use sound like gibberish!). You supported me throughout my college work. And you encouraged and helped me through my graduate career. To my brothers, sister, and sister-in-law, thanks I guess....Ha! In all truth, thank you for your encouragement and love; and always taking time out of your own studies and careers to invest in me.

August 15, 2017

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CHAPTER 1

INTRODUCTION

Understanding how people produce and comprehend sentences has been a long-standing goal of research in psycholinguistics. One facet of this problem relates to the computation of subject-verb agreement. This computation is interesting because it can provide insight into how the mind processes long-distance dependencies during sentence comprehension. Long-distance dependencies exist between elements that are separated by intervening material but that require each other for their integration into the sentence. These dependencies can exist between elements in their canonical positions, as is typically the case with subject-verb agreement, as well as in sentences that involve displaced elements, such as filler-gap dependencies in sentences with "moved" *wh*-phrases. Research into these sentence types is particularly important because it sheds light on how the language processor uses grammatical information as sentence representations are developed. Specifically, this research has helped determine what grammatical cues are important for the language processor and what structures are relevant as it resolves long-distance dependencies during incremental sentence processing. Research into these phenomena also helps to clarify the time course of comprehenders' access to information sources that allow for dependency resolution. Lastly, because the resolution of long-distance dependencies requires the processor to integrate elements stored in working memory into de-

veloping sentence representations, the processing of these sentence types can provide insight into how memory interacts with the language processor during comprehension.

One way to gain a better understanding of subject-verb agreement computation in particular is to examine agreement errors. A number of early production studies examined naturally occurring errors to shed light on agreement processing (Bock & Cutting, 1992; Bock & Eberhard, 1993; Bock & Miller, 1991). This research and many studies since have also induced agreement errors experimentally. The errors of particular interest relate to a phenomenon called *agreement attraction*. Agreement attraction occurs when an agreement bearing element in the sentence does not agree with its controller, but rather with a distractor element. Example (1) demonstrates this, in that the verb *are* agrees with the noun inside the prepositional phrase (PP), *cabinets*, rather than with the head noun in its controlling subject, *key*.

(1) *The key to the cabinets are on the table.

A number of studies have investigated this kind of error during production (Bock & Miller, 1991; Eberhard, Cutting & Bock, 2005; Haskell & MacDonald, 2003; among others). These studies have shown that when a participant is given a preamble such as *The key to the cabinets*... they often choose a plural-inflected verb (*are*) to complete the sentence rather than a correctly inflected, singular verb (*is*). In fact, in studies using simple count nouns with singular-plural preambles, as in (1), participants complete the sentence with a plural verb about 13% of the time (Eberhard et al., 2005).

Comparable effects have also been examined in sentence comprehension (Dillon, Mishler, Slogget & Phillips, 2013; Pearlmutter, Garnsey & Bock, 1999; Tanner, Nicol, & Brehm, 2014; Wagers, Lau, & Phillips, 2009; Xiang, Grove, Giannakidou, 2013). In comprehension studies, the participant is typically asked to read sentences, such as (1) above, along with their grammatical counterparts. Reading times (RTs) on such sentences indicate that items with plural attractor elements create an "illusion of grammaticality". That is, although there are clear indications of processing difficulty at mismatching verb agreement targets in ungrammatical sentences with singular attractors (**The key to the cabinet are*...), this difficulty is attenuated or eliminated in ungrammatical sentences with plural attractors (**The key to the cabinets are*...). This has been taken to suggest that comprehenders incorrectly check the verb's agreement features with those of the subject NP (The term 'subject NP' is used to refer to the syntactic category DP.).

There are several accounts for this attraction effect, which can be broadly categorized into two classes – *number mismarking models* and *memory retrieval models*. Number mismarking models propose that attraction effects occur when the subject number is misrepresented or confused because of a plural element within the noun phrase (NP) (Eberhard et al., 2005; Nicol, Forster & Veres, 1997; Pearlmutter, 2000; Vigglioco & Nicol, 1997). One crucial aspect of these models is that the feature tracking system uses syntactic hierarchy to modulate the representation of subject number. This means, for instance, that the closer the attractor element is to the head noun, the more influence it will have on number specification for the subject NP. Under retrieval models (Badecker & Kuminiak, 2007; Wagers et al., 2009), on the

other hand, agreement attraction does not occur because of the faulty representation of subject number. Rather, these models propose that when an agreement target (*are*) is encountered, a search is initiated through the memory representation of the sentence for a controlling element (*key*) with matching agreement features. When the search mechanism finds a controlling element with matching features, the search ends successfully; however, in instances of a mismatch with its controller, the mechanism may incorrectly satisfy the agreement requirements of the verb with a grammatically inaccessible noun (*cabinets*) that nevertheless has some of the required features.

It is important to note that these number mismarking and retrieval models make different predictions with respect to the structures that give rise to agreement attraction and the features that modulate these effects. For example, support for retrieval-based models comes from the illusion of grammaticality for sentences in which the attractor NP does not intervene between the subject head noun and the agreeing verb as in (2).

(2) *The musicians that the reviewer praise so highly won the prestigious award.

Under retrieval models, this illusion occurs because the plural relative clause (RC) head allows for long-distance agreement attraction – a finding that number mismarking models have difficulty accounting for. As mentioned above, these models hold that the intervening plural attractor (*cabinets*) affects the number representation of the subject. However, in sentences like (2), the attractor element (*musicians*) precedes the relevant RC subject (*reviewer*). And more importantly, this attractor noun occurs higher in the syntactic structure and outside the

noun complex of the RC subject, meaning that it is not in a syntactic position where its features could affect the RC subject NP's number representation. Since this type of agreement attraction effect strongly favors memory retrieval models, this dissertation investigates these effects further by examining two questions. First, this project examines whether this long-distance attraction effect is observed for more salient agreement targets, such as free auxiliary verbs (*was/were*), compared to inflected main verbs (*praise-s/-∅*). If this effect reflects core properties of subject-verb agreement processing, it should be observed regardless of the form of the agreement target. Second, this dissertation examines the time course of long-distance agreement attraction. To date, the time course of these effects has not been examined. This is important because it is as yet unclear whether the attractor element in these sentences influences early agreement processing or late processing, as a part of a recovery mechanism after ungrammaticality has been indexed.

A second area of difference between number mismarking and retrieval models relates to the morphosyntactic features that are predicted to influence agreement processing. In particular, agreement attraction effects in intervening cases have been shown to be sensitive to the structural relationship between the head noun and the attractor noun (this research is summarized in Chapter 2), which has been taken as evidence for number mismarking models. However, it has been suggested that under memory retrieval models, agreement processing – and agreement attraction in particular – is influenced less by structural information than by activation strength/recency for the relevant NPs. This dissertation probes further into the relationship between structure and agreement processing by examining whether the structural position of

the attractor noun, either as the syntactic subject or object of an intervening RC, affects its viability as a controller for the verb.

These issues are addressed in this dissertation as follows: Chapter 2 provides a review of the relevant literature, including a detailed discussion of competing models of agreement attraction as well as of the syntactic and semantic factors that appear to modulate these effects. Chapter 3 details three self-paced reading studies that examine long-distance agreement attraction across multiple agreement targets, and demonstrate evidence of attraction effects regardless of the verbal agreement target. Experiment 1 reveals evidence of agreement attraction in sentences with inflected main verbs (*praise-s/-∅*), while Experiments 2 and 3 reveal evidence of agreement attraction in sentences with auxiliary verb agreement targets (*was/were*). Chapter 4 also examines long-distance agreement attraction, but with eye tracking in Experiment 4. This method is used to shed light onto the time course of agreement attraction and the results indicate evidence of attraction effects at the earliest stages of agreement processing. Chapter 5 examines whether the agreement processor is modulated by the structural position of the attractor noun. This question is addressed by comparing the processing of sentences with the attractor noun in the subject position to sentences with the attractor noun in the object position. These results indicate that the agreement processor is sensitive to structural information on the attractor noun in that the processor ignores the features of an attractor that has been encoded as the subject of a verb in a previous clause. Lastly, Chapter 6 provides concluding remarks.

CHAPTER 2

Literature Review

Many of the initial investigations into agreement processing were sentence production studies. As mentioned in the previous chapter, many of these studies have found that speakers regularly produce ungrammatical subject-verb combinations due to the presence of an attractor element (Bock & Cutting, 1992; Bock & Eberhard, 1993; Bock & Miller, 1991). One of the important early discoveries related to this phenomenon is that these agreement attraction errors tend to occur when the subject is singular and the attractor noun is plural. Plural subjects with singular attractor elements do not show similar attraction effects. In English (and most other languages), the singular form of a noun is unmarked, while the plural form is marked. It has been hypothesized that the reason for this singular/plural asymmetry relates to the markedness of plurality (Bock & Eberhard, 1993).

The phenomenon of agreement attraction has also been tackled in comprehension studies. These studies have demonstrated that the processor is sensitive to grammatical number agreement in that they have shown clear indications of processing difficulty when the subject and verb mismatch in terms of number. However, these studies have also shown that, in cases where the head noun is singular, this processing disruption can be attenuated by the presence of a plural attractor noun (Dillon et al., 2013; Kaan, 2002; Pearlmutter, 2000; Pearlmutter et al., 1999; Staub, 2009; Tanner et al., 2014; Wagers et al., 2009; Xiang et al., 2013). Similar to

production studies, the same pattern of attenuation does not occur in mismatch situations where the head noun is plural and the attractor noun is singular. Another important finding from these studies is that these agreement attraction effects are stronger in ungrammatical sentences than in grammatical sentences. That is, these effects are revealed in the attenuation of processing difficulty for ungrammatical sentences, rather than in processing disruptions for grammatical sentences (Dillon et al., 2013; Kaan, 2002; Pearlmutter, 2000; Pearlmutter et al., 1999; Staub, 2009; Wagers et al., 2009; Xiang et al., 2013; but see Nicol et al., 1997; Pearlmutter, 2000).

As mentioned in the previous chapter, these agreement attraction effects have been explained in terms of two main classes of models – number mismarking models and memory retrieval models. Number mismarking models have been instantiated in several ways, but the underlying concept behind these accounts is that attraction effects arise because the subject NP has been (mis)marked as plural, or marked in such a way that it predicts a plural verbal agreement target. The two most prominent models of this type are the *feature percolation model* (Bock, Eberhard, Cutting, Meyer & Schriefers, 2001; Franck, Vigliocco & Nicol, 2002; Hartsuiker, Antón-Méndez & van Zee, 2001; Vigliocco & Nicol, 1998) and the *marking and morphing model* (Bock et al., 2001; Eberhard et al., 2005).

In order to understand these models, consider again the example of agreement attraction in (3):

(3) *The key to the cabinets are on the table.

The feature percolation model proposes that in sentences such as this, the features of the attractor NP (*cabinets*) occasionally percolate up the larger constituent NP and lead to the mismarking of the subject as plural, which is then carried forward to subsequent agreement processing operations. When the agreeing verb (*are*) is reached, the processor checks its features against the representation of the subject NP. In cases where it has been mismarked as plural, the agreement features of the verb match those of the subject, leading to agreement attraction effects.

The marking and morphing model, on the other hand, accounts for attraction effects such as these with reference to two stages of number calculation for the subject NP before it is transmitted to the verb for agreement processing. The first step, *marking*, is the process whereby the elements are grammatically marked according to their semantic information. At this stage, nouns in the sentence are marked for number according to semantic information regarding the number of elements that they refer to. Thus, in *the key to the cabinets*, the marking process would mark *cabinets* as plural and leave the head noun *key* unmarked. The second step in this model is the *morphing* process. This process creates representations for phonological encoding; that is, it unites lexical and structural number features and transmits them to structurally controlled morphemes (verb). It is in this step that the number of the attractor noun can create confusion about the number of the subject NP. Specifically, under this model, the number of the subject NP is calculated based on the elements inside the phrase and given a value from strongly singular (-1) to strongly plural (1). In cases like *the key to the cabinets*, the plural attractor noun will often cause the number to be somewhere between

singular and plural, giving a value close to 0, neither strongly singular nor strongly plural. In such cases, there is an increased likelihood of incorrect agreement matching.

The second class of models involves retrieval mechanisms in working memory. As the processor works through a sentence, it holds information in working memory. When it reaches a trigger element such as an agreeing verb, it searches this working memory representation to find its agreement controller (Badecker & Kuminiak, 2007; Staub, 2009; Wagers, 2008; Wagers et al., 2009). Retrieval models suggest that the comprehension mechanism uses cues to trigger searches through memory and relies on the activation of possible controllers and their features to find the correct match for the target. For example, under such a model, the verb *are* in (4) acts as the cue to trigger a search through working memory.

(4) *The key to the cabinets are on the table.

Specifically, the processor searches through working memory looking for a controlling noun/NP to check its agreement features. The memory representation of the sentence holds two possible controlling nouns, *key* and *cabinets*. When considering possible controllers, the subject-verb agreement processor looks for a noun/NP that matches the agreement target in terms of number features (plural) and that has been encoded in a compatible structural position (subject). This model assumes that singular nouns are not given a feature for number. In instances where one of the possible controllers matches the verb with respect to both of these features, this controller will be selected as the best match. However, in some instances none of the relevant nouns is an optimal match. For instance, as in the example above, only the subject head noun (*key*)

provides a match with respect to structural position. However, with respect to number, only the grammatically inaccessible attractor noun (*cabinets*) provides a match. Since both nouns match/mismatch with respect to at least one feature, the number-matching attractor noun can be selected as the best available match, resulting in an attenuation of processing difficulty during the comprehension of an ungrammatical sentence of this type. Importantly, the retrieval process does not incorrectly choose the attractor noun *cabinets* as the sentential subject, but incorrectly selects it to match the verb's agreement features.

Further investigations into agreement attraction have shown that a number of factors modulate the effect of the attractor noun on subject-verb agreement. The studies that have examined these factors not only elucidate the mechanics of agreement processing, but also offer evidence in support of the competing models discussed above. One area of this research relates to how semantic factors influence agreement attraction errors in production (Barker, Nicol, & Garrett, 2001; Bock & Eberhard, 1993; Bock & Miller, 1991; Humphreys & Bock, 2005; Vigliocco, Butterworth, & Semenza, 1995). One such factor that appears to influence the production of agreement errors is the level of semantic overlap between a head noun and the attractor noun. For instance, Barker and colleagues (2001) used preambles as in (5) in a sentence production study.

(5) a. The canoe by the sailboats… high overlap

b. The canoe by the cabins… low overlap

Preambles with high semantic overlap between the head noun and the attractor noun, as in (5a), were shown to yield significantly more agreement errors than preambles with low semantic overlap, as in (5b). In order to further investigate the influence of semantic factors on attraction effects, this study also examined the interaction of the animacy of the head noun and the attractor noun on agreement errors. Interestingly, errors were produced more often when the head noun was inanimate than when it was animate, and errors were most prevalent when both the head noun and the attractor noun were inanimate.

These results were taken to support an activation-based model of number mismarking (Eberhard, 1997). Under this model, agreement errors occur when the agreement mechanism incorrectly detects an activated number feature on a lower node in the NP. Plural features sometimes cause such errors because they are highly activated as a result of their markedness. Barker et al. (2001) argue that factors that increase the activation of features on attractor nouns will increase attraction errors. One such factor is a high semantic overlap between the head noun and attractor noun. On the other hand, animate head nouns would have higher activation and would decrease attraction errors. It is important to note, however, that these results can also be accommodated under memory retrieval models. Specifically, under such models, the increase in errors for subjects with semantically related head and attractor nouns might be attributed to greater retrieval difficulty in such situations.

A second area of this research relates to the potential influence of structural properties on agreement attraction. For instance, several studies have indicated that shorter structural distance between the head noun and the attractor noun results in more instances of agreement

attraction errors (Bock & Cutting, 1992; Franck et al., 2002; Vigliocco & Nicol, 1998). In one such study, Bock and Cutting (1992) compared agreement errors produced in sentences with preambles that had either subject NPs with PP or RC modifiers as in (6a) and (6b).

(6) a. The editor of the history books…

b. The editor who rejected the books…

They found that subject NPs with PP modifiers resulted in the production of more incorrect verbs than those with RC modifiers. They suggested the reason for this asymmetry is that the RC boundary creates more structural information between the head noun and the attractor noun than the PP boundary. Due to the smaller boundary, the attractor noun is able to exert greater influence from within a PP. Since these effects appear to indicate sensitivity to structural material within the NP, they have been taken as support for number mismarking models.

Further support for such models, and more particularly the feature percolation model, comes from Franck, Vigliocco, and Nicol (2002). This study examined agreement errors in response to preambles like (7), in which the head noun was followed by two PPs containing possible attractor elements.

(7) The inscription on the door(s) of the toilet(s)…

Crucially, speakers produced more errors when the second noun (*doors*) was plural than when the third noun (*toilets*) was plural, demonstrating that the agreement processor is sensitive

to the structural relationships between the nouns in the subject NP and is influenced by these relationships more than by the linear distance between the attractor noun and the agreeing verb.

Comparable results have been found in comprehension studies. For example, Pearlmutter (2000) found that agreement attraction in comprehension also appears to take syntactic structure into account. Using a self-paced moving window paradigm, speakers read sentences like *The lamps near the paintings of the house were…* and *The lamps near the painting of the houses were….* Participants had longer RTs at the verb when *paintings* was plural than when *houses* was plural. That is, just as in Frank et al.'s (2002) production study, the mismatched noun appeared to create more difficulty for the processor when it occurred in the PP immediately following the head noun compared to when it occurred inside the PP closer to the verb. This finding has been taken to indicate that in the comprehension of subject-verb agreement as well, the structural relationship between the head noun and the attractor noun is more important than the linear distance between the attractor noun and the verb.

Nicol et al. (1997) also showed effects along these lines. In particular, in a speeded grammaticality judgment experiment, the attachment site of an RC with a potential attractor noun was varied. In high attachment cases like (8a), the RC attached to the subject head noun (*owner*); whereas in low attachment cases as in (8b), it attached to a structurally lower noun in the PP modifier (*house*).

(8) a. The owner of the house who charmed the realtor(s) was no longer willing to sell.

b. The owner of the house which charmed the realtor(s) was no longer willing to sell.

The study found processing difficulty (in the form of longer judgment times) for sentences that had plural attractors (*realtors*) in the RCs that attached high, as in (8a). These results were taken to indicate that the agreement processor is sensitive to structural distance because readers had more difficulty judging sentences when the RC containing the attractor noun modified the subject head noun (*owner*). This places it structurally closer to head of the agreement controller. Taken together, these studies indicate that the agreement processor is sensitive to the structural relationships within the subject NP, and that these relationships seem to be considered over the linear distance between the attractor and the verb. Number mismarking models offer a straightforward explanation for these effects. As discussed above, these models hold that the processor incorrectly calculates the number of the subject NP due to interference from an attractor noun. Under such models, structural information is important as it can modulate the strength of the influence that the attractor noun can exert on the number specification for the subject.

However, there are several findings that number mismarking models have a more difficult time explaining. For example, these models do not provide a clear account for the grammaticality asymmetry found in comprehension studies. As detailed above, this asymmetry refers to findings indicating that attraction effects are revealed in the attenuation of processing difficulty for ungrammatical sentences, rather than in processing disruptions for grammatical sentences (Dillon et al., 2013; Kaan, 2002; Pearlmutter, 2000; Pearlmutter et al., 1999; Staub, 2009; Wagers et al., 2009; Xiang et al., 2013; but see Nicol et al., 1997; Pearlmutter, 2000). It is unclear however, what would prevent number mismarking from occurring on grammati-

cal sentences. Under these models, sentences such as (9) should trigger processing disruption when the plural attractor *cabinets* causes the subject noun complex to be mismarked.

(9) The key to the cabinets is on the table.

Memory retrieval models on the other hand, provide a straightforward account for this grammaticality asymmetry. In grammatical sentences, the head noun (*key*) matches in all relevant features while the attractor noun (*cabinets*) does not. Thus, when the verb (*is*) triggers a search for controlling nouns with matching features, the agreement match is made straightforwardly with the head of the subject NP.

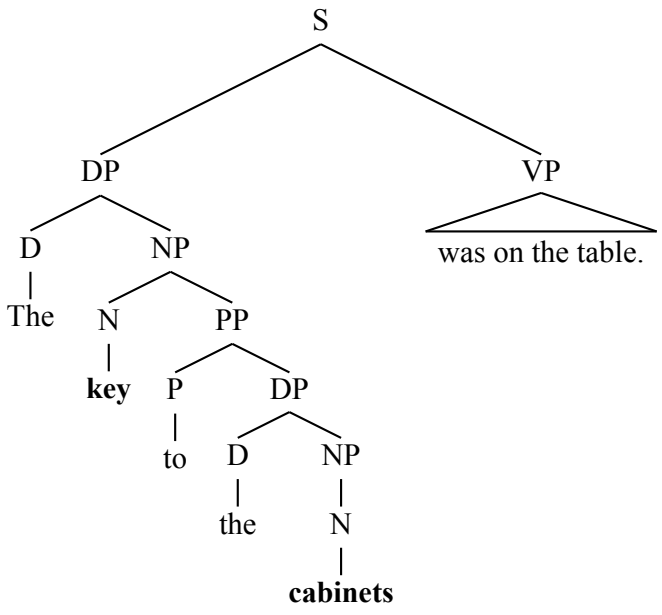
Number mismarking models also have a difficult time accounting for situations in which attraction effects occur when the head noun and the attractor noun have a weak structural relationship. One such situation is discussed by Wagers et al. (2009). One of the experiments in this study of agreement comprehension used self-paced reading to examine long-distance agreement attraction involving sentences in which the attractor noun does not intervene between the subject and the agreeing verb, such as (10).

(10) *The musicians that the reviewer praise so highly won a Grammy.

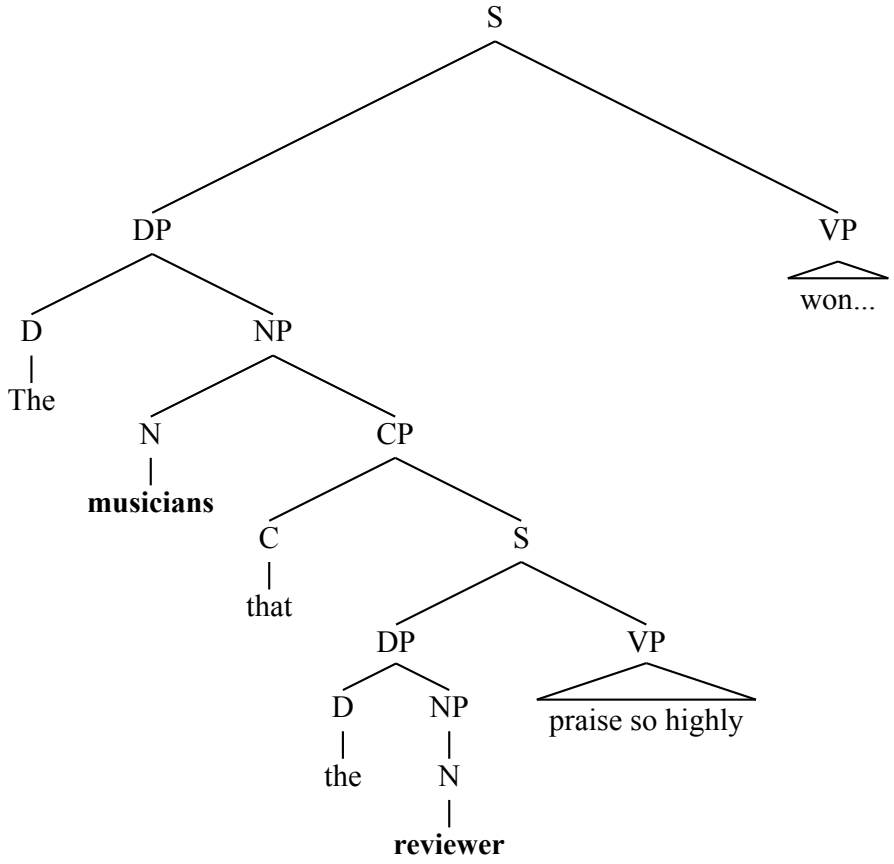
This sentence contains an RC subject (*reviewer*) that is mismatched with its verb (*praise*) in terms of its number feature. The attractor element (*musicians*) occurs in a non-intervening position, before both the subject and the verb. Wagers et al. (2009) found that participants

had inflated RTs at the RC verb when presented with sentences containing a singular attractor (**The musician that the reviewer praise*...). However, in sentences with plural attractors, such as (10), processing difficulty at the RC verb disappeared, in that participants had RTs comparable to grammatical sentences – i.e, they displayed an illusion of grammaticality. This finding is important because it provides evidence that agreement attraction can occur even when the attractor noun is not part of the subject NP that controls agreement. These results create a problem for number mismarking models because there is not an straightforward way to explain how the attractor noun (*musicians*) would be able to affect the number of the subject NP (*the reviewer*). Recall that in all previous examples the attractor noun was in an intervening position, but more importantly, it was part of the subject NP. This is not the case in (10) and this distinction is illustrated in (11) below.

(11) a.



b.



In (11a) the head noun (*key*) and the attractor noun (*cabinets*) are both within the larger subject NP. Namely, *key* is the head of the NP which is modified by a PP containing *cabinets*. This means *cabinets* is in a position to influence the larger noun complex via feature percolation as described by the feature percolation model or through a number calculation resulting in a semi-singular/semi-plural result as described by the marking and morphing model. The structure in (11b), however, does not follow the same pattern. In this case, the controlling subject *reviewer*, though it is located in the same NP as the attractor noun *musicians*, occurs lower than the attractor noun within the hierarchical structure; in fact, *reviewer* occurs inside the CP that modifies *musicians*. In order for feature percolation to occur, the plural feature from

musicians would have to move down the hierarchical structure onto the DP located inside the relative clause. However, this is not the traditional method by which feature percolation applies. Furthermore, the marking and morphing model would also face difficulty dealing with (11b). It would mark *musicians* as plural and leave *reviewer* unmarked during the marking stage. However, since *musicians* is not located inside the DP *the reviewer*, it has no clear influence on *reviewer* during the morphing stage.

Memory retrieval models, on the other hand, provide a much clearer explanation for long-distance agreement attraction effects. As stated above, these models hold that a search through memory is triggered by the verb, and that this search relies on the activation of possible controllers to find a controlling noun/NP that matches its agreement features. In (11b), the search through working memory is cued by *praise*, and the possible controlling nouns are *musicians* and *reviewer*. When considering possible controllers, the subject-verb agreement processor looks for a noun/NP that matches the agreement target in terms of number features (plural) and that has been encoded in a compatible structural position (subject). In (11b), both *musicians* and *reviewer* are encoded as subject head nouns, meaning that both possible controllers match the verb with respect to structural position. However, with respect to number, only the attractor noun (*musicians*) provides a match. Thus, the results of this search reveal that *musicians* matches the verb with respect to both features making it the best available match. While this approach straightforwardly accounts for the data in (11), it also predicts the attractor noun will be the optimal match in ungrammatical sentences with singular attractors as in (12). However, as discussed above, attraction effects clearly express an asymmetry, occurring only

in the presence of a plural attractor. Retrieval-based models correctly predict this asymmetry if one additional cue is considered in the search through working memory. Namely, retrieval processes search for possible controllers occurring within the same clause (Wagers, 2008; Wagers et al., 2009).

(12) *The musician that the reviewers praises so highly won the prestigious award.

With all three cues active during the search process, retrieval models correctly predict that sentences like (12) will not show attraction effects. The RC subject matches for both structural position and clause, while the attractor noun matches for structural position. With respect to number, recall that singular nouns are not given a number feature, so there is no feature available to match. Thus, the RC subject *reviewers* would be chosen as the best match despite the mismatch for number, resulting in processing difficulty for (12). Crucially, the addition of this clause matching cue still predicts attraction effects for sentences like (11b). The RC subject *reviewer* now matches the verb's clause but mismatches its number, while the attractor noun *musicians* now matches the verb's number but mismatches its clause. Since both nouns match/mismatch with respect to at least one feature, the number-matching attractor noun can be selected as the best match, resulting in an attenuation of processing difficulty during the comprehension of an ungrammatical sentence just as before. In this way, long-distance attraction effects are especially interesting because they can be accounted for straightforwardly under memory retrieval models, but they are difficult to account for under number mismarking

models. As such, long-distance cases provide an excellent context to examine the role memory retrieval plays in agreement processing.

With these issues in mind, Experiments 1-3 of this dissertation examine long-distance agreement attraction to determine whether these effects apply across verb agreement targets. Specifically, these experiments examine these effects when the verb agreement target is an inflected main verb (*praise-s/-∅*) as well as when it is a free auxiliary morpheme (*was/were*). If these effects reflect fundamental processes in the computation of agreement, it is predicted that they will be observed across different verbal agreement targets. The results of these experiments reveal evidence of agreement attraction both when the agreement target is an inflected main verb as well as when it is a free auxiliary morpheme, indicating that long-distance agreement attraction reflects core properties of agreement computation.

Another pertinent line of inquiry relates to the time course of long-distance attraction effects. Since long-distance attraction effects of this kind strongly favor the memory retrieval model, the time at which they apply can provide insight into the time course of memory retrieval processes. Currently, there is no clear evidence that delineates whether long-distance attraction effects influence early or late processing. To date, the work on long-distance agreement attraction has taken the form of self-paced reading, a method that is not capable of clearly indicating processing at different stages of comprehension. With respect to agreement attraction with intervening attractor nouns (e.g., *The key to the cabinets…*), however, both eye tracking and ERP studies have produced results related to the time course of this process, but this work has yielded somewhat conflicting results. Specifically, ERP work by Tanner et al. (2014) showed

that agreement attraction occurs as early as 150-300ms after the onset of the verb, which was taken to indicate that the processes that give rise to these effects are present at early stages of agreement processing. A different pattern of results was found in an eye-tracking study by Dillon and colleagues (2013) that compared attraction effects in subject-verb agreement to that of anaphora. In this study, early eye-tracking measures showed clear indications that readers recognized ungrammaticality related to subject-verb agreement even in ungrammatical sentences with plural attractors – that is, even in sentences that typically give rise to attraction effects. The attenuation of processing difficulty that characterizes agreement attraction was not seen until the total time measure, which is often taken to reflect late stages of processing. Because these studies seem to provide conflicting indications of the time at which attraction effects occur, further investigation into the time course of agreement processing would appear to be necessary.

Experiment 4 addresses this issue. Specifically, this experiment uses eye tracking to examine long-distance agreement attraction to determine if attraction effects occur early or late in processing. It is predicted that if agreement attraction influences early stages of agreement processing, there should be attraction effects in the form of attenuated processing difficulty in first-pass reading measures. However, if agreement attraction influences late stage processing, attraction effects should not occur until measures that tap into later reading comprehension processes, such as second-pass time (see Experiment 4 below, for more on these measures). The results of this experiment indicate that long-distance attraction effects influence the earliest stages of agreement processing, and this influence persists until the very latest stages of

processing, only disappearing after the final progressive fixation in the sentence. This result is especially interesting to find because it suggests that memory retrieval processes are involved at the earliest stages of agreement processing.

Finally, it is important to clarify the extent to which structural features inform agreement processing during comprehension. The research to date has provided somewhat conflicting evidence related to the influence of structural information on attraction effects. On the one hand, several studies on agreement attraction with intervening attractor nouns have shown that the structural relationships between the head noun and the attractor noun are important to the agreement processing system (Frank et al., 2002; Nicol et al., 1997; Pearlmutter, 2000). On the other hand, in their eye tracking study, Dillon et al. (2013) found intrusion effects for agreement attraction, as indicated by attenuated processing difficulty in ungrammatical sentences with plural attractors; however, they did not find comparable intrusion effects for reflexives. This result was taken to indicate that when searching for a possible controller, reflexives ignore structurally illicit nouns, but verb agreement targets do not. Similar to what was found by Dillon et al. (2013), long-distance attraction effects also appear to be relatively insensitive to structural properties of the sentence (Wagers et al. 2009). The final experiment in this dissertation, Experiment 5, will further examine the role of structure in agreement processing by determining whether the syntactic position of the attractor noun modulates its influence on agreement processing. Using eye tracking, the experiment will examine sentences in which the attractor noun is in either the subject position or object position. If the agreement processing system is sensitive to the syntactic position of the attractor noun, attraction effects should only

occur or should be significantly stronger when the attractor noun is in the subject position. If, however, the agreement processor is not sensitive to the syntactic position of the attractor noun, then attraction effects should occur with similar strength when the attractor noun is in the subject or object position. The results of Experiment 5 reveal evidence of agreement attraction in the presence of an attractor in the object position; furthermore, they show no evidence of agreement attraction in the presence of an attractor in the subject position. These results do not indicate whether the structural position of the attractor noun modulates agreement computation, but rather suggest that the agreement processor is sensitive to structural information on the attractor noun. Specifically, the agreement processor ignores an attractor noun's features if that noun has been encoded as the syntactic subject of a verb in a previous clause.

CHAPTER 3

Self-Paced Reading Experiments

3.1 Experiment 1

The goal of Experiment 1 was to replicate the long-distance agreement attraction study in Wagers et al. (2009). Items adapted from Wagers et al. (2009) Experiment 2 were tested. These items are shown in (13).

(13) a. Singular attractor / grammatical

The musician that the reviewer praises so highly won the prestigious award.

b. Singular attractor / ungrammatical

*The musician that the reviewer praise so highly won the prestigious award.

c. Plural attractor / grammatical

The musicians that the reviewer praises so highly won the prestigious award.

d. Plural attractor / ungrammatical

*The musicians that the reviewer praise so highly won the prestigious award.

As in Wagers et al., these items allowed for an examination of agreement attraction in long-distance contexts. Specifically, the sentences contained an object-extracted RC (ORC) construction that modified the main-clause subject (*musician(s)*). This main-clause subject/RC head acted as a potential attractor and, importantly, did not intervene between the RC subject

(*reviewer*) and its agreeing verb (*praise(s)*). The main-clause subject acted as the attractor and appeared both as singular, as in (13a) and (13b), and plural, as in (13c) and (13d). Because agreement attraction in comprehension occurs more robustly in ungrammatical sentences, the sentences were given grammatical and ungrammatical versions. In the grammatical sentences, such as (13a) and (13c), the RC verb was inflected for the third person singular (*praises*) in order to agree with the singular RC subject. In the ungrammatical sentences, such as (13b) and (13d), the RC verb was not inflected for the third person singular (*praise*), and thus did not agree with the singular RC subject.

Consistent with the findings from Wagers et al. (2009), it was predicted that ungrammatical sentences with singular attractors as in (13b) would show clear processing difficulty. This should be indicated by inflated RTs at and immediately after the RC verb. Attraction effects were predicted for ungrammatical sentences with plural attractors as in (13d). That is, RTs at and after the RC verb should not be significantly different from those of (13c), its grammatical counterpart.

3.1.1 Method

3.1.1.1 Participants

Forty graduate and undergraduate students at the University of Texas at Arlington participated in this experiment. All participants were native speakers of English.

3.1.1.2 Materials & Design

The experiment consisted of 48 experimental items adapted from Wagers et al. 2009. These items appeared in a 2x2 design with attractor number and grammaticality as factors. Each item appeared in four variations based on these factors; an example set is given in (13) (see Appendix A for a full list of experimental items). The experiment also included eight practice items and 72 fillers. Twenty-four of these fillers had the same RC structure as the experimental items, with plural RC subjects and correctly inflected verbs (e.g. *The criminal that the lawyers defend so strongly went to federal prison*). In the experimental items, there were 24 instances of plural RC verbs, but in every instance these verbs appeared in ungrammatical sentences. These fillers were created so that there would be an equal number of plural RC verbs in grammatical sentences in the experiment. The remaining fillers were grammatical sentences that had various structures and agreement targets (e.g. *The captain of the ship introduced himself to the king*). The combination of experimental items with these filler items meant that 20% of the items were ungrammatical. All of the experimental items and 54/72 filler items were followed by a YES/NO comprehension questions (e.g. *Did the captain of the ship introduce himself to the queen?*). These questions contained an equal number of YES and NO answers.

3.1.1.3 Procedure

The materials were divided into four lists in a Latin square design, and 10 participants were assigned to each list. The lists were administered to the participants in a self-paced,

moving-window reading task (Just, Carpenter & Wooley, 1982) on desktop PCs using DMDX (Forster & Forster, 2003), in the Psycholinguistics Lab at the University of Texas-Arlington. Experimental and filler items were randomized for each participant and presented in sets of 12, with a short break after each set. Participants were shown a sentence in which the words were masked by dashes. They were then asked to read through the sentence word by word. In order to read the sentence, the participants used a game controller with buttons designated R (right) and L (left). The participants pushed the button designated R to proceed through the sentence word by word. They were asked to read the sentence as quickly as possible without compromising comprehension. The participants clicked R for "yes" and L for "no" to answer the end-of-sentence comprehension questions.

3.1.2 Results

Each participant had an error rate of 20% or less on comprehension questions (M = 12.76%; SD = 5.26). RTs were recorded for each word of the sentence for analysis. Only sentences with correct responses to the comprehension questions were included in the analysis. RTs longer than 2000 ms were discarded, and outlier data points for each region were adjusted to two SD units above and below each participant's the mean for that region. These trimming procedures affected 4.66% of the data. The regions of interest were the RC verb (V) and the three words that immediately followed this verb (V+1, V+2, V+3). These regions are shown in (14).

(14) *The musicians that the reviewer | praise | so | highly | won | the prestigious award.
V V+1 V+2 V+3

In the statistical analyses of the RTs for each region, both subjects and items were treated as random factors. These by-subjects ($F1$) and by-items ($F2$) analyses consisted of 2x2x4 ANOVAs, with attractor number (singular, plural) and grammaticality (grammatical, ungrammatical) as repeated measures, and list/item group as a non-repeated factor. These analyses were followed up with tests of the simple effects of (i) grammaticality (grammatical vs. ungrammatical) in both singular- and plural-attractor sentences and (ii) attractor number (singular vs. plural) in both grammatical and ungrammatical sentences. The mean RTs for the regions of interest are shown in Table 3.1, and these results are graphed in Figure 3.1.

Table 3.1. Mean reading times (in ms) by condition and region (with standard errors of the mean by subjects for repeated measures in parentheses (Cousineau, 2005)), Experiment 1

	V (praise(s))	V+1 (so)	V+2 (highly)	V+3 (won)
Sing/Gram	337 (7)	340 (5)	330 (4)	326 (5)
Sing/Ungram	348 (6)	345 (7)	340 (4)	345 (5)
Plural/Gram	336 (6)	342 (8)	341 (6)	341 (5)
Plural/Ungram	351 (6)	339 (6)	337 (5)	344 (4)

At the RC verb (V), there was a marginal effect of grammaticality ($F1(1, 36) = 3.58$, $p = .07$; $F2(1, 44) = 4.15$, $p < .05$), suggesting longer RTs for ungrammatical sentences (attractor number, attractor x grammaticality: all F's < 1). Planned comparisons indicated that this effect approached significance only for sentences with plural attractors ($F1(1, 36) = 2.86$, $p = .10$; $F2(1, 44) = 3.56$, $p = .07$; singular-attractor sentences: both F's < 1.5). There were no statistically reliable results for regions V+1 and V+2 (all F's < 1.5). At region V+3, there was a marginal main effect of grammaticality ($F1(1, 36) = 3.99$, $p = .053$; $F2(1, 44) = 1.89$, $p = .17$;

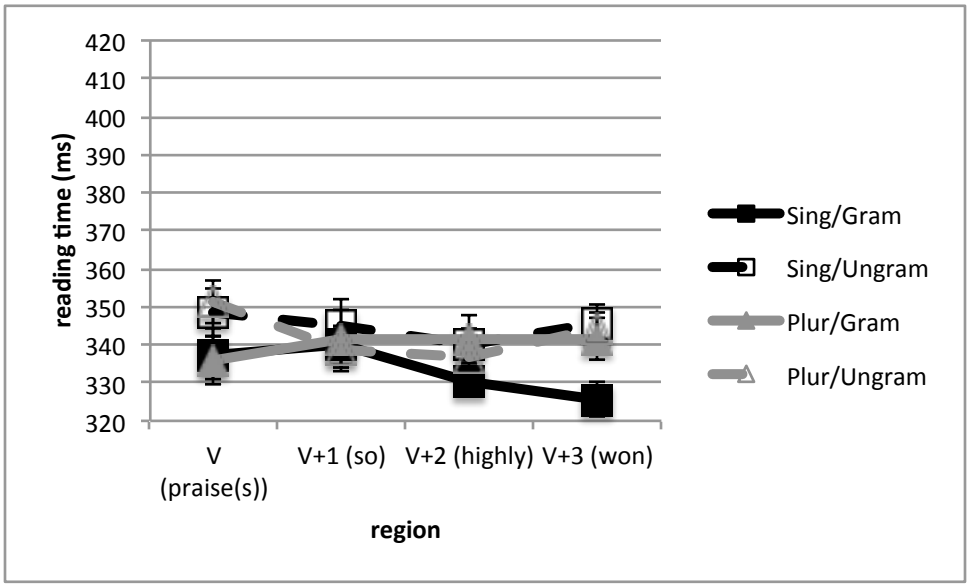


Figure 3.1. Mean reading times (by subjects) for grammatical and ungrammatical sentences with singular and plural attractor variants, Experiment 1. Error bars show ±1 standard error of the mean for repeated measures.

attractor number: both F's < 1.25) and a marginal interaction of grammaticality and attractor number ($F1(1, 36) = 3.18$, $p = .08$; $F2(1, 44) = 1.73$, $p = .20$). Planned comparisons revealed a trend toward longer RTs for ungrammatical sentences only for singular-attractor sentences ($F1(1, 36) = 6.72$, $p < .05$, $F2(1, 44) = 3.06$, $p = .09$; plural-attractor sentences: both F's < 1).

3.1.3 Discussion

Experiment 1 revealed a pattern of results indicating an attenuation of processing difficulty for ungrammatical plural-attractor sentences. However, this attenuation did not occur until after the agreeing verb, at region V+3. More specifically, the results at the agreeing verb (region V) suggest that readers recognized ungrammaticality for sentences with both singular and plural attractors, and that this recognition was strongest in sentences with plural attractors.

However, this pattern was not maintained throughout the subsequent regions. While regions V+1 and V+2 did not show reliable effects, region V+3 indicated an attenuation of processing difficulty for plural-attractor sentences. This was suggested first by the marginal interaction of attractor number and grammaticality, and second by an effect of ungrammaticality that approached significance in the planned comparisons only for singular-attractor sentences.

While these results are consistent with long-distance agreement attraction, it is important to note that the effects do not demonstrate the illusion of grammaticality found in Wagers et al. (2009). A pattern of results consistent with an illusion of grammaticality would show singular-attractor ungrammatical sentences, such as (13b), to have significantly longer RTs than all other sentence types. Experiment 1 clearly does not demonstrate this pattern of results (see Figure 3.1). Furthermore, at the agreeing verb, there were indications that readers recognized ungrammaticality for all ungrammatical sentences and it was only in region V+3 that ungrammatical sentences with plural attractors showed an attenuation of processing difficulty. This pattern of results suggests that ungrammatical sentences with plural attractors were not read as though they were grammatical. Rather, it might be taken to indicate that ungrammaticality was recognized across the board, but that the presence of the plural attractor eased the processing costs associated with this recognition.

Another note about the effects in this experiment is that they are not particularly robust. Thus, although the data appear to indicate that processing difficulty occurred for ungrammatical sentences and was attenuated in the presence of a plural attractor, the relatively weak and inconsistent results do not allow for firm conclusions to be drawn. One explanation for the lack

of robust effects could relate to the type of morphological marking on the verb. In English, the present tense is marked on the (third-person) singular with the affix *-s*, while the plural is "marked" by the lack of an overt inflectional morpheme, or by a null morpheme. The fact that the overt marking occurs on the singular verb rather than on the plural verb contrasts with nominal morphology. In nominal morphology, plurality is marked with overt plural marking (*-s*) but there is no marking for singular forms. As such, the plural is considered to be more complex than the singular, making it more difficult to process. The lack of overt morphology on the plural verbs in this experiment could mean that these verbs provided a relatively weak cue to search for the relevant agreement controller, resulting in less robust results. Although this certainly seems possible, it is important to note that Wagers et al. (2009) were able to provide clear indications of ungrammaticality using these same simple present verbs as agreement targets.

With respect to this issue of number marking on the verb, it is interesting to note that most other studies examining the phenomenon of agreement attraction – i.e., essentially all of the studies reviewed above – have used variations of the stative *be*, such as *is/are* or *was/were* as agreement targets. These verb forms of course distinguish between singular and plural via suppletion, meaning that there is overt marking for both the singular and plural forms. In order to provide stronger evidence for long-distance agreement attraction the following experiments use *was/were* as the agreeing morpheme, following the pattern traditionally used in the literature.

3.2 Experiment 2

The results of Experiment 1 were consistent with long-distance agreement attraction; however, these results were not as strong or consistent as those reported in Wagers et al. (2009). One explanation for this could be that the comparison of *-s* to the null plural marker in the verb agreement targets did not provide a sufficiently salient target for agreement processing. The purpose of Experiment 2 was to determine whether using a free agreeing morpheme, *was/were*, would give rise to stronger long-distance attraction effects. This also allowed for a test of the "generality" of long-distance agreement attraction effects. That is, to the extent that these effects reflect fundamental processes in the computation of agreement, they should be observed across different verb agreement targets. To test this, the items from Experiment 1 were changed so that the simple present RC verb (*praise(s)*) was past progressive (*was/were praising*) as in (15).

(15) a. Singular attractor / grammatical

The musician that the reviewer was praising so highly won the prestigious award.

b. Singular attractor / ungrammatical

*The musician that the reviewer were praising so highly won the prestigious award.

c. Plural attractor / grammatical

The musicians that the reviewer was praising so highly won the prestigious award.

d. Plural attractor / ungrammatical

*The musicians that the reviewer were praising so highly won the prestigious award.

The singular form (*was*) was used for grammatical sentences, as in (15a) and (15c), while the plural form (*were*) was used for ungrammatical sentences, as in (15b) and (15d). This changed the verb agreement target in two ways. First, the agreement target was a free morpheme, rather than a bound suffix; and second, the plural agreement feature was marked overtly rather than by a null morpheme. Just as in Experiment 1, the attractor number was manipulated via the main clause subject *musician*, as in (15a) and (15b), and *musicians*, as in (15c) and (15d).

As in Experiment 1, ungrammatical sentences with singular attractors, as in (15b), were expected to show processing difficulty, as indicated by inflated RTs at and/or immediately after the RC verb. Ungrammatical sentences with plural attractors, as in (15d), were expected to show long-distance attraction effects, as indicated by patterns of results similar to their grammatical counterparts.

3.2.1 Method

3.2.1.1 Participants

Forty graduate and undergraduate students at the University of Texas at Arlington participated in this study. All participants were native speakers of English.

3.2.1.2 Materials & Design

The experiment consisted of 48 experimental items similar to those in Experiment 1. However, as discussed above, in this case the relevant agreement target – the RC verb – took the form of the past progressive, using *was* or *were* as the agreeing verb. These items appeared in a 2x2 design with attractor number and grammaticality as factors. Each item appeared in four variations based on these factors; an example set is given in (15) (see Appendix B for a full list of experimental items). The experiment also included 8 practice items and 72 fillers. Twenty-four of these fillers had the same RC structure as the experimental items, with plural RC subjects and correctly inflected verbs (e.g. *The criminal that the lawyers were defending so strongly went to federal prison.*). In the experimental items, there were 24 instances of plural RC verbs, but in every instance these verbs appeared in ungrammatical sentences. These fillers were created so that there would be an equal number of plural RC verbs in grammatical sentences in the experiment. The remaining fillers were grammatical sentences that had various structures and agreement targets (e.g. *The captain of the ship introduced himself to the king*). The combination of experimental items with these filler items meant that 20% of the items were ungrammatical. All of the experimental items and 54/72 filler items were followed by a YES/NO comprehension questions (e.g. *Did the captain of the ship introduce himself to the queen?*). These questions contained an equal number of YES and NO answers.

3.2.1.3 Procedure

The procedure was the same as in Experiment 1.

3.2.2 Results

Each participant had an error rate of 20% or less on comprehension questions (M = 11.47%; SD = 3.61). RTs were recorded for each word of the sentence for analysis. Only sentences with correct responses to the comprehension questions were included in the analysis. RTs longer than 2000 ms were discarded, and outlier data points for each region were adjusted to two SD units above and below each participant's the mean for that region. These trimming procedures affected 5.29% of the data. The regions of interest were the agreeing verb (AV) and the three words that immediately followed this verb (V, V+1, V+2). These regions are shown in (16).

(16) *The musicians that the reviewer | were | praising | so | highly won the…
AV V V+1 V+2

As in Experiment 1, both subjects and items were treated as random factors in the statistical analyses of the RTs for each region. These by-subjects ($F1$) and by-items ($F2$) analyses consisted of 2x2x4 ANOVAs, with attractor number (singular, plural) and grammaticality (grammatical, ungrammatical) as repeated measures, and list/item group as a non-repeated factor. These analyses were followed up with tests of the simple effects of (i) grammaticality (grammatical vs. ungrammatical) in both singular- and plural-attractor sentences and (ii) attractor number (singular vs. plural) in both grammatical and ungrammatical sentences. The mean RTs for the regions of interest are shown in Table 3.2, and these results are graphed in Figure 3.2.

There was a significant effect of grammaticality at the agreeing verb (AV) ($F1(1, 36) = 4.30$, $p < .05$; $F2(1, 44) = 10.62$, $p < .01$), with longer RTs for ungrammatical sentences

Table 3.2. Mean reading times (in ms) by condition and region (with standard errors of the mean by subjects for repeated measures in parentheses), Experiment 2

	AV (was/were)	V (praising)	V+1 (so)	V+2 (highly)
Sing/Gram	355 (7)	379 (8)	395 (7)	376 (6)
Sing/Ungram	383 (8)	432 (10)	410 (6)	383 (6)
Plural/Gram	366 (6)	358 (8)	377 (6)	357 (6)
Plural/Ungram	377 (8)	410 (9)	409 (7)	367 (6)

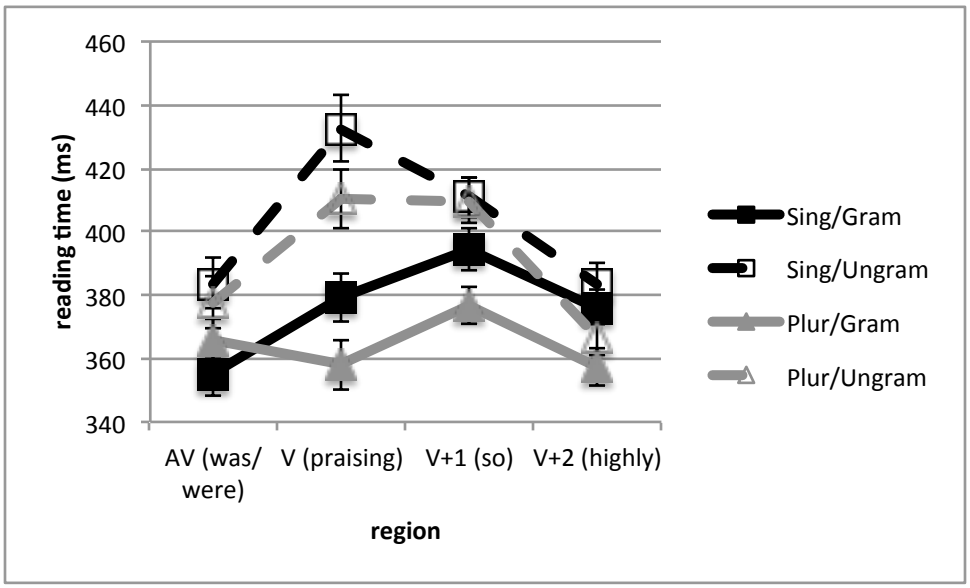


Figure 3.2. Mean reading times (by subjects) for grammatical and ungrammatical sentences with singular and plural attractor variants, Experiment 2. Error bars show ±1 standard error of the mean for repeated measures.

(attractor number, attractor x grammaticality: all F's < 1.5). Planned comparisons showed that this effect was significant only for sentences with singular attractors ($F1(1, 36) = 5.12$, $p < .05$; $F2(1, 44) = 8.28$, $p < .01$; plural-attractor sentences: both F's < 2). The immediately following region of the content verb (V) showed main effects for attractor number and grammaticality. The effect of attractor number indicated that there were longer RTs for sentences with singular attractors ($F1(1, 36) = 5.22$, $p < .05$; $F2(1, 44) = 6.03$, $p < .05$), while the effect

of grammaticality showed longer RTs for ungrammatical sentences ($F1(1, 36) = 17.96$, $p < .001$; $F2(1, 44) = 19.86$, $p < .001$; attractor x grammaticality: both F's < 1). Moreover, the planned comparisons showed that both singular-attractor and plural-attractor ungrammatical sentences had significantly longer RTs than their grammatical counterparts (singular-attractor sentences: $F1(1, 36) = 11.04$, $p < .01$; $F2(1, 44) = 13.46$, $p < .001$; plural-attractor sentences: $F1(1, 36) = 12.79$, $p < .01$; $F2(1, 44) = 12.41$, $p < .01$). In region V+1, there was again a main effect of grammaticality, with longer RTs for ungrammatical sentences ($F1(1, 36) = 10.75$, $p < .01$; $F2(1, 44) = 8.34$, $p < .01$; attractor number, attractor x grammaticality: all F's < 2). In this case, however, planned comparisons showed that this grammaticality effect was reliable only for sentences with plural attractors ($F1(1, 36) = 8.41$, $p < .01$; $F2(1, 44) = 6.81$, $p < .05$; singular-attractor sentences: $F1(1, 36) = 2.23$; $F2(1, 44) = 1.43$). Region V+2 showed only a main effect of attractor number ($F1(1, 36) = 7.12$, $p < .05$; $F2(1, 44) = 8.42$, $p < .01$), with longer RTs for singular-attractor sentences (grammaticality, attractor x grammaticality: all F's < 1.5). Planned comparisons of the effect of grammaticality for singular attractor and plural-attractor sentences revealed no statistically reliable results (singular- and plural-attractor sentences: all F's < 1.5).

3.2.3 Discussion

The pattern of results in Experiment 2 showed an indication of agreement attraction effects at the agreeing verb, but interestingly these effects seemed to disappear by the immediately following content verb. At the agreeing verb (region AV), sentences with plural attractors showed attenuated processing difficulty, in that the effect of grammaticality was reliable only

for singular-attractor sentences under planned comparisons. Similar to Experiment 1, this result showed an attenuation of processing difficulty for ungrammatical plural-attractor sentences, but it still differs from the illusion of grammaticality found by Wagers et al. (2009). The initial indications of agreement attraction effects seemed to disappear in subsequent regions. Indeed, regions V and V+1 both revealed main effects of grammaticality, and this effect was reliable in sentences with both singular and plural attractors.

While Experiments 1 and 2 both indicate an attenuation of processing difficulty for ungrammatical plural-attractor sentences, they differ in both the strength and timing of the observed attraction effects. Experiment 1 revealed weak agreement attraction effects that occurred well after the agreeing verb, at region V+3. Experiment 2 revealed indications of agreement attraction at the agreeing verb itself, but these effects dissipated rather quickly, with only evidence of processing difficulty in the following regions. One explanation for the pattern of results in Experiment 2 is that the RTs after the agreeing verb might have been influenced by the markedness of plurality on the verb morphemes. Recall that in this experiment, grammaticality was manipulated via the RC verb – *was* for grammatical sentences and *were* for ungrammatical sentences. The more complex plural verb morpheme could have caused an additional processing cost on top of ungrammaticality, meaning that the difference in RTs between grammatical and ungrammatical sentences might have been due to both ungrammaticality and plurality. In order to separate these two variables, Experiment 3 held the form of the verb agreement target constant as *were*, thus controlling for costs related to plural marking on the verb and testing only for processing difficulties related to ungrammaticality.

3.3 Experiment 3

Experiment 2 found initial indications of attraction effects at the agreeing verb, but these effects disappeared in the following two regions. This pattern of results might be due to the fact that the ungrammatical sentences in Experiment 2 had a plural agreeing verb (*were*) while the grammatical sentences contained a singular agreeing verb (*was*). In order to control for plurality effects at the agreeing verb, Experiment 3 used *were* as the RC verb in both the grammatical and ungrammatical conditions. This was done to examine agreement attraction in a context where the agreeing verb was held constant. Sentences as in (17) were tested:

(17) a. Singular attractor / grammatical

The musician that the reviewers were praising so highly won the prestigious award.

b. Singular attractor / ungrammatical

*The musician that the reviewer were praising so highly won the prestigious award.

c. Plural attractor / grammatical

The musicians that the reviewers were praising so highly won the prestigious award.

d. Plural attractor / ungrammatical

*The musicians that the reviewer were praising so highly won the prestigious award.

In these sentences, grammaticality was manipulated via the RC subject. Specifically, grammatical sentences had plural RC subjects (*reviewers*), as in (17a) and (17c), and ungrammatical sentences had singular RC subjects (*reviewer*), as in (17b) and (17d). As before, the main clause subject functioned as the attractor element and appeared in both singular, as in (17a) and (17b), and plural, as in (17c) and (17d). As in Experiments 1 and 2, ungrammatical sentences with singular attractors were expected to show clear processing difficulty in the form of inflated RTs at and after the RC verb. Ungrammatical sentences with plural attractors were expected to show long-distance attraction effects, as indicated by patterns of results similar to their grammatical counterparts.

3.3.1 Methods

3.3.1.1 Participants

Forty graduate and undergraduate students at the University of Texas at Arlington participated in this study. All participants were native speakers of English.

3.3.1.2 Materials & Design

The experiment consisted of 48 experimental items similar to those in Experiment 2. However, the items differed in that grammaticality was not manipulated via the RC verb. Rather, the RC verb was held constant as *were*, and grammaticality was manipulated by changing the number of the RC subject – singular for ungrammatical sentences and plural for grammatical sentences – as shown in (17a) and (17b). These items appeared in a 2x2 design with

attractor number and grammaticality as factors. Each item appeared in four variations based on these factors; an example set is given in (17) (see Appendix C for a full list of experimental items). The experiment also included 8 practice items and 72 fillers. 24 of these fillers had the same RC structure as the experimental items, with singular RC subjects and correctly inflected verbs (e.g. *The criminal that the lawyer was defending so strongly went to federal prison.*) In the experimental items, there were no instances of singular RC verbs. These fillers were created in order that the subjects see both singular and plural agreement targets at this verb. The remaining fillers were grammatical sentences that had various structures and agreement targets (e.g. *The captain of the ship introduced himself to the king*). The combination of experimental items with these filler items meant that 20% of the items were ungrammatical. All of the experimental items and 54/72 filler items were followed by a YES/NO comprehension questions (e.g. *Did the captain of the ship introduce himself to the queen?*). These questions contained an equal number of YES and NO answers.

3.3.1.3 Procedure

The procedure was the same as in Experiments 1 and 2.

3.3.2 Results

Each participant had an error rate of 20% or less on comprehension questions (M = 11.22%; SD = 4.38). RTs were recorded for each word of the sentence for analysis. Only sentences with correct responses to the comprehension questions were included in the analysis. RTs longer than 2000 ms were discarded, and outlier data points for each region were adjusted

to two SD units above and below each participant's the mean for that region. These trimming procedures affected 5.01% of the data. The regions of interest were the agreeing verb (AV) and the three words that immediately followed this verb (V, V+1, V+2). These regions are shown in (18).

(18) *The musicians that the reviewer | were | praising | so | highly | won the…
AV V V+1 V+2

As in the previous experiments, both subjects and items were treated as random factors in the statistical analyses of the RTs for each region. These by-subjects ($F1$) and by-items ($F2$) analyses consisted of 2x2 ANOVAs, with attractor number (singular, plural) and grammaticality (grammatical, ungrammatical) as repeated measures, and list/item group as a non-repeated factor. These analyses were followed up with tests of the simple effects of (i) grammaticality (grammatical vs. ungrammatical) in both singular- and plural-attractor sentences and (ii) attractor number (singular vs. plural) in both grammatical and ungrammatical sentences. The mean RTs for the regions of interest are shown in Table 3.3, and these results are graphed in Figure 3.3.

Table 3.3. Mean reading times (in ms) by condition and region (with standard errors of the mean by subjects for repeated measures in parentheses), Experiment 3

	AV (were)	V (praising)	V+1 (so)	V+2 (highly)
Sing/Gram	344 (5)	350 (5)	346 (4)	342 (6)
Sing/Ungram	343 (8)	387 (8)	373 (7)	363 (6)
Plural/Gram	343 (4)	364 (7)	356 (6)	355 (5)
Plural/Ungram	337 (5)	368 (5)	367 (6)	352 (6)

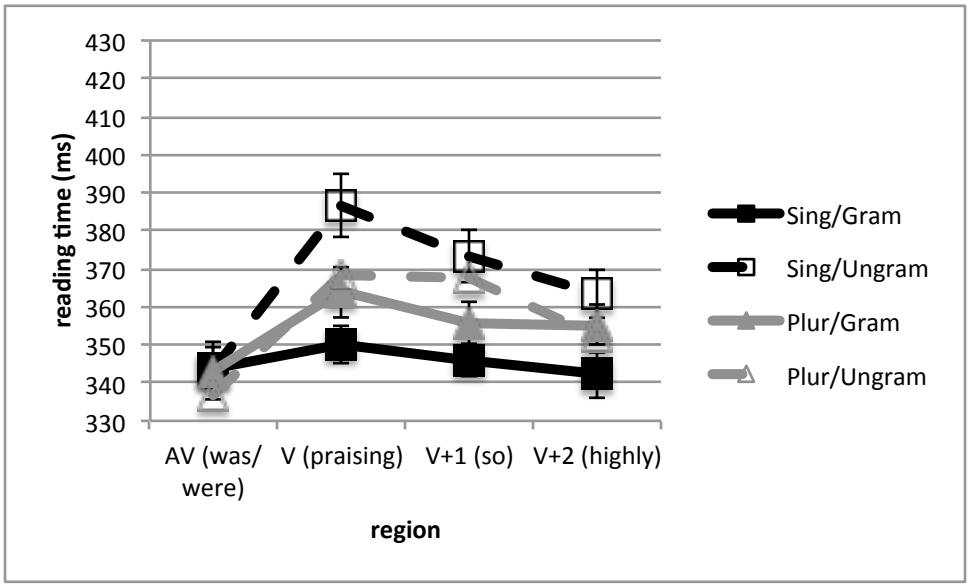


Figure 3.3. Mean reading times (by subjects) for grammatical and ungrammatical sentences with singular and plural attractor variants, Experiment 3. Error bars show ±1 standard error of the mean for repeated measures.

There were no statistically reliable results at the agreeing verb (AV) (all F's < 1). At region V, however, a main effect of grammaticality was observed, with longer RTs for ungrammatical sentences ($F1(1, 36) = 7.25$, $p < .05$; $F2(1, 44) = 10.57$, $p < .01$). Region V also revealed a marginal interaction effect of attractor number and grammaticality ($F1(1, 36) = 4.20$, $p < .05$; $F2(1, 44) = 2.71$, $p = .11$; attractor number: both F's < 1). Planned comparisons of grammaticality showed a significant effect only for singular-attractor sentences ($F1(1, 36) = 9.35$, $p < .01$; $F2(1, 44) = 10.48$, $p < .01$; plural-attractor sentences: F's < 1). Region V+1 also revealed a significant main effect of grammaticality, with longer RTs for ungrammatical sentences ($F1(1, 36) = 9.55$. $p < .01$; $F2(1, 44) = 12.36$, $p < .01$; attractor number, attractor x grammaticality: all F's < 1.5). Planned comparisons again showed a significant effect of grammaticality only for singular-attractor sentences ($F1(1, 36) = 8.00$, $p < .01$; $F2(1, 44) = 9.10$,

$p < .01$; plural-attractor sentences: $F1(1, 36) = 1.51$; $F2(1, 44) = 1.55$). At region V+2 there was a marginal interaction effect of attractor number and grammaticality ($F1(1, 36) = 3.28$, $p = .08$; $F2(1, 44) = 4.09$, $p < .05$; attractor number, grammaticality: all F's < 2.5). Planned comparisons of grammaticality in this region were again significant only for singular-attractor sentences ($F1(1, 36) = 4.19$, $p < .05$; $F2(1, 44) = 6.86$, $p < .01$; plural-attractor sentences: both F's < 1).

3.3.3 Discussion

Consistent with the previous experiments, the results of Experiment 3 revealed evidence of long-distance agreement attraction effects. This was shown by the fact that, at regions V, V+1 and V+2, tests of the simple effect of grammaticality revealed effects only for ungrammatical sentences with singular attractors, indicating attenuated processing difficulty for ungrammatical sentences with plural attractors. Thus, all three experiments revealed attenuated processing difficulty for ungrammatical sentences with plural attractors, but Experiment 3 provided stronger and more sustained indications of these attraction effects than Experiments 1 and 2. In the present experiment, an attenuation of processing difficulty was seen at *praising* and the following two regions. This particularly contrasts with Experiment 2, which found attenuated processing difficulty for ungrammatical sentences with plural attractors at the agreeing verb *were*, but clear indications of processing difficulty in subsequent regions. It was suggested that the pattern of results in Experiment 2 could be due to plurality effects between the agreeing verbs *was* and *were*, which were used in grammatical and ungrammatical sentences,

respectively. The results of Experiment 3 appear to indicate that holding the verb form constant provides a clearer test of long-distance agreement attraction effects.

Consistent with Wagers et al. (2009), the results of Experiments 1-3 show that cases of non-intervening attractor nouns elicit attraction effects in the form of attenuated processing difficulty for ungrammatical sentences with plural attractors. Furthermore, these experiments show that long-distance agreement attraction occurs when triggered by bound and free verb agreement targets. Experiment 1 showed a partial replication of Wagers et al. (2009), providing further evidence that agreement attraction effects occur in sentences which contain a verb agreement target that lacks overt inflectional morphology such as *praise* in (19).

(19) *The musicians that the reviewer praise so highly won the prestigious award.

Experiments 2 and 3 showed that processing attenuation is maintained when *was/were* is used as the verb agreement target. These results are important because the presence of long-distance agreement attraction effects across different verb targets provides additional evidence that these effects reflect core properties of agreement processing, further suggesting that retrieval processes play a crucial role in agreement computation.

While the results of these three experiments appear to align in that they all revealed attenuated processing difficulty for ungrammatical sentences with plural attractors, this attenuation was seen in different regions with different strengths. While these results clearly show that plural attractors interfere with agreement processing in long-distance cases, they do not provide a clear indication of the timing of this interference. Understanding when long-distance

attraction effects influence agreement processing is important because it has implications for the role that retrieval processes play in agreement computation. Specifically, it sheds light onto whether retrieval processes are active during early agreement processing or late agreement processing, after ungrammaticality has been indexed. Experiment 4 addresses this time course issue by using eye tracking to examine the stage of processing at which long-distance agreement attraction effects occur.

CHAPTER 4

Experiment 4.

As discussed in Chapter 3, Experiments 1-3 indicated an attenuation of agreement processing difficulty for ungrammatical sentences with plural attractors, even when these attractors precede and are not part of the controlling subject. It is important to note, however, that these experiments did not reveal a clear illusion of grammaticality, as in Wagers et al. (2009). Recall that the illusion of grammaticality refers to a pattern of results in which ungrammatical sentences with singular attractors, but not ungrammatical sentences with plural attractors, have inflated RTs consistent with the indexation of ungrammaticality. In contrast to this pattern, Experiments 1-3 indicated processing difficulty for ungrammatical sentences generally, but that this processing difficulty was attenuated in sentences with plural attractors. The differing timing and strength of agreement attraction in Experiments 1-3, as well as in Wagers et al. (2009), thus do not provide a clear picture of when long-distance attraction effects exert their influence on agreement processing. For instance, the illusion of grammaticality shown by Wagers et al. (2009) might lead one to conclude that retrieval processes are active during early agreement processing because there was no indication that ungrammaticality was indexed for sentences with plural attractors. However, the pattern of results shown in Experiments 1-3 might suggest that retrieval processes are active relatively late in agreement processing because they showed indications of processing difficulty for ungrammatical sentences with plural attractors. This

difficulty was just found to be attenuated relative to that which was shown for ungrammatical sentences with singular attractors.

In light of these somewhat conflicting findings and in order to gain a clearer understanding of retrieval-based processes in agreement computation, it is therefore necessary to put a finer point on precisely when long-distance attraction effects influence online sentence comprehension. Unfortunately, self-paced reading is not the best online reading task for such an investigation because it relies on a single processing time measure – the length of time between button presses when advancing through the words/regions of a sentence. Eye tracking, however, allows for the calculation of reading measures related to eye movements in normal reading, arguably making it more sensitive to incremental processing difficulty than self-paced reading (Rayner, 1998; Rayner et al., 1989; Witzel et al., 2012). Eye tracking then can indicate the time course of agreement computation through a comparison of reading times under first-pass measures, which are generally taken to indicate early sentence processing effects, and second-pass measures, which are often taken to reflect later comprehension processes. In this experiment, early sentence processing effects were associated with the following first-pass measures: first-pass time, regression-path duration, and first-pass regression proportion (see 4.1 *Method* for definitions of reading measures). Second-pass time (as well as two other measures derived from this measure; see the Discussion section) provided indications of later stages of sentence comprehension.

The items for this experiment are identical to those of Experiment 3 and are shown again in (20).

(20) a. Singular attractor / grammatical

The musician that the reviewers were praising so highly won the prestigious award.

b. Singular attractor / ungrammatical

*The musician that the reviewer were praising so highly won the prestigious award.

c. Plural attractor / grammatical

The musicians that the reviewers were praising so highly won the prestigious award.

d. Plural attractor / ungrammatical

*The musicians that the reviewer were praising so highly won the prestigious award.

Ungrammatical sentences with singular attractors were predicted to show clear processing costs under all measures, as indicated by inflated reading times and a greater incidence of regressive eye movements at and after the RC verb. If agreement attraction influences early-stage agreement computation, it was predicted that ungrammatical sentences with plural attractors would show agreement attraction effects under first-pass measures, as indicated by patterns of results similar to their grammatical counterparts. This would then be followed by the late recognition of ungrammaticality, as indicated by processing difficulty under second-pass time. However, if agreement attraction influences late-stage agreement computation, it was predicted that ungrammatical sentences with plural attractors would show an initial recognition of ungram-

maticality, with inflated reading times and a greater incidence of regressive eye movements in first-pass measures followed by the attenuation of these effects in second-pass time.

4.1 Method

4.1.1 Participants

Thirty-two (graduate and undergraduate) students at the University of Texas at Arlington participated in this study. All participants were native speakers of English.

4.1.2 Materials & Design

The same materials in Experiment 3 were used in this experiment. These items appeared in a 2x2 design with attractor number and grammaticality as factors. Each item appeared in four variations based on these factors; an example set is given in (20) (see Appendix C for a complete list of experimental items). The experiment also included 12 practice items and 72 fillers. Twenty-four of these fillers had the same RC structure as the experimental items, with singular RC subjects and correctly inflected verbs (e.g. *The criminal that the lawyer was defending so strongly went to federal prison.*). In the experimental items, there were no instances of singular RC verbs. These fillers were created in order that the subjects see both singular and plural agreement targets at the RC verb. The remaining fillers were grammatical sentences that had various structures and agreement targets (e.g. *The captain of the ship introduced himself to the king*). The combination of experimental items with these filler items meant that 20% of the items were ungrammatical. All of the experimental items and 54/72 filler items were

followed by a YES/NO comprehension questions (e.g. *Did the captain of the ship introduce himself to the queen?*). These questions contained an equal number of YES and NO answers.

4.1.3 Procedure

The materials were divided into four lists in a Latin square design and 8 participants were assigned to each list. The items were administered to the participants as complete sentences on one line of text (with standard punctuation and capitalization) in 14-point Courier font on a 19-inch CRT monitor in the Eye-tracking Lab at the University of Texas at Arlington. The screen was located approximately 60 cm from subjects' eyes, and a chin rest was used to minimize head movements. The participants were asked to read the sentence as fast as they could without compromising comprehension. Eye movements were recorded with an EyeLink 1000 (SR Research) eye tracker, which monitored the movement of the right eye (though viewing was binocular) at a sampling rate of 1000 Hz.

At the beginning of each trial, a calibration dot appeared on the left side of the screen. The participants were instructed to look at this dot to ensure that the eye tracker was correctly calibrated. The participants were given a gamepad in order to progress from the sentence to the comprehension question. The sentence was then displayed and the participants read the sentence silently and pressed a button on the gamepad when finished. There was 10-second timeout for each sentence. After the participant finished reading the sentence, it disappeared from the screen, and a YES/NO comprehension question was displayed. The participants were told to press GREEN for "yes" and RED for "no" to answer the comprehension questions. The task began with 12 practice items. Experimental and filler items were randomized for each

participant and presented in sets of 12, with a short break after each set. The eye tracker was calibrated before each set and then recalibrated as necessary.

4.2 Results

Each participant had an error rate of 20% or less on comprehension questions (M = 13.55%; SD = 3.49). The sentences were divided into the following regions for analysis, as shown in (21): the agreeing RC verb (AV), the following content verb (V) and the post-verbal adverb (V+1). Regions AV and V were also combined into a 'combined verbal' region for analysis.

(21) The musician(s) | that | the reviewer(s) | were | praising | so highly | won…
AV V V+1

Four measures were calculated for each region of interest: first-pass time, regression-path duration, first-pass regression proportion, and second-pass time. First-pass time includes all fixations in a region of interest after participants first enter the region until the first saccade out of that region (either to the right or the left). Regression-path duration includes all fixation durations from the first fixation in a region until gaze is directed away from the region to the right. First-pass regression proportion is the probability that a regression is initiated from a particular region before exiting that region to the right. Second-pass time includes the sum of all regressive fixation durations in a region. The reading measures in each region of interest were input into 2x2x4 ANOVAs with attractor number (singular, plural) and grammaticality (grammatical, ungrammatical) as repeated measures, and list/item group as a non-repeated factor. The

results were analyzed over both by-subjects ($F1$) and by-items ($F2$) means. These analyses were followed up with tests of the simple effects of (i) grammaticality (grammatical vs. ungrammatical) in both singular- and plural-attractor sentences and (ii) attractor number (singular vs. plural) in both grammatical and ungrammatical sentences. The means for first-pass time, regression-path duration, first-pass regression proportion, and second-pass time in each region, are presented in Table 4.1. Table 4.2 provides a summary of main statistical analyses, while Tables 4.3 and 4.4 summarize the results of the tests of the simple effects of grammaticality and attractor number.

Table 4.1. Mean first-pass times, regression-path durations, first-pass regression proportions, and second-pass times (in ms where applicable) by condition and region (with standard errors of the mean by subjects for repeated measures in parentheses), Experiment 4.

	AV (*were*)	V (*praising*)	AV & V (*were praising*)	V+1 (*so highly*)
First-pass time				
Sing/Gram	233 (5)	300 (6)	458 (8)	406 (8)
Sing/Ungram	253 (8)	312 (7)	533 (11)	417 (8)
Plural/Gram	247 (9)	301 (6)	461 (9)	378 (10)
Plural/Ungram	241 (5)	315 (7)	479 (9)	397 (8)
Regression-path duration				
Sing/Gram	267 (10)	362 (12)	535 (14)	458 (13)
Sing/Ungram	291 (11)	481 (24)	683 (21)	478 (12)
Plural/Gram	286 (15)	362 (10)	548 (14)	431 (12)
Plural/Ungram	280 (11)	375 (14)	566 (14)	466 (13)
First-pass regression proportion				
Sing/Gram	.05 (.01)	.12 (.02)	.09 (.01)	.07 (.01)
Sing/Ungram	.07 (.01)	.26 (.02)	.17 (.02)	.07 (.01)
Plural/Gram	.04 (.01)	.09 (.01)	.09 (.01)	.08 (.01)
Plural/Ungram	.06 (.01)	.10 (.01)	.10 (.02)	.10 (.01)
Second-pass time				
Sing/Gram	72 (6)	112 (9)	179 (15)	117 (9)
Sing/Ungram	119 (9)	148 (11)	227 (16)	127 (10)
Plural/Gram	53 (5)	94 (7)	147 (12)	108 (9)
Plural/Ungram	75 (6)	118 (8)	190 (11)	141 (8)

Table 4.2. Summary of the effects of attractor number and grammaticality for first-pass times, regression-path durations, first-pass regression proportions, and second-pass times by region, Experiment 4.

	Attractor number		Grammaticality		Attractor number x Grammaticality	
	*F*1 (1,28)	*F*2 (1,44)	*F*1 (1,28)	*F*2 (1,44)	*F*1 (1,28)	*F*2 (1,44)
AV (*were*)						
First-pass time	<1	<1	<1	2.50	2.88	5.34*
Regression-path duration	<1	<1	<1	1.32	1.20	2.75
First-pass regression proportion	<1	<1	3.12	2.98	<1	<1
Second-pass time	19.39***	11.66**	20.57***	23.33***	2.70	1.08
V (*praising*)						
First-pass time	<1	<1	3.76	6.91*	<1	<1
Regression-path duration	10.12**	7.55**	16.70**	17.06***	6.29*	11.78**
First-pass regression proportion	25.56***	14.80***	15.26***	23.89***	10.22**	15.65***
Second-pass time	7.63*	5.09*	7.81**	8.29**	<1	<1
AV & V (*were praising*)						
First-pass time	3.30	1.68	31.40***	18.02***	7.95**	8.74**
Regression-path duration	8.68**	3.95	18.76***	16.29***	12.70**	10.71**
First-pass regression proportion	2.06	2.63	7.74**	6.73*	4.22*	2.63
Second-pass time	5.57*	4.35*	7.98**	12.70***	<1	<1
V+1 (*so highly*)						
First-pass time	7.48*	4.15*	1.67	4.76*	<1	<1
Regression-path duration	1.98	<1	2.58	6.08*	<1	<1
First-pass regression proportion	<1	1.39	<1	<1	<1	<1
Second-pass time	<1	<1	4.60*	3.62	1.24	1.58

*$p < .05$. **$p < .01$. ***$p < .001$.

Table 4.3. Summary of the tests of the simple effect of grammaticality for first-pass times, regression-path durations, first-pass regression proportions, and second-pass times by region, Experiment 4.

	Singular		Plural	
	$F1$ (1, 28)	$F2$ (1, 44)	$F1$ (1, 28)	$F2$ (1, 44)
AV (*were*)				
First-pass time	4.57*	6.40*	<1	<1
Regression-path duration	2.18	4.22*	<1	<1
First-pass regression proportion	1.38	<1	1.46	2.47
Second-pass time	12.81**	12.66***	7.84**	6.88*
V (*praising*)				
First-pass time	1.21	1.97	1.64	4.91*
Regression-path duration	13.15**	25.28***	<1	<1
First-pass regression proportion	16.28***	36.31***	1.41	<1
Second-pass time	4.26*	3.95	4.15	4.29*
AV & V (*were praising*)				
First-pass time	30.18***	21.21***	2.04	1.65
Regression-path duration	23.90***	24.64***	<1	<1
First-pass regression proportion	8.93**	8.83**	<1	<1
Second-pass time	2.85	2.29	6.37*	7.23*
V+1 (*so highly*)				
First-pass time	<1	3.32	1.50	2.66
Regression-path duration	<1	2.05	2.59	3.13
First-pass regression proportion	1.45	<1	<1	<1
Second-pass time	<1	<1	5.83*	4.34*

*$p < .05$. **$p < .01$. ***$p < .001$.

Table 4.4. Summary of the tests of the simple effect of attractor number for first-pass times, regression-path durations, first-pass regression proportions, and second-pass times by region, Experiment 4.

	Grammatical		Ungrammatical	
	*F*1 (1,28)	*F*2 (1,44)	*F*1 (1,28)	*F*2 (1,44)
AV (*were*)				
First-pass time	1.01	2.24	1.21	2.63
Regression-path duration	<1	3.18	<1	<1
First-pass regression proportion	<1	<1	<1	<1
Second-pass time	4.82*	3.40	13.19**	9.43**
V (*praising*)				
First-pass time	<1	<1	<1	<1
Regression-path duration	<1	<1	9.06**	14.65***
First-pass regression proportion	<1	<1	26.16***	26.92***
Second-pass time	2.15	2.02	4.21*	3.19
AV & V (*were praising*)				
First-pass time	<1	<1	8.41**	7.42**
Regression-path duration	<1	<1	15.95***	9.91**
First-pass regression proportion	<1	<1	4.26*	3.98
Second-pass time	2.06	3.78	2.77	<1
V+1 (*so highly*)				
First-pass time	4.00	2.10	2.91	3.09
Regression-path duration	1.93	<1	<1	<1
First-pass regression proportion	<1	<1	<1	1.32
Second-pass time	<1	<1	<1	1.33

*$p < .05$. **$p < .01$. ***$p < .001$.

4.2.1 First-pass measures

At the agreeing verb (AV), first-pass time revealed a marginal interaction of attractor number and grammaticality ($F1(1, 28) = 2.88$, $p = .10$; $F2(1, 44) = 5.34$, $p < .05$; grammaticality, attractor number: all F's < 2.5), suggesting particularly long RTs for singular ungrammatical sentences. Planned comparisons for grammaticality showed a significant effect only for singular-attractor sentences ($F1(1, 28) = 4.57$, $p < .05$; $F2(1, 44) = 6.40$, $p < .05$; plural-attractor sentences: both F's < 1), with singular ungrammatical sentences taking longer than their grammatical counterparts. These effects, graphed in Figure 4.1, indicate that singular ungrammatical sentences revealed processing costs related to the indexation of ungrammaticality, but plural ungrammatical sentences did not.

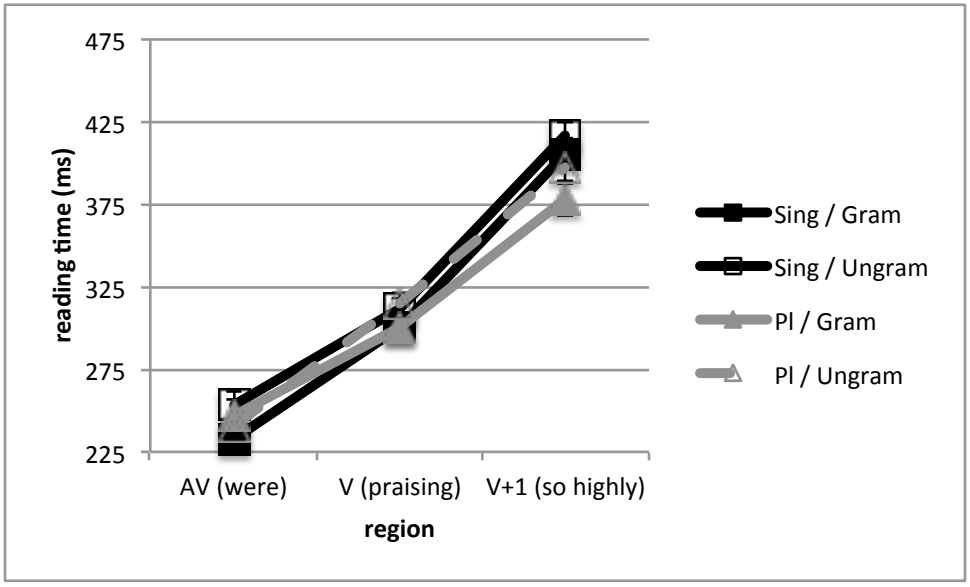


Figure 4.1. Mean first-pass times (by subjects) for grammatical and ungrammatical sentences with singular and plural attractor variants, Experiment 4. Error bars show ±1 standard error of the mean for repeated measures.

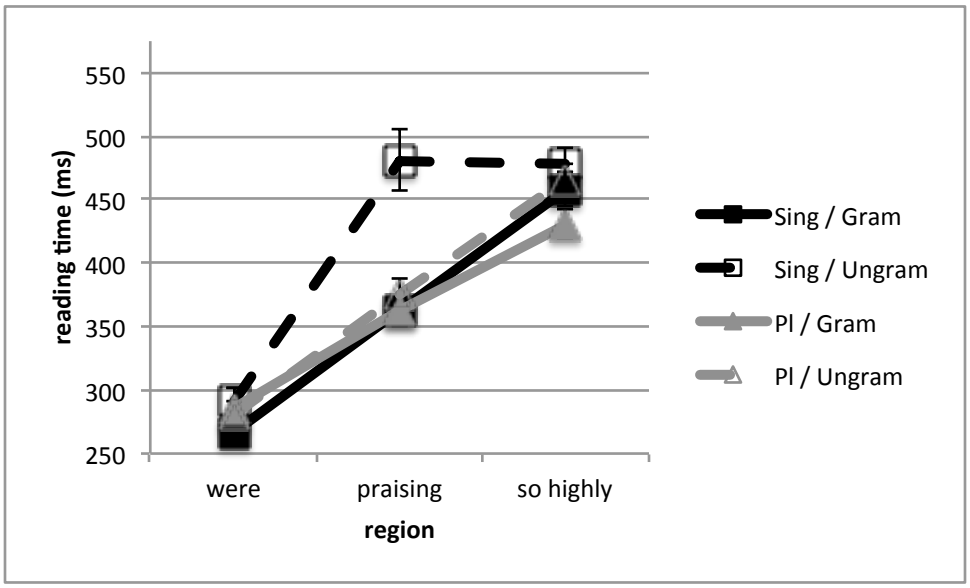


Figure 4.2. Mean regression-path durations (by subjects) for grammatical and ungrammatical sentences with singular and plural attractor variants, Experiment 4. Error bars show ±1 standard error of the mean for repeated measures.

At the content verb (V), first-pass time revealed a marginal effect of grammaticality, with longer RTs for ungrammatical sentences ($F1(1, 28) = 3.76$, $p = .06$; $F2(1, 44) = 6.91$, $p < .05$; attractor number, attractor number x grammaticality: all F's < 1). Under planned comparisons, the effect of grammaticality approached significance only for plural-attractor sentences ($F1(1, 28) = 1.64$; $F2(1, 44) = 4.91$, $p < .05$; singular-attractor sentences: both F's < 2). Regression-path duration, shown in Figure 4.2, revealed main effects of attractor number and grammaticality at the content verb. The grammaticality effect showed longer RTs for ungrammatical sentences ($F1(1, 28) = 16.70$, $p < .01$; $F2(1, 44) = 17.06$, $p < .001$), while the effect of attractor number showed longer RTs for singular-attractor sentences ($F1(1, 28) = 10.12$, $p < .01$; $F2(1, 44) = 7.55$, $p < .01$). More importantly, there was an interaction of attractor number and grammaticality ($F1(1, 28) = 6.29$, $p < .05$; $F2(1, 44) = 11.78$, $p < .01$), indicating particularly long

regression-path durations for singular ungrammatical sentences. These effects indicate that processing costs related to indexing ungrammaticality again occurred only in singular ungrammatical sentences. This is further supported by the tests of the simple effects of grammaticality and attractor number. Planned comparisons for grammaticality revealed a significant effect only for singular-attractor sentences ($F1(1, 28) = 13.15$, $p < .01$; $F2(1, 44) = 25.28$, $p < .001$; plural-attractor sentences: both F's < 1), with singular ungrammatical sentences taking longer than their grammatical counterparts. Planned comparisons for attractor number revealed a significant effect for ungrammatical sentences ($F1(1, 28) = 9.06$, $p < .01$; $F2(1, 44) = 14.65$, $p < .001$; grammatical sentences: both F's < 1), with singular ungrammatical sentences taking longer than plural ungrammatical sentences.

Further evidence that processing costs for ungrammaticality were indexed only in singular-attractor sentences was observed in first-pass regression proportion, shown in Figure 4.3. This measure showed main effects of grammaticality and attractor number. The grammaticality effect revealed more regressions in ungrammatical sentences ($F1(1, 28) = 15.26$, $p < .001$; $F2(1, 44) = 23.89$, $p < .001$), while the effect of attractor number revealed more regressions in singular-attractor sentences ($F1(1, 28) = 25.56$, $p < .001$; $F2(1, 44) = 14.80$, $p < .001$). Additionally, an interaction of attractor number and grammaticality occurred under this measure ($F1(1, 28) = 10.22$, $p < .01$; $F2(1, 44) = 15.65$, $p < .001$), indicating especially large first-pass regression proportions for singular ungrammatical sentences. These results were supported by planned comparisons for grammaticality and attractor number. The grammaticality effect revealed more regressions in ungrammatical sentences with singular attractors ($F1(1, 28) =$

16.28, $p < .001$; $F2(1, 44) = 36.31$, $p < .001$; plural attractor: all F's < 1.5), while the effect of attractor number revealed more regressions in singular-attractor sentences only when they are ungrammatical ($F1(1, 28) = 26.16$, $p < .001$; $F2(1, 44) = 26.92$, $p < .001$; grammatical: all F's < 1).

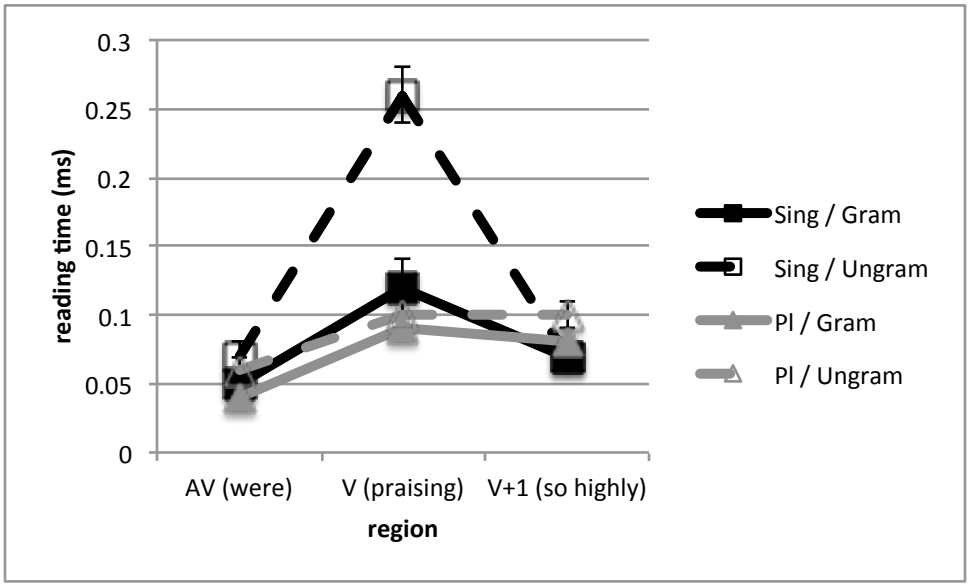


Figure 4.3. Probability of first-pass regression (by subjects) for grammatical and ungrammatical sentences with singular and plural attractor variants, Experiment 4. Error bars show ±1 standard error of the mean for repeated measures.

The combined verbal region yielded further indications that singular ungrammatical sentences triggered reliably higher processing costs related to indexing ungrammaticality. First-pass time revealed a main effect of grammaticality, with longer RTs for ungrammatical sentences ($F1(1, 28) = 31.40$, $p < .001$; $F2(1, 44) = 18.02$, $p < .001$). This measure also revealed a marginal effect at $F2$ for attractor number, suggesting longer RTs for singular-attractor sentences ($F1(1, 28) = 3.30$, $p = .08$; $F2(1, 44) = 1.68$). Crucially, there was again an interaction of attractor number and grammaticality ($F1(1, 28) = 7.95$, $p < .01$; $F2(1, 44) = 8.74$, $p < .01$),

indicating especially long first-pass times for singular ungrammatical sentences. As expected, planned comparisons for grammaticality revealed a significant effect only for singular-attractor sentences ($F1(1, 28) = 30.18$, $p < .001$; $F2(1, 44) = 21.21$, $p < .001$; plural-attractor sentences: both F's < 2.5)), with singular ungrammatical sentences taking longer than their grammatical counterparts. Also, planned comparisons for attractor number revealed a significant effect for ungrammatical sentences ($F1(1, 28) = 8.41$, $p < .01$; $F2(1, 44) = 7.42$, $p < .01$; grammatical sentences: both F's < 1), with singular ungrammatical sentences taking longer than plural ungrammatical sentences. These results are shown Figure 4.4.

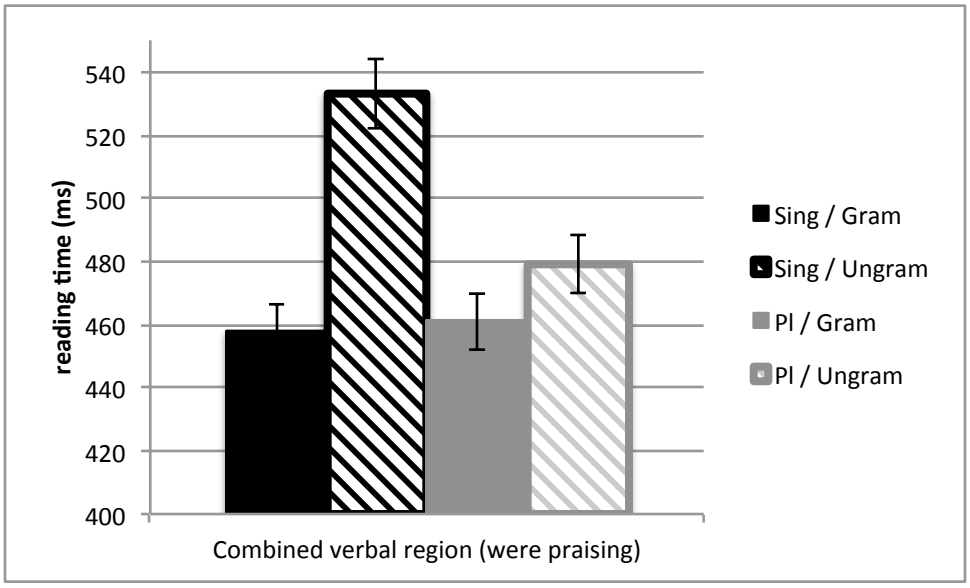


Figure 4.4. Mean first-pass times (by subjects) for grammatical and ungrammatical sentences with singular and plural attractor variants at the combined verbal region, Experiment 4. Error bars show ±1 standard error of the mean for repeated measures.

Comparable effects were also observed in regression-path duration. This measure revealed a main effect of grammaticality, with longer RTs for ungrammatical sentences ($F1(1, 28) = 18.76$, $p < .001$; $F2(1, 44) = 16.29$, $p < .001$), as well as a marginal effect of attractor

number, with longer RTs for singular-attractor sentences ($F1(1, 28) = 8.68$, $p < .01$; $F2(1, 44) = 3.95$, $p = .05$). Importantly, there was also an interaction of attractor number and grammaticality ($F1(1, 28) = 12.70$, $p < .01$; $F2(1, 44) = 10.71$, $p < .01$), indicating particularly long RTs for singular ungrammatical sentences. Again, planned comparisons for grammaticality revealed a significant effect only for singular-attractor sentences ($F1(1, 28) = 23.90$, $p < .001$; $F2(1, 44) = 24.64$, $p < .001$; plural-attractor sentences: both F's < 1), while planned comparisons for attractor number revealed a significant effect for ungrammatical sentences ($F1(1, 28) = 15.95$, $p < .001$; $F2(1, 44) = 9.91$, $p < .01$; grammatical sentences: both F's < 1).

Comparable findings were revealed under first-pass regression proportion. This measure yielded a main effect of grammaticality ($F1(1, 28) = 7.74$, $p < .01$; $F2(1, 44) = 6.73$, $p < .05$), with more regressions for ungrammatical sentences. Here also there was an interaction of attractor number and grammaticality that was significant by subjects suggesting more regressions for singular ungrammatical sentences ($F1(1, 28) = 4.22$, $p < .05$; $F2(1, 44) = 2.63$, $p = .11$; attractor number: $F1(1, 28) = 2.06$; $F2(1, 44) = 2.63$). Planned comparisons for grammaticality and attractor number further demonstrate evidence for attraction effects. The grammaticality effect revealed more regressions in ungrammatical sentences with singular attractors ($F1(1, 28) = 8.93$, $p < .01$; $F2(1, 44) = 8.83$, $p < .01$; plural attractor: all F's < 1), while the effect of attractor number suggested more regressions in singular-attractor sentences only when they are ungrammatical ($F1(1, 28) = 4.26$, $p < .05$; $F2(1, 44) = 3.98$, $p = .05$; grammatical: all F's < 1).

At region V+1, first-pass time revealed a main effect of attractor number, with longer RTs for singular-attractor sentences ($F1(1, 28) = 7.48$, $p < .05$; $F2(1, 44) = 4.15$, $p < .05$), as well as a marginal effect of grammaticality, with longer RTs for ungrammatical sentences ($F1(1, 28) = 1.67$; $F2(1, 44) = 4.76$, $p < .05$; attractor number x grammaticality: both F's < 1). A marginal effect of grammaticality was also observed in regression-path duration, with longer RTs for ungrammatical sentences ($F1(1, 28) = 2.58$; $F2(1, 44) = 6.08$, $p < .05$; grammaticality, attractor number x grammaticality: all F's < 2). These effects suggest that, at this late region, processing costs related to indexing ungrammaticality might be present for both singular- and plural-attractor sentences.

4.2.2 Second-pass time

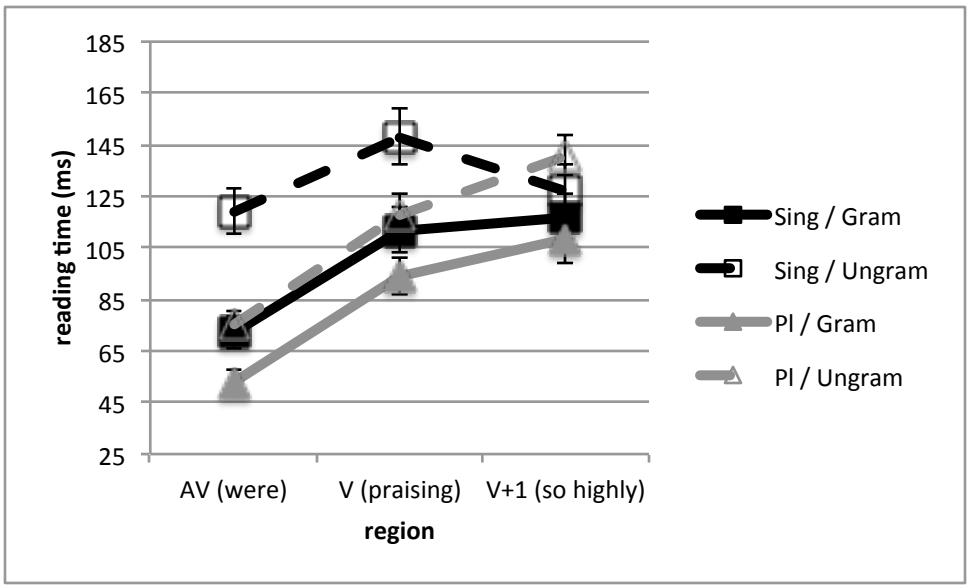


Figure 4.5. Mean second-pass times (by subjects) for grammatical and ungrammatical sentences with singular and plural attractor variants, Experiment 4. Error bars show ±1 standard error of the mean for repeated measures.

Early processing measures revealed processing costs related to indexing ungrammaticality only for singular ungrammatical sentences, in that these sentences had longer RTs and triggered more first-pass regressive eye movements compared to the other three sentence types. However, a different pattern of results was observed under the late processing measure, second-pass time. This measure, shown in Figure 4.5, revealed that the agreeing verb (AV) showed a main effect of grammaticality, with longer RTs for ungrammatical sentences ($F1(1, 28) = 20.57$, $p < .001$; $F2(1, 44) = 23.33$, $p < .001$). There was also a main effect of attractor number, with longer RTs for singular-attractor sentences ($F1(1, 28) = 19.39$, $p < .001$; $F2(1, 44) = 11.66$, $p < .01$; attractor number x grammaticality: $F1\ (1, 28) = 2.7$; $F2(1, 44) = 1.08$). Tests of the simple effect of grammaticality revealed that these effects were reliable for both singular- and plural-attractor sentences (singular-attractor sentences: $F1\ (1, 28) = 12.81$, $p < .01$; $F2(1, 44) = 12.66$, $p < .001$; plural-attractor sentences: $F1\ (1, 28) = 7.84$, $p < .01$; $F2(1, 44) = 6.88$, $p < .05$). These effects can be taken to indicate that processing costs related to indexing ungrammaticality were observed for sentences with both singular and plural attractors.

Region V also showed main effects of grammaticality and attractor number. The grammaticality effect revealed longer second-pass times for ungrammatical sentences ($F1(1, 28) = 7.81$, $p < .01$; $F2(1, 44) = 8.29$, $p < .01$), while the effect of attractor number revealed longer second-pass times for singular-attractor sentences ($F1(1, 28) = 7.63$, $p < .05$; $F2(1, 44) = 5.09$, $p < .05$; attractor number x grammaticality: both F's < 1). Planned comparisons for grammaticality showed marginal effects for both singular- and plural-attractor sentences (singular-attractor

sentences: $F1$ (1, 28) = 4.26, $p < .05$; $F2$(1, 44) = 3.95, $p = .05$; plural-attractor sentences: $F1$ (1, 28) = 4.15, $p = .05$; $F2$(1, 44) = 4.29, $p < .05$).

Furthermore, the combined verbal region showed a main effect of grammaticality, with longer RTs for ungrammatical sentences ($F1$(1, 28) = 7.98, $p < .01$; $F2$(1, 44) = 12.70, $p < .001$), as well as a main effect of attractor number, with longer RTs for singular-attractor sentences ($F1$(1, 28) = 5.57, $p < .05$; $F2$(1, 44) = 4.35, $p < .05$; attractor number x grammaticality: both F's < 1). In this region, planned comparisons for grammaticality showed significant results only for plural-attractor sentences ($F1$(1, 28) = 6.37, $p < .05$; $F2$(1, 44) = 7.23, $p < .05$; singular-attractor sentences: $F1$ (1, 28) = 2.85; $F2$(1, 44) = 2.29), further demonstrating that processing costs related to indexing ungrammaticality occurred in plural-attractor sentences in second-pass time. These results are graphed in Figure 4.6.

Second-pass time did not reveal reliable results at region V+1; however, this measure did show a marginal effect of grammaticality, with longer RTs for ungrammatical sentences ($F1$(1, 28) = 4.60, $p < .05$; $F2$(1, 44) = 3.62, $p = .06$; attractor number, attractor number x grammaticality: all F's < 2). Planned comparisons for grammaticality again indicated that this effect was only significant for plural-attractor sentences ($F1$(1, 28) = 5.83, $p < .05$; $F2$(1, 44) = 4.34, $p < .05$; singular-attractor: both F's < 1).

4.3 Discussion

The results of Experiment 4 revealed clear evidence of attraction effects at the earliest stages of sentences processing. This was shown by an illusion of grammaticality for ungram-

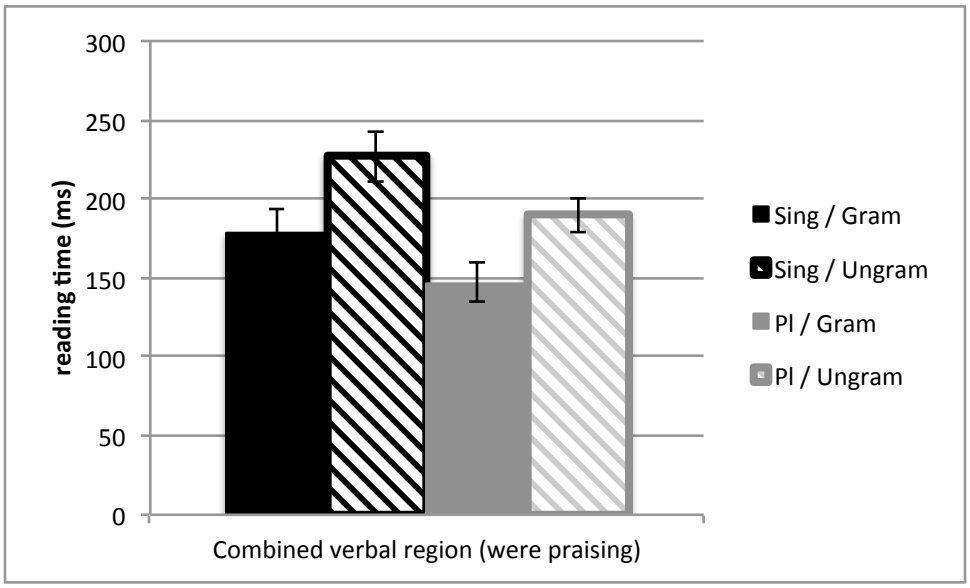


Figure 4.6. Mean second-pass times (by subjects) for grammatical and ungrammatical sentences with singular and plural attractor variants at the combined verbal region, Experiment 4. Error bars show ±1 standard error of the mean for repeated measures.

matical sentences with plural attractors – that is, evidence of processing difficulty only for ungrammatical sentences with singular attractors. In first-pass time, the marginal interaction at the agreeing verb and the reliable interaction at the combined verbal region only showed processing difficulty for sentences with singular attractors. This result was supported by interactions in regression-path duration at the content verb and the combined verbal region, which again, only revealed processing difficulty for ungrammatical sentences with singular attractors. Lastly, first-pass regression proportion revealed an interaction at the content verb indicating that the largest number of regressions occurred in ungrammatical sentences with singular attractors. In sum, first-pass measures showed that the ungrammatical sentences with singular attractors indicated significant evidence of processing difficulty, but ungrammatical sentences with plural attractors did not. In fact, no reliable difference was found between ungrammati-

cal sentences with plural attractors and their grammatical counterparts, demonstrating a clear illusion of grammaticality under these measures. This illusion of grammaticality in first-pass measures shows that attraction effects exert their influence at the earliest stages of agreement processing. This evidence also suggests that memory retrieval processes are active during early processing stages and are therefore a core part of agreement computation.

Second-pass time however, showed evidence of processing difficulty for ungrammatical sentences regardless of attractor number. These later effects suggest that the illusion of grammaticality found in first-pass measures disappears in later stages of processing and is replaced by an indexation of ungrammaticality. This pattern of results is interesting because it is unclear is why ungrammaticality is recognized at all for ungrammatical sentences with plural attractors. That is, in light of the fact that participants demonstrated an illusion of grammaticality for these sentences in first-pass measures, it is unclear why this pattern does not persist through second-pass time. However, it is important to remember that second-pass time represents regressive fixations made before and after participants have made their final progressive fixation in the sentence. This differentiation is important because fixations before and after the final fixation could represent different stages of processing. Specifically, regressive fixations that occur before readers have reached the end of the sentence might still represent sentence processing that occurs while the representation of the sentence is being developed. However, fixations that occur after participants have reached the end of the sentence might simply represent processing related to checking a complete representation for the sentence. With this distinction in mind, these fixations were separated into two measures and analyzed separately:

non-terminal second-pass time takes into consideration all regressive fixations made before the final progressive fixation in the sentence, while review time includes all regressive fixations made after the final progressive fixation.

4.3.1 Second-pass time reanalysis

Just as before, the reading measures in each region of interest were input into 2x2x4 ANOVAs with attractor number (singular, plural) and grammaticality (grammatical, ungrammatical) as repeated measures, and list/item group as a non-repeated factor. The results were analyzed over both by-subjects ($F1$) and by-items ($F2$) means. These analyses were followed up with tests of the simple effects of (i) grammaticality (grammatical vs. ungrammatical) in both singular- and plural-attractor sentences and (ii) attractor number (singular vs. plural) in both grammatical and ungrammatical sentences. The means for non-terminal second-pass time and review time in each region are presented in Table 4.5. Table 4.6 provides a summary of main statistical analyses, while Tables 4.7 and 4.8 summarize the results of the tests of the simple effects of grammaticality and attractor number.

Table 4.5. Mean non-terminal second-pass times and review times (in ms) by condition and region (with standard errors of the mean by subjects for repeated measures in parentheses), Experiment 4.

	AV (*were*)	V (*praising*)	AV & V (*were praising*)	V+1 (*so highly*)
Non-terminal second-pass time				
Sing/Gram	25 (5)	45 (6)	65 (11)	57 (6)
Sing/Ungram	73 (9)	77 (8)	110 (13)	63 (8)
Plural/Gram	24 (4)	46 (6)	70 (9)	58 (8)
Plural/Ungram	36 (4)	54 (5)	87 (8)	75 (8)
Review time				
Sing/Gram	47 (6)	67 (6)	114 (10)	60 (6)
Sing/Ungram	46 (5)	71 (6)	117 (9)	64 (7)
Plural/Gram	29 (4)	48 (5)	77 (8)	50 (5)
Plural/Ungram	39 (5)	65 (7)	104 (8)	66 (6)

Table 4.6. Summary of the effects of attractor number and grammaticality for non-terminal second-pass times and review times by region, Experiment 4.

	Attractor number		Grammaticality		Attractor number x Grammaticality	
	*F*1 (1,28)	*F*2 (1,44)	*F*1 (1,28)	*F*2 (1,44)	*F*1 (1,28)	*F*2 (1,44)
AV (*were*)						
Non-terminal second-pass time	8.75**	15.20***	16.70***	32.30***	7.50*	14.06***
Review time	5.27*	2.93	<1	<1	<1	4.18*
V (*praising*)						
Non-terminal second-pass time	2.09	1.32	8.96**	5.79*	3.16	4.50*
Review time	3.36	2.16	2.19	2.21	<1	1.18
AV & V (*were praising*)						
Non-terminal second-pass time	<1	<1	6.70*	7.77**	1.52	<1
Review time	8.87**	3.46	1.56	2.14	1.26	3.14
V+1 (*so highly*)						
Non-terminal second-pass time	<1	<1	1.78	<1	<1	<1
Review time	<1	<1	2.02	2.96	1.40	1.13

*$p < .05$. **$p < .01$. ***$p < .001$.

Table 4.7. Summary of the tests of the simple effect of grammaticality for non-terminal second-pass times and review times by region, Experiment 4.

	Singular		Plural	
	$F1$ (1, 28)	$F2$ (1, 44)	$F1$ (1, 28)	$F2$ (1, 44)
AV (*were*)				
Non-terminal second-pass time	14.01***	37.57***	4.45*	2.38
Review time	<1	<1	1.90	3.20
V (*praising*)				
Non-terminal second-pass time	7.15*	9.61**	1.52	<1
Review time	<1	<1	2.97	4.91*
AV & V (*were praising*)				
Non-terminal second-pass time	4.69*	8.23**	2.63	1.55
Review time	<1	<1	3.52	5.81*
V+1 (*so highly*)				
Non-terminal second-pass time	<1	<1	1.50	2.66
Review time	<1	<1	4.15	3.34
*p < .05. **p < .01. ***p < .001.				

Table 4.8. Summary of the tests of the simple effect of attractor number for non-terminal second-pass times and review times by region, Experiment 4.

	Grammatical		Ungrammatical	
	$F1$ (1, 28)	$F2$ (1, 44)	$F1$ (1, 28)	$F2$ (1, 44)
AV (*were*)				
Non-terminal second-pass time	<1	<1	10.23**	21.95***
Review time	4.27*	7.25**	<1	<1
V (*praising*)				
Non-terminal second-pass time	<1	<1	4.63*	4.10*
Review time	4.31*	3.46	<1	<1
AV & V (*were praising*)				
Non-terminal second-pass time	<1	<1	1.61	1.02
Review time	7.17*	6.95*	<1	<1
V+1 (*so highly*)				
Non-terminal second-pass time	<1	3.32	1.50	2.66
Review time	1.78	<1	<1	<1
*p < .05. **p < .01. ***p < .001.				

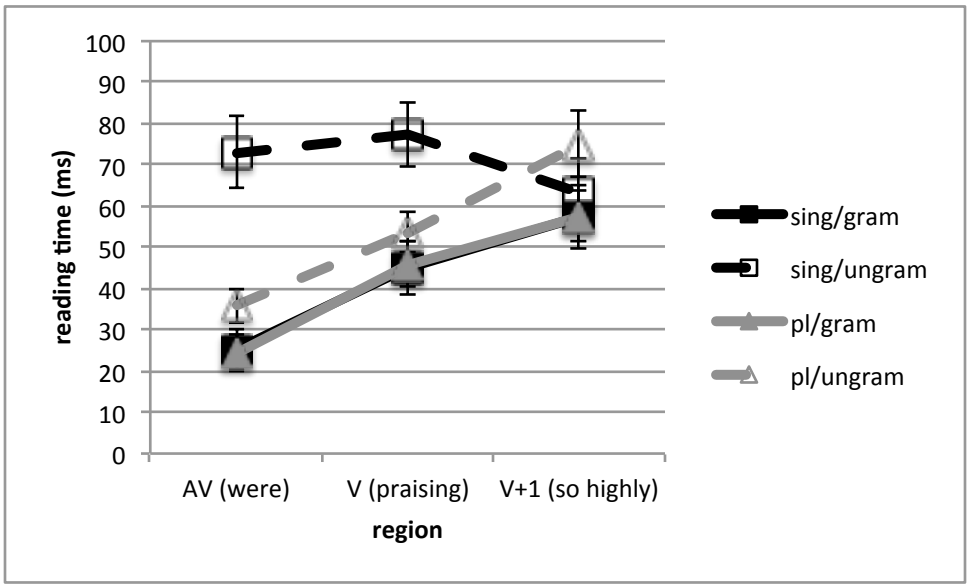


Figure 4.7. Mean non-terminal second-pass times (by subjects) for grammatical and ungrammatical sentences with singular and plural attractor variants, Experiment 4. Error bars show ±1 standard error of the mean for repeated measures.

4.3.1.1 Non-terminal second-pass time results

At the agreeing verb (AV), non-terminal second-pass time revealed main effects of grammaticality and attractor number. The grammaticality effect showed longer RTs for ungrammatical sentences ($F1(1, 28) = 16.70$, $p < .001$; $F2(1, 44) = 32.30$, $p < .001$), while the effect of attractor number showed longer RTs for singular-attractor sentences ($F1(1, 28) = 8.75$, $p < .01$; $F2(1, 44) = 15.20$, $p < .001$). Crucially, there was also an interaction of attractor number and grammaticality ($F1(1, 28) = 7.50$, $p < .05$; $F2(1, 44) = 14.06$, $p < .001$), indicating particularly long non-terminal second-pass times for singular ungrammatical sentences and showing that processing costs related to indexing ungrammaticality only occurred in these sentences. This is further supported by the tests of the simple effects of grammaticality and attractor number. Planned comparisons for grammaticality showed a significant effect for singular-attractor sen-

tences ($F1(1, 28) = 14.01$, $p < .001$; $F2(1, 44) = 37.57$, $p < .001$) and only marginal results for plural-attractor sentences ($F1(1, 28) = 4.45$, $p < .05$; $F2(1, 44) = 2.38$), with ungrammatical sentences taking longer than their grammatical counterparts. Planned comparisons for attractor number revealed a significant effect for ungrammatical sentences ($F1(1, 28) = 10.23$, $p < .01$; $F2(1, 44) = 21.95$, $p < .001$; grammatical sentences: both F's < 1), with singular ungrammatical sentences taking longer than plural ungrammatical sentences. These effects, shown in Figure 4.7, indicate that singular ungrammatical sentences revealed processing costs related to the indexation of ungrammaticality much more strongly than plural ungrammatical sentences.

Non-terminal second-pass time also revealed a main effect of grammaticality at region V. The grammaticality effect showed longer RTs for ungrammatical sentences ($F1(1, 28) = 8.96$, $p < .01$; $F2(1, 44) = 5.79$, $p < .05$; attractor number: both F's < 2.5). Here also, there was a marginal interaction of attractor number and grammaticality ($F1(1, 28) = 3.16$, $p = .08$; $F2(1, 44) = 4.50$, $p < .05$), indicating that singular ungrammatical sentences had particularly long non-terminal second-pass times. These effects can be taken to indicate that processing costs related to indexing ungrammaticality occurred only in singular ungrammatical sentences. This is further supported by the tests of the simple effects of grammaticality and attractor number. Planned comparisons for grammaticality revealed a significant effect only for singular-attractor sentences ($F1(1, 28) = 7.15$, $p < .05$; $F2(1, 44) = 9.61$, $p < .01$; plural-attractor sentences: both F's < 2), with singular ungrammatical sentences taking longer than their grammatical counterparts. Planned comparisons for attractor number revealed a significant effect for ungrammatical sentences ($F1(1, 28) = 4.63$, $p < .05$; $F2(1, 44) = 4.10$, $p < .05$; grammatical sentences:

both F's < 1), with singular ungrammatical sentences taking longer than plural ungrammatical sentences.

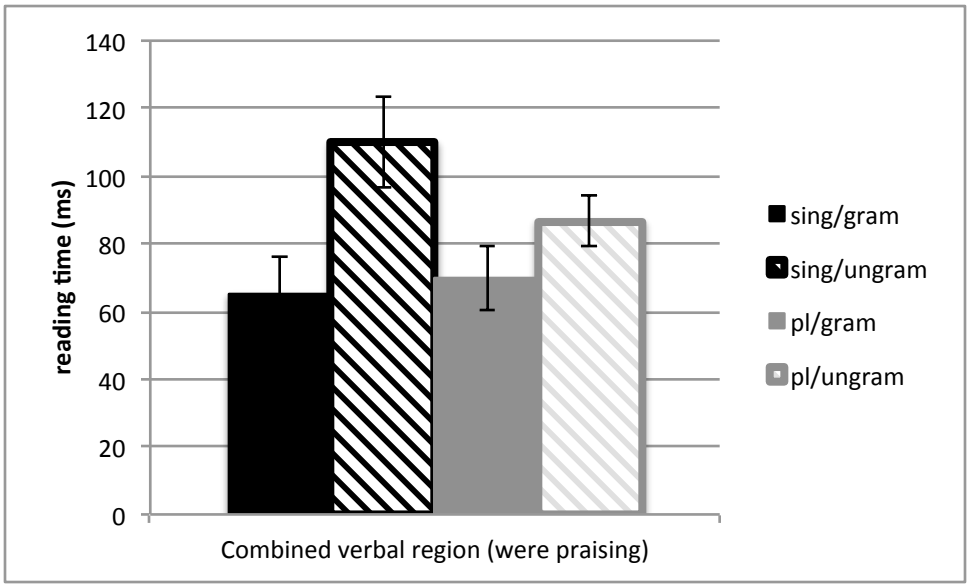


Figure 4.8. Mean non-terminal second-pass times (by subjects) for grammatical and ungrammatical sentences with singular and plural attractor variants at the combined verbal region, Experiment 4. Error bars show ±1 standard error of the mean for repeated measures.

The combined verbal region demonstrated similar effects for non-terminal second-pass time; these results are graphed in Figure 4.8. A main effect of grammaticality showed longer RTs for ungrammatical sentences ($F1(1, 28) = 6.70$, $p < .05$; $F2(1, 44) = 7.77$, $p < .01$; attractor number: both F's < 1). In this region there was no interaction (both F's <2), but planned comparisons for grammaticality revealed a significant effect only for singular-attractor sentences ($F1(1, 28) = 4.69$, $p < .05$; $F2(1, 44) = 8.23$, $p < .01$; plural-attractor sentences: $F1(1, 28) = 2.63$, $F2(1, 44) = 1.55$), with singular ungrammatical sentences taking longer than their grammatical counterparts. These effects further indicate that processing costs related to index-

ing ungrammaticality again occurred only in singular ungrammatical sentences. No effects for non-terminal second-pass time were observed at region V+1.

4.3.1.2 Review time results

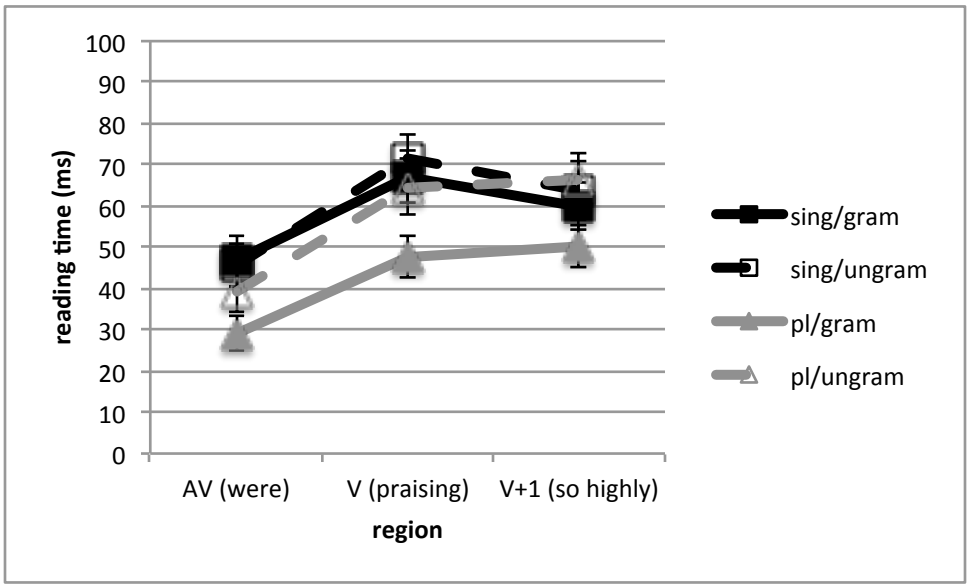


Figure 4.9. Mean review times (by subjects) for grammatical and ungrammatical sentences with singular and plural attractor variants, Experiment 4. Error bars show ±1 standard error of the mean for repeated measures.

Review time, shown in Figure 4.9, demonstrated a different pattern of results. Region AV indicated a marginal effect of attractor number ($F1(1, 28) = 5.27$, $p < .05$; $F2(1, 44) = 2.93$, $p = .09$; grammaticality: all F's <1), suggesting longer review times for singular-attractor sentences. There was also a marginal interaction ($F1 < 1$; $F2(1, 44) = 4.18$, $p < .05$), suggesting particularly short review times for plural grammatical sentences. Planned comparisons revealed an effect of attractor number only in grammatical sentences ($F1(1, 28) = 4.27$, $p < .05$; $F2(1, 44) = 7.25$, $p < .01$; plural-attractor sentences: both F's <1), with singular-attractor sen-

tences taking longer than plural-attractor sentences. Planned comparisons of the simple effect of grammaticality revealed a marginal effect for plural-attractor sentences ($F1 = 1.9$; $F2(1, 44) = 3.20$, $p = .08$; singular-attractor sentences: both F's < 1), with a trend towards ungrammatical sentences taking longer than their grammatical counterparts. The results in this region suggest that processing costs related to indexing ungrammaticality are only seen on plural-attractor sentences under review time.

Similar effects were observed at the content verb (V). This region only revealed a marginal effect of attractor number ($F1$ (1, 28) = 3.36, p = .08; $F2(1, 44) = 2.16$; grammaticality and grammaticality x attractor number: all F's < 2.5), suggesting longer review times for singular-attractor sentences. Planned comparisons found this effect was marginal in grammatical sentences ($F1(1, 28) = 4.31$, $p < .05$; $F2(1, 44) = 3.46$, $p = .07$; ungrammatical sentences: both F's < 1), with singular-attractor sentences taking longer than plural-attractor sentences. Planned comparisons for the simple effect of grammaticality revealed a marginal effect in plural-attractor sentences ($F1(1, 28) = 2.97$, p = .1; $F2(1, 44) = 4.90$, $p < .05$; singular-attractor sentences: both F's < 1), with ungrammatical sentences taking longer than grammatical sentences. These results continue to suggest that processing costs related to indexing ungrammaticality are only seen on plural-attractor sentences.

The combined verbal region (AV & V, shown in Figure 4.10, revealed a marginal effect of attractor number ($F1(1, 28) = 8.87$, $p < .01$; $F2(1, 44) = 3.46$, $p = .07$; grammaticality: both F's < 2.5), with singular-attractor sentences suggested to have longer review times. There was also an interaction that is marginally significant by items ($F1(1, 28) = 1.26$; $F2(1, 44) = 3.14$, p

= .08). Planned comparisons of the simple effects of grammaticality revealed a marginal effect for plural-attractor sentences ($F1(1, 28) = 3.52$, $p = .07$; $F2(1, 44) = 5.81$, $p < .05$; singular-attractor sentences: both F's < 1), suggesting that ungrammatical plural-attractor sentences take longer to process than their grammatical counterparts. Planned comparisons also showed an effect of attractor number for grammatical sentences ($F1(1, 28) = 7.17$, $p < .05$; $F2(1, 44) = 6.95$, $p < .05$: ungrammatical sentences: both F's < 1), with singular-attractor sentences showing longer review times than plural-attractor sentences. These results continue to indicate that ungrammatical plural-attractor sentences show processing costs related to indexing ungrammaticality, but singular-attractor sentences do not. Finally, the post-verbal adverb (V+1) only showed a marginal effect of grammaticality ($F1(1, 28) = 2.02$; $F2(1, 44) = 2.96$, $p = .09$; attractor number and attractor number x grammaticality: all F's < 1.5), with ungrammatical sentences taking longer than grammatical sentences. Planned comparisons revealed this effect only occurs marginally within plural-attractor sentences ($F1(1, 28) = 4.15$, $p = .05$; $F2(1, 44) = 3.34$, $p = .07$; singular-attractor: all F's < 1), showing longer review times for ungrammatical sentences. Consistent with the previous regions, these results suggest that processing costs related to indexing ungrammaticality were observed on ungrammatical sentences with plural attractors but not on ungrammatical sentences with singular attractors.

4.3.2 Discussion continued

These results provide evidence that the influence of attraction effects does not diminish until after the final progressive fixation has been made. Non-terminal second-pass time indicated that only ungrammatical sentences with singular attractors have significantly longer

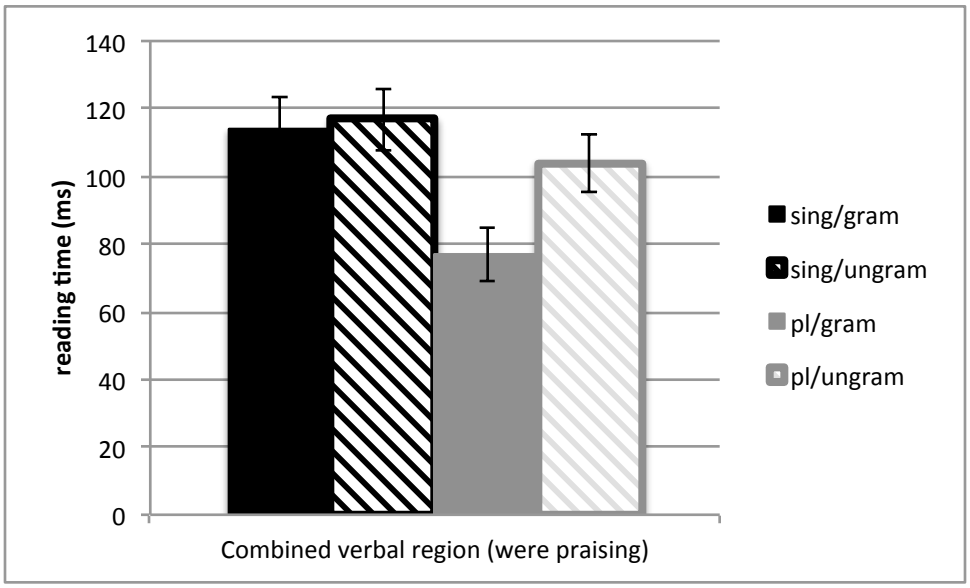


Figure 4.10. Mean review times (by subjects) for grammatical and ungrammatical sentences with singular and plural attractor variants at the combined verbal region, Experiment 4. Error bars show ±1 standard error of the mean for repeated measures.

RTs than their grammatical counterparts. Ungrammatical sentences with plural attractors show a similar profile to that of first-pass time, regression-path duration, and first-pass regression proportion. This was demonstrated in non-terminal second-pass time by the interaction of grammaticality and attractor number at the agreeing verb as well as the planned comparisons of grammaticality for both the agreeing verb and the content verb. Thus, the separation of non-terminal second-pass time from review time revealed that the illusion of grammaticality found in early processing measures persists all the way through the final progressive fixation within a sentence. Only after the final progressive fixation do ungrammatical sentences with plural attractors display processing costs associated with the recognition of ungrammaticality, as shown by the processing costs for these sentences under review time.

As discussed above, the reasoning behind separating non-terminal second-pass time and review time is that the two measures seemingly reflect different stages of processing. Since non-terminal second-pass time only includes regressive fixations that occur before the final fixation, it would still seem to represent processing that occurs while the representation of the sentence is being developed. However, review time only includes fixations that occur after the final progressive fixation, suggesting that it is representative of processing related to a final review or check of the sentence. This would mean that the illusion of grammaticality described for ungrammatical sentences with plural attractors persists through the entire sentence, and ungrammaticality for sentences with plural attractors is only recognized during the review stage of processing. This suggests that attraction effects influence agreement processing from the first stages of processing until the review stage begins, providing even more compelling evidence that memory retrieval processes are involved in core agreement processing.

As outlined in Chapter 2, the memory retrieval model proposes that a verb (*were*) triggers a search through the memory representation of the sentence for a previously activated NP with matching agreement features. In most cases the search ends successfully when the mechanism finds the subject NP with matching features; however, in instances of a mismatch with the subject, the mechanism may allow a grammatically inaccessible NP with matching number features to interfere with agreement computation. However, the memory representation of nouns involves more than just a feature for number. Barker et al. (2001) showed that semantic features on an attractor noun influence agreement attraction and work related to the structural distance between nouns has suggested that the structural properties of an attractor noun can

modulate agreement attraction (Nicol et al., 1997; Pearlmutter 2000). Contrastively, Dillon and colleagues (2013) showed that agreement processing is not sensitive to structural information in the same manner that anaphora is and Wagers et al. (2009) found evidence of attraction effects in long-distance cases, which appear to be relatively insensitive to the structural relationship between the attractor and the subject. Thus, work to date does not clearly delineate the extent to which structural information modulates agreement processing. Experiment 5 will address this question by examining whether the syntactic position of the attractor influences the amount of interference it provides.

CHAPTER 5

Experiment 5

Experiments 1-4 provide clear evidence for long-distance agreement attraction during sentence comprehension. The self-paced reading experiments, Experiments 1-3, revealed attenuated processing difficulty for ungrammatical plural-attractor sentences with both bound and free agreeing morphemes, indicating that long-distance attraction effects reflect core properties of the agreement processing system. Experiment 4 revealed a clear illusion of grammaticality for ungrammatical plural-attractor sentences under first-pass reading measures, indicating that long-distance attraction influences the earliest stages of agreement processing. Since long-distance agreement attraction strongly favors a memory retrieval account of online agreement computation, the results of these experiments suggest that these retrieval processes are fundamental to agreement processing.

With this in mind, it is important to understand the features that modulate memory retrieval processes. Recall that the memory retrieval model proposes that a verb (*were*) triggers a search through the memory representation of the sentence for a previously activated NP with matching agreement features. When considering possible controllers, the subject-verb agreement processor looks for a noun/NP that matches the agreement target in terms of number features (plural), that has been encoded in a compatible structural position (subject), and that occurs within the same clause as the agreeing verb. The abundant evidence for agreement

attraction indicates that retrieval processes are highly influenced by number features, namely plurality, on the attractor noun. Research into the role of structure has been less one-sided. Studies investigating the structural distance between the head noun and attractor noun have indicated that this distance modulates attraction effects, suggesting the structural position of the attractor noun plays a role in agreement computation (Frank et al., 2002; Nicol et al., 1997; Pearlmutter, 2000). However, more recent research by Dillon and colleagues (2013) found intrusion effects for subject-verb agreement – as indicated by attenuated processing difficulty in ungrammatical sentences with plural attractors – but not for reflexives. This was taken to indicate that subject-verb agreement processing ignores structure in a way that reflexive binding does not. Likewise, long-distance attraction effects appear to be relatively insensitive to structural properties of the sentence. Specifically, the attractor noun and the controlling subject do not have a clear structural relationship as the attractor noun occurs higher in the structural representation, functioning as the main clause subject. Crucially though, despite the lack of a structural relationship between the two possible controllers, long-distance attractors elicit attraction effects in the form of an illusion of grammaticality.

However, while there is no clear structural relationship between the attractor noun and the controlling subject in long-distance agreement attraction, it is important to note that these two nouns both occur as syntactic subjects, as shown in (22). In particular, the attractor noun (*musicians*) is the main clause subject and the controlling noun (*reviewer*) is the RC subject.

(22) *The musicians that the reviewer were praising so highly won the prestigious award.

As a result, the attractor noun matches the agreeing verb (*were*) both with respect to its number feature (plural) and its structural position (subject), the combination of which might make this a particularly salient attractor. Experiment 5 examines whether an attractor's structural position influences attraction effects, and, more specifically, whether attractor nouns in the subject position give rise to particularly strong agreement attraction effects. This was done by comparing attraction effects when the attractor noun was either a syntactic subject or object.

Since the paradigm of long-distance agreement attraction places the attractor noun in the subject position of the main clause, it does not provide the necessary context for this experiment. Rather, to investigate the possible influence of structural position on attraction effects, Experiment 5 examined intervening agreement attraction and compared object-extracted RC (ORC) sentences to subject-extracted RC (SRC) sentences. In these items, SRC sentences contain an attractor that occurs as the object of the RC (*officer(s)*), as shown in (23). ORC sentences, on the other hand, contain an attractor that occurs as the subject of the RC (*officer(s)*) as in (24).

(23) a. SRC / Singular attractor / grammatical

The Marines that saved the officer last week were promoting the military very forcefully.

b. SRC / Singular attractor / ungrammatical

*The Marine that saved the officer last week were promoting the military very forcefully.

c. SRC / Plural attractor / grammatical

The Marines that saved the officers last week were promoting the military very forcefully.

d. SRC / Plural attractor / ungrammatical

*The Marine that saved the officers last week were promoting the military very forcefully.

(24) a. ORC / Singular attractor / grammatical

The Marines that the officer saved last week were promoting the military very forcefully.

b. ORC / Singular attractor / ungrammatical

*The Marine that the officer saved last week were promoting the military very forcefully.

c. ORC / Plural attractor / grammatical

The Marines that the officers saved last week were promoting the military very forcefully.

d. ORC / Plural attractor / ungrammatical

*The Marine that the officers saved last week were promoting the military very forcefully.

This manipulation directly compares cases where the attractor noun is in the subject position to cases where the attractor noun is in the object position and addresses the question of whether

a subject-encoded attractor yields particularly strong agreement attraction effects. As in the previous experiments, the attractor number appears as both singular (a and b examples) and plural (c and d examples), and the sentences also appear in grammatical (a and c examples) and ungrammatical (b and d examples) forms. This experiment continues to use eye tracking to further examine the time course of agreement attraction.

While a comparison of structural position has not been carried out, Dillon et al.'s (2013) eye tracking study used sentences patterning like the SRC sentences in (23), where the attractor noun is in the object position, as in (25).

(25) *The new executive who oversaw the middle managers apparently were dishonest about the company's profits.

As with SRC sentences in Experiment 5, their items used intervening attraction with the controlling subject (*new executive*) and the agreeing verb (*were*) occurring in the main clause and the intervening attractor (*middle managers*) occurring in the RC. They reported effects of ungrammaticality under first-pass time, first-pass regression proportion, and total time, with evidence of attraction effects only occurring in total time (a late measure indicating the total time spent in a region). In this way, their results differ quite drastically from those found in Experiment 4, which demonstrated evidence attraction effects in early measures, including first-pass time and first-pass regression. One explanation for the difference in these effects could be that structural position of a noun influences its effectiveness as an attractor. Specif-

ically, it might be the case that object-encoded attractor nouns lead to weaker attraction than subject-encoded attractor nouns.

With these ideas in mind, the predictions for Experiment 5 were as follows: ungrammatical sentences with singular attractors were predicted to show clear indexation of ungrammaticality under all measures in both SRC and ORC conditions, as indicated by inflated RTs and a greater incidence of regressive eye movements at and after the agreeing verb. If the structural position of the attractor noun influences agreement attraction effects, it was predicted that ungrammatical ORC sentences with plural attractors would show stronger attraction effects than their SRC counterparts. This would be indicated by ungrammatical ORC sentences with plural attractors showing patterns of results similar to their grammatical counterparts at and after the agreeing verb, while ungrammatical SRC sentences with plural attractors would show clear indications of processing difficulty at and after the agreeing verb. However, if agreement attraction is not influenced by the structural position of the attractor noun, then ungrammatical sentences with plural attractors in both SRC and ORC conditions should show comparable agreement attraction effects, as indicated by patterns of results similar to their grammatical counterparts.

5.1 Method

5.1.1 Participants

56 graduate and undergraduate students at the University of Texas at Arlington participated in this study. All participants were native speakers of English.

5.1.2 Materials & Design

The materials were adapted in part from the items in Experiments 3 and 4. These items appeared in a 2x2x2 design with attractor number, grammaticality, and RC type as factors. Each item appeared in eight variations based on these factors; an example set is given in (24) and (25) (see Appendix D for a full list of experimental items). The experiment had 12 practice items and 80 fillers. Thirty-two of these fillers followed the same pattern as the experimental items, with an intervening RC and correctly inflected verbs. Sixteen of these fillers were ORC sentences (e.g. *The criminal that the lawyer was defending so strongly went to federal prison.*) and sixteen were SRC sentences (*The researcher that was consulting the graduate so often published a new article.*). The remaining fillers were grammatical sentences with various structures and agreement targets (e.g. *The captain of the ship introduced himself to the king*). The combination of experimental items with these filler items meant that 20% of the items were ungrammatical. All of the experimental items and half of the filler items were followed by a YES/NO comprehension question (e.g. *Did the captain of the ship introduce himself to the queen?*). These questions contained an equal number of YES and NO answers.

5.1.3 Procedure

The materials were divided into eight lists in a Latin square design and 7 participants were assigned to each list. The reading task was administered using the same procedures as Experiment 4. The sentences were divided into regions, as shown in (26), and the analyzed regions were the agreeing verb (AV), the following content verb (V), and the post-verbal adverb (V+1). Regions AV and V were also combined into a 'combined verbal region' for analysis.

(26) a. *The Marine | that | saved | the | officers | last week | were | promoting |
AV V

the military…
V+1

b. *The Marine | that | the | officers | saved | last week | were | promoting |
AV V

the military…
V+1

Seven measures were calculated for each region of interest. Three of these are generally considered measures of early comprehension processes: first-pass time, regression-path duration, and first-pass regression proportion. Second-pass time, non-terminal second-pass time, review time, and total time were also calculated as measures of later comprehension processes. Total time includes the sum of all fixations in a region (see 4.1.3 *Procedures* and 4.3.1 *Second-pass time reanalysis* for definitions of other measures).

5.2 Results

Each participant had an error rate of 30% or less on comprehension questions (M = 19.7%; SD = 5.72). The RT measures in each region of interest were input into 2x2x2x8 ANOVAs with attractor number (singular, plural), grammaticality (grammatical, ungrammatical), and RC type (SRC, ORC) as repeated measures, and list/item group as a non-repeated factor. The results were analyzed over both by-subjects ($F1$) and by-items ($F2$) means. These analyses were followed up by 2x2x4 ANOVAs run for each RC type with attractor number (singular, plural) and grammaticality (grammatical, ungrammatical) as repeated measures, and list/item group as a non-repeated factor. Finally, tests of simple effects were conducted for

(i) grammaticality (grammatical vs. ungrammatical) in both singular- and plural-attractor sentences and (ii) attractor number (singular vs. plural) in both grammatical and ungrammatical sentences. The means for first-pass time, regression-path duration, first-pass regression proportion, second-pass time, non-terminal second-pass time, review time, and total time in each region, are presented in Tables 5.1 and 5.2. Table 5.3 provides a summary of the main effects and Tables 5.4 and 5.5 provide a summary of the overall interactions. Tables 5.6 and 5.7 summarize of the effects by RC type. Lastly, Tables 5.8 and 5.9 summarize the results of the tests of the simple effect of grammaticality, and Tables 5.10 and 5.11 summarize the results of the tests of the simple effect of attractor number.

Table 5.1: Mean first-pass times, regression-path durations, first-pass regression proportions, second-pass times, non-terminal second-pass times, review times, and total times for SRC sentences (in ms where applicable) by condition and region (with standard errors of the mean by subjects for repeated measures in parentheses), Experiment 5.

	AV (*were*)	V (*promoting*)	AV & V(*were promoting*)	V+1 (*the military*)
First-pass time				
Sing/Gram	252 (6)	274 (8)	434 (11)	255 (8)
Sing/Ungram	252 (8)	293 (7)	462 (13)	260 (10)
Plural/Gram	234 (7)	278 (8)	420 (12)	267 (10)
Plural/Ungram	248 (7)	294 (9)	451 (12)	267 (9)
Regression-path duration				
Sing/Gram	316 (25)	376 (18)	543 (19)	386 (17)
Sing/Ungram	309 (17)	416 (21)	573 (23)	396 (20)
Plural/Gram	303 (17)	394 (20)	539 (18)	407 (19)
Plural/Ungram	298 (21)	404 (30)	557 (25)	399 (19)
First-pass regression proportion				
Sing/Gram	.08 (.01)	.16 (.02)	.13 (.01)	.16 (.02)
Sing/Ungram	.07 (.01)	.21 (.02)	.13 (.02)	.16 (.02)
Plural/Gram	.08 (.02)	.19 (.02)	.14 (.02)	.17 (.02)
Plural/Ungram	.08 (.02)	.17 (.02)	.13 (.02)	.18 (.02)

Table 5.1 (Cont.): Mean first-pass times, regression-path durations, first-pass regression proportions, second-pass times, non-terminal second-pass times, review times, and total times for SRC sentences (in ms where applicable) by condition and region (with standard errors of the mean by subjects for repeated measures in parentheses), Experiment 5.

	AV (*were*)	V (*promoting*)	AV & V(*were promoting*)	V+1 (*the military*)
Second-pass time				
Sing/Gram	65 (7)	83 (9)	131 (12)	56 (9)
Sing/Ungram	78 (9)	113 (10)	155 (13)	53 (7)
Plural/Gram	65 (7)	100 (9)	146 (15)	54 (8)
Plural/Ungram	79 (8)	104 (8)	164 (14)	51 (7)
Non-terminal second-pass time				
Sing/Gram	43 (6)	55 (6)	81 (9)	78 (11)
Sing/Ungram	57 (6)	78 (7)	96 (11)	76 (11)
Plural/Gram	47 (7)	77 (9)	103 (13)	77 (11)
Plural/Ungram	58 (7)	71 (8)	107 (12)	70 (11)
Review time				
Sing/Gram	22 (4)	29 (7)	50 (9)	53 (9)
Sing/Ungram	21 (5)	40 (8)	59 (11)	57 (11)
Plural/Gram	18 (4)	26 (5)	43 (7)	55 (8)
Plural/Ungram	23 (5)	36 (5)	57 (7)	50 (7)
Total time				
Sing/Gram	300 (10)	356 (14)	563 (16)	254 (8)
Sing/Ungram	302 (11)	411 (14)	616 (20)	255 (9)
Plural/Gram	284 (10)	380 (14)	566 (17)	258 (9)
Plural/Ungram	307 (9)	392 (12)	611 (17)	254 (7)

Table 5.2: Mean first-pass times, regression-path durations, first-pass regression proportions, second-pass times, non-terminal second-pass times, review times, and total times for ORC sentences (in ms where applicable) by condition and region (with standard errors of the mean by subjects for repeated measures in parentheses), Experiment 5.

	AV (*were*)	V (*promoting*)	AV & V(*were promoting*)	V+1 (*the military*)
First-pass time				
Sing/Gram	249 (8)	279 (10)	417 (13)	263 (8)
Sing/Ungram	246 (8)	289 (9)	446 (13)	258 (9)
Plural/Gram	247 (7)	269 (7)	417 (10)	261 (10)
Plural/Ungram	246 (10)	284 (8)	439 (11)	261 (8)
Regression-path duration				
Sing/Gram	345 (19)	369 (25)	551 (27)	403 (19)
Sing/Ungram	322 (23)	373 (20)	549 (22)	407 (23)
Plural/Gram	323 (45)	340 (20)	497 (16)	358 (16)
Plural/Ungram	311 (21)	381 (16)	553 (19)	404 (19)
First-pass regression proportion				
Sing/Gram	.12 (.02)	.15 (.02)	.16 (.02	.16 (.02)
Sing/Ungram	.08 (.02)	.15 (.02)	.12 (.02)	.19 (.02)
Plural/Gram	.06 (.01)	.11 (.02)	.10 (.01)	.15 (.02)
Plural/Ungram	.09 (.01)	.16 (.02)	.14 (.01)	.17 (.02)

Table 5.2 (Cont.): Mean first-pass times, regression-path durations, first-pass regression proportions, second-pass times, non-terminal second-pass times, review times, and total times for ORC sentences (in ms where applicable) by condition and region (with standard errors of the mean by subjects for repeated measures in parentheses), Experiment 5.

	AV (*were*)	V (*promoting*)	AV & V(*were promoting*)	V+1 (*the military*)
Second-pass time				
Sing/Gram	65 (7)	92 (10)	149 (16)	49 (7)
Sing/Ungram	75 (7)	103 (12)	154 (15)	54 (8)
Plural/Gram	48 (7)	67 (11)	106 (13)	46 (6)
Plural/Ungram	78 (7)	96 (8)	164 (12)	57 (8)
Non-terminal second-pass time				
Sing/Gram	42 (6)	67 (8)	100 (14)	84 (11)
Sing/Ungram	51 (6)	70 (9)	97 (10)	74 (12)
Plural/Gram	32 (6)	43 (9)	65 (11)	73 (10)
Plural/Ungram	51 (6)	63 (7)	101 (12)	80 (12)
Review time				
Sing/Gram	23 (4)	27 (6)	50 (7)	46 (9)
Sing/Ungram	23 (4)	34 (6)	57 (9)	55 (8)
Plural/Gram	18 (4)	26 (7)	42 (7)	43 (8)
Plural/Ungram	23 (5)	36 (5)	62 (7)	56 (7)
Total time				
Sing/Gram	301 (11)	368 (14)	567 (19)	247 (9)
Sing/Ungram	305 (12)	391 (15)	600 (18)	253 (8)
Plural/Gram	282 (11)	335 (11)	521 (17)	247 (7)
Plural/Ungram	298 (10)	376 (13)	599 (17)	257 (8)

Table 5.3: Summary the main effects of attractor number, grammaticality, and RC type for first-pass times, regression-path durations, first-pass regression proportions, second-pass times, non-terminal second-pass times, review times, and total times by region, Experiment 5.

	Attractor number		Grammaticality		RC type	
	*F*1 (1, 48)	*F*2 (1, 56)	*F*1 (1, 48)	*F*2 (1, 56)	*F*1 (1, 48)	*F*2 (1, 56)
AV (*were*)						
First-pass time	1.91	3.12	<1	<1	<1	<1
Regression-path duration	1.01	8.37*	<1	<1	2.12	<1
First-pass regression proportion	1.97	1.04	<1	<1	2.01	1.21
Second-pass time	<1	<1	9.34**	13.37***	1.79	1.19
Non-terminal second-pass time	<1	<1	8.74**	14.46***	4.78*	3.48
Review time	<1	<1	2.26	1.77	<1	<1
Total time	2.26	2.39	2.60	6.78*	<1	<1
V (*promoting*)						
First-pass time	<1	<1	8.03**	10.03**	<1	<1
Regression-path duration	<1	1.27	2.32	7.02*	6.57*	6.04*
First-pass regression proportion	<1	<1	3.24	3.56	11.24**	10.71**
Second-pass time	1.03	<1	11.72**	10.06*	3.65	3.63
Non-terminal second-pass time	<1	<1	4.32*	5.88*	3.93	4.59*
Review time	<1	<1	10.96**	7.62**	<1	<1
Total time	2.32	3.26	18.48***	16.84***	4.20*	4.82*

*$p < .05$. **$p < .01$. ***$p < .001$.

Table 5.3 (Cont.): Summary the main effects of attractor number, grammaticality, and RC type for first-pass times, regression-path durations, first-pass regression proportions, second-pass times, non-terminal second-pass times, review times, and total times by region, Experiment 5.

	Attractor number		Grammaticality		RC type	
	$F1$ (1, 48)	$F2$ (1, 56)	$F1$ (1, 48)	$F2$ (1, 56)	$F1$ (1, 48)	$F2$ (1, 56)
AV & V (*were promoting*)						
First-pass time	1.19	1.86	11.51**	21.10***	3.41	4.86*
Regression-path duration	1.52	3.05	2.48	4.73*	1.62	2.12
First-pass regression proportion	<1	<1	<1	<1	<1	<1
Second-pass time	<1	<1	10.31**	8.93**	<1	<1
Non-terminal second-pass time	<1	<1	3.71	4.12*	<1	<1
Review time	<1	<1	8.91**	6.25*	<1	<1
Total time	1.47	1.91	22.87***	25.93***	3.79	3.69
V+1 (*the military*)						
First-pass time	<1	1.80	<1	<1	<1	<1
Regression-path duration	<1	<1	1.00	1.82	<1	<1
First-pass regression proportion	<1	<1	2.08	4.27*	<1	<1
Second-pass time	<1	<1	<1	<1	<1	<1
Non-terminal second-pass time	<1	<1	<1	<1	<1	<1
Review time	<1	<1	1.39	1.15	<1	<1
Total time	<1	<1	<1	<1	<1	<1

*p < .05. **p < .01. ***p < .001.

Table 5.4: Summary the two-way interactions of attractor number, grammaticality, and RC type for first-pass times, regression-path durations, first-pass regression proportions, second-pass times, non-terminal second-pass times, review times, and total times by region, Experiment 5.

	Attractor number x Grammaticality		Attractor number x RC type		RC type x Grammaticality	
	*F*1 (1, 48)	*F*2 (1, 56)	*F*1 (1, 48)	*F*2 (1, 56)	*F*1 (1, 48)	*F*2 (1, 56)
AV (*were*)						
First-pass time	<1	3.12	<1	<1	<1	3.09
Regression-path duration	1.05	<1	<1	<1	<1	<1
First-pass regression proportion	2.30	2.22	3.16	2.35	<1	<1
Second-pass time	1.92	1.34	<1	<1	<1	<1
Non-terminal second-pass time	<1	<1	1.34	1.36	<1	<1
Review time	5.10*	2.56	<1	<1	<1	<1
Total time	<1	1.08	<1	<1	1.19	<1
V (*promoting*)						
First-pass time	<1	<1	1.79	1.19	<1	<1
Regression-path duration	<1	<1	<1	<1	<1	<1
First-pass regression proportion	<1	<1	<1	<1	<1	<1
Second-pass time	<1	<1	2.62	3.25	<1	<1
Non-terminal second-pass time	<1	<1	6.07*	5.07*	<1	<1
Review time	<1	<1	<1	<1	<1	<1
Total time	<1	<1	3.37	3.44	<1	<1

*$p < .05$. **$p < .01$. ***$p < .001$.

Table 5.4 (Cont.): Summary the two-way interactions of attractor number, grammaticality, and RC type for first-pass times, regression-path durations, first-pass regression proportions, second-pass times, non-terminal second-pass times, review times, and total times by region, Experiment 5.

	Attractor number x Grammaticality		Attractor number x RC type		RC type x Grammaticality	
	*F*1 (1, 48)	*F*2 (1, 56)	*F*1 (1, 48)	*F*2 (1, 56)	*F*1 (1, 48)	*F*2 (1, 56)
AV & V (*were promoting*)						
First-pass time	<1	<1	<1	<1	<1	<1
Regression-path duration	1.11	<1	<1	<1	<1	<1
First-pass regression proportion	2.70	1.81	1.71	1.13	<1	<1
Second-pass time	2.33	1.57	2.96	3.31	<1	<1
Non-terminal second-pass time	<1	<1	7.48**	5.74*	<1	<1
Review time	1.24	<1	<1	<1	<1	<1
Total time	<1	<1	1.03	1.06	<1	<1
V+1 (*the military*)						
First-pass time	<1	<1	1.36	1.67	<1	<1
Regression-path duration	<1	<1	2.80	2.64	1.40	1.76
First-pass regression proportion	<1	<1	1.77	2.19	<1	1.33
Second-pass time	<1	<1	<1	<1	1.71	2.41
Non-terminal second-pass time	<1	<1	<1	<1	<1	<1
Review time	<1	<1	<1	<1	1.44	1.19
Total time	<1	<1	<1	<1	<1	<1

*p < .05. **p < .01. ***p < .001.

Table 5.5. Summary the three-way interaction of attractor number, grammaticality, and RC type for first-pass times, regression-path durations, first-pass regression proportions, second-pass times, non-terminal second-pass times, review times, and total times by region, Experiment 5.

	Attractor number x Grammaticality x RC type	
	*F*1 (1, 48)	*F*2 (1, 56)
AV (*were*)		
First-pass time	<1	<1
Regression-path duration	<1	<1
First-pass regression proportion	2.14	2.02
Second-pass time	1.32	1.06
Non-terminal second-pass time	1.21	<1
Review time	<1	<1
Total time	<1	<1
V (*promoting*)		
First-pass time	<1	<1
Regression-path duration	2.96	2.90
First-pass regression proportion	7.30**	5.72*
Second-pass time	3.59	4.41*
Non-terminal second-pass time	7.85**	4.64*
Review time	<1	<1
Total time	<1	5.28*
AV & V (*were promoting*)		
First-pass time	<1	<1
Regression-path duration	2.48	1.17
First-pass regression proportion	4.64*	4.26*
Second-pass time	2.49	3.08
Non-terminal second-pass time	3.37	2.92
Review time	<1	<1
Total time	1.59	1.64
V+1 (*the military*)		
First-pass time	<1	<1
Regression-path duration	1.43	2.42
First-pass regression proportion	<1	<1
Second-pass time	<1	<1
Non-terminal second-pass time	<1	<1
Review time	<1	<1
Total time	<1	<1

*$p < .05$. **$p < .01$. ***$p < .001$.

Table 5.6: Summary of the effects of attractor number and grammaticality in SRC sentences for first-pass times, regression-path durations, first-pass regression proportions, second-pass times, non-terminal second-pass times, review times, and total times by region, Experiment 5.

	Attractor number		Grammaticality		Attractor Number x Grammaticality	
	*F*1 (1, 48)	*F*2 (1, 56)	*F*1 (1, 48)	*F*2 (1, 56)	*F*1 (1, 48)	*F*2 (1, 56)
AV (*were*)						
First-pass time	2.77	3.34	1.48	4.27*	<1	1.80
Regression-path duration	<1	3.04	<1	<1	<1	<1
First-pass regression proportion	<1	<1	<1	<1	<1	<1
Second-pass time	<1	<1	3.78	4.56*	<1	<1
Non-terminal second-pass time	<1	<1	4.96*	5.38*	<1	<1
Review time	<1	<1	<1	<1	1.21	<1
Total time	<1	<1	1.95	4.67*	<1	<1
V (*promoting*)						
First-pass time	<1	<1	6.83*	5.74*	<1	<1
Regression-path duration	<1	<1	1.88	2.29	<1	1.46
First-pass regression proportion	<1	<1	1.04	<1	3.72	4.46*
Second-pass time	<1	<1	6.28*	5.51*	2.58	2.49
Non-terminal second-pass time	1.28	<1	2.38	1.82	4.27*	2.98
Review time	<1	1.05	6.27*	6.93*	<1	<1
Total time	<1	<1	9.72**	8.87**	3.73	3.90

*$p < .05$. **$p < .01$. ***$p < .001$.

Table 5.6 (Cont.): Summary of the effects of attractor number and grammaticality in SRC sentences for first-pass times, regression-path durations, first-pass regression proportions, second-pass times, non-terminal second-pass times, review times, and total times by region, Experiment 5.

	Attractor number		Grammaticality		Attractor number x Grammaticality	
	$F1$ (1, 48)	$F2$ (1, 56)	$F1$ (1, 48)	$F2$ (1, 56)	$F1$ (1, 48)	$F2$ (1, 56)
AV & V (*were promoting*)						
First-pass time	1.68	1.35	7.70**	9.42**	<1	<1
Regression-path duration	<1	<1	1.90	2.05	<1	<1
First-pass regression proportion	3.89	2.77	<1	<1	4.28*	3.86
Second-pass time	1.28	1.13	3.49	4.01	<1	<1
Non-terminal second-pass time	4.02*	2.65	1.22	1.42	<1	<1
Review time	<1	<1	3.14	4.25*	<1	<1
Total time	<1	<1	11.43**	12.54***	<1	<1
V+1 (*the military*)						
First-pass time	4.33*	2.77	<1	<1	<1	<1
Regression-path duration	<1	1.20	<1	<1	<1	<1
First-pass regression proportion	<1	1.06	<1	<1	<1	<1
Second-pass time	<1	<1	<1	<1	<1	<1
Non-terminal second-pass time	<1	<1	<1	<1	<1	<1
Review time	<1	<1	<1	<1	<1	<1
Total time	<1	<1	<1	<1	<1	<1

*p < .05. **p < .01. ***p < .001.

Table 5.7: Summary of the effects of attractor number and grammaticality in ORC sentences for first-pass times, regression-path durations, first-pass regression proportions, second-pass times, non-terminal second-pass times, review times, and total times by region, Experiment 5.

	Attractor number		Grammaticality		Attractor number x Grammaticality	
	*F*1 (1, 48)	*F*2 (1, 56)	*F*1 (1, 48)	*F*2 (1, 56)	*F*1 (1, 48)	*F*2 (1, 56)
AV (*were*)						
First-pass time	<1	<1	<1	<1	1.97	<1
Regression-path duration	<1	5.22*	<1	1.32	<1	<1
First-pass regression proportion	3.89	2.77	<1	<1	4.28*	3.86
Second-pass time	1.18	1.82	11.46**	9.99**	3.34	2.84
Non-terminal second-pass time	1.30	1.45	7.35**	7.46**	1.11	<1
Review time	<1	<1	2.40	2.56	3.35	2.25
Total time	2.54	2.38	1.25	1.98	<1	<1
V (*promoting*)						
First-pass time	1.75	<1	3.35	3.26	<1	<1
Regression-path duration	<1	1.26	1.41	5.43*	1.50	1.78
First-pass regression proportion	1.01	1.24	1.82	2.45	3.95	2.84
Second-pass time	3.20	4.59*	5.99*	6.03*	1.27	1.17
Non-terminal second-pass time	4.20*	6.70*	3.12	4.22*	2.12	1.16
Review time	<1	<1	3.06	3.09	<1	<1
Total time	5.86*	8.74**	10.18**	9.18**	<1	<1

*$p < .05$. **$p < .01$. ***$p < .001$.

Table 5.7 (Cont.): Summary of the effects of attractor number and grammaticality in ORC sentences for first-pass times, regression-path durations, first-pass regression proportions, second-pass times, non-terminal second-pass times, review times, and total times by condition and region, Experiment 5.

	Attractor number		Grammaticality		Attractor number x Grammaticality	
	*F*1 (1, 48)	*F*2 (1, 56)	*F*1 (1, 48)	*F*2 (1, 56)	*F*1 (1, 48)	*F*2 (1, 56)
AV & V (*were promoting*)						
First-pass time	<1	<1	7.64**	7.09*	<1	<1
Regression-path duration	1.84	2.35	1.97	3.85	3.81	1.87
First-pass regression proportion	1.47	<1	<1	<1	5.99*	5.77*
Second-pass time	2.00	2.78	8.53**	6.91*	3.96	4.81*
Non-terminal second-pass time	3.10	3.77	3.59	3.26	3.50	3.48
Review time	<1	<1	4.50*	3.69	<1	1.34
Total time	2.48	3.32	18.01***	14.74***	2.23	3.29
V+1 (*the military*)						
First-pass time	<1	<1	<1	<1	<1	<1
Regression-path duration	2.00	1.16	1.96	3.81	2.24	2.87
First-pass regression proportion	1.36	1.65	1.77	4.53*	<1	<1
Second-pass time	<1	<1	1.58	2.32	<1	<1
Non-terminal second-pass time	<1	<1	<1	<1	<1	<1
Review time	<1	<1	2.85	2.40	<1	<1
Total time	<1	<1	1.21	<1	<1	<1

*$p < .05$. **$p < .01$. ***$p < .001$.

Table 5.8. Summary of the tests of the simple effect of grammaticality in SRC sentences for first-pass times, regression-path durations, first-pass regression proportions, second-pass times, non-terminal second-pass times, review times, and total times by region, Experiment 5.

	Singular		Plural	
	$F1$ (1, 48)	$F2$ (1, 56)	$F1$ (1, 48)	$F2$ (1, 56)
AV (*were*)				
First-pass time	<1	<1	3.53	8.47**
Regression-path duration	<1	<1	<1	<1
First-pass regression proportion	<1	<1	<1	<1
Second-pass time	2.02	2.02	2.35	2.14
Non-terminal second-pass time	4.27*	4.69*	1.30	1.22
Review time	<1	<1	<1	1.07
Total time	<1	<1	4.41*	4.89*
V (*promoting*)				
First-pass time	4.79*	4.76*	3.02	1.83
Regression-path duration	2.69	4.07*	<1	<1
First-pass regression proportion	5.23*	6.03*	<1	<1
Second-pass time	6.97*	8.02**	<1	<1
Non-terminal second-pass time	6.84*	4.73*	<1	<1
Review time	2.32	2.92	4.90*	3.43
Total time	11.38**	15.97***	<1	<1
AV & V (*were promoting*)				
First-pass time	3.27	5.13*	5.75*	4.63*
Regression-path duration	1.29	1.61	<1	<1
First-pass regression proportion	<1	<1	<1	<1
Second-pass time	2.66	2.04	1.23	1.48
Non-terminal second-pass time	1.73	1.28	<1	<1
Review time	<1	<1	3.93	3.53
Total time	6.23*	8.28**	6.10*	4.67*
V+1 (*the military*)				
First-pass time	<1	<1	<1	<1
Regression-path duration	<1	<1	<1	<1
First-pass regression proportion	<1	<1	<1	<1
Second-pass time	<1	<1	<1	<1
Non-terminal second-pass time	<1	<1	<1	<1
Review time	<1	<1	<1	<1
Total time	<1	<1	<1	<1

*$p < .05$. **$p < .01$. ***$p < .001$.

Table 5.9. Summary of the tests of the simple effect of grammaticality in ORC sentences for first-pass times, regression-path durations, first-pass regression proportions, second-pass times, non-terminal second-pass times, review times, and total times by region, Experiment 5.

	Singular		Plural	
	$F1$ (1, 48)	$F2$ (1, 56)	$F1$ (1, 48)	$F2$ (1, 56)
AV (*were*)				
First-pass time	<1	<1	<1	<1
Regression-path duration	1.06	<1	<1	<1
First-pass regression proportion	2.32	2.06	2.95	2.31
Second-pass time	1.34	1.27	13.56***	11.57**
Non-terminal second-pass time	1.99	2.18	6.47*	6.83*
Review time	<1	<1	4.67*	5.05*
Total time	<1	<1	1.50	1.64
V (*promoting*)				
First-pass time	<1	1.04	3.28	2.23
Regression-path duration	<1	<1	3.17	6.69*
First-pass regression proportion	<1	<1	7.07*	6.16*
Second-pass time	1.02	1.29	6.72*	6.41*
Non-terminal second-pass time	<1	<1	4.82*	5.62*
Review time	1.03	1.68	1.86	2.07
Total time	2.25	3.31	9.56**	7.13**
AV & V (*were promoting*)				
First-pass time	3.89	3.71	3.43	3.97
Regression-path duration	<1	<1	6.82*	5.23*
First-pass regression proportion	2.93	2.66	4.88*	3.73
Second-pass time	<1	<1	13.69***	12.10***
Non-terminal second-pass time	<1	<1	7.61**	8.52**
Review time	<1	<1	4.03	4.32*
Total time	2.73	3.96	16.11***	16.58***
V+1 (*the military*)				
First-pass time	<1	<1	<1	<1
Regression-path duration	<1	<1	6.62*	8.17**
First-pass regression proportion	1.80	2.61	<1	1.55
Second-pass time	<1	<1	2.23	2.15
Non-terminal second-pass time	<1	<1	<1	<1
Review time	<1	<1	2.77	2.05
Total time	<1	<1	1.27	1.06

*$p < .05$. **$p < .01$. ***$p < .001$.

Table 5.10. Summary of the tests of the simple effect of attractor number in SRC sentences for first-pass times, regression-path durations, first-pass regression proportions, second-pass times, non-terminal second-pass times, review times, and total times by region, Experiment 5.

	Grammatical		Ungrammatical	
	$F1$ (1, 48)	$F2$ (1, 56)	$F1$ (1, 48)	$F2$ (1, 56)
AV (*were*)				
First-pass time	5.62*	4.88*	<1	<1
Regression-path duration	<1	<1	<1	<1
First-pass regression proportion	<1	<1	<1	<1
Second-pass time	<1	<1	<1	<1
Non-terminal second-pass time	<1	<1	<1	<1
Review time	1.37	<1	<1	<1
Total time	1.62	2.02	<1	<1
V (*promoting*)				
First-pass time	<1	<1	<1	<1
Regression-path duration	<1	<1	<1	1.36
First-pass regression proportion	1.31	1.88	1.83	2.09
Second-pass time	2.65	2.16	<1	<1
Non-terminal second-pass time	5.46*	3.09	<1	<1
Review time	<1	<1	<1	<1
Total time	2.87	2.29	<1	1.52
AV & V (*were promoting*)				
First-pass time	1.36	<1	<1	<1
Regression-path duration	<1	<1	<1	<1
First-pass regression proportion	<1	<1	<1	<1
Second-pass time	1.07	<1	<1	<1
Non-terminal second-pass time	3.59	3.05	<1	<1
Review time	<1	<1	<1	<1
Total time	<1	<1	<1	<1
V+1 (*the military*)				
First-pass time	3.48	3.22	<1	<1
Regression-path duration	1.02	<1	<1	<1
First-pass regression proportion	<1	<1	<1	1.57
Second-pass time	<1	<1	<1	<1
Non-terminal second-pass time	<1	<1	<1	<1
Review time	<1	<1	<1	<1
Total time	<1	<1	<1	<1

*$p < .05$. **$p < .01$. ***$p < .001$.

Table 5.11. Summary of the tests of the simple effect of attractor number in ORC sentences for first-pass times, regression-path durations, first-pass regression proportions, second-pass times, non-terminal second-pass times, review times, and total times by region, Experiment 5.

	Grammatical		Ungrammatical	
	$F1$ (1, 48)	$F2$ (1, 56)	$F1$ (1, 48)	$F2$ (1, 56)
AV (*were*)				
First-pass time	<1	<1	<1	<1
Regression-path duration	<1	3.31	<1	<1
First-pass regression proportion	8.16**	5.57*	<1	<1
Second-pass time	5.23*	4.10*	<1	<1
Non-terminal second-pass time	2.45	2.63	<1	<1
Review time	2.55	2.14	<1	<1
Total time	2.36	1.78	<1	<1
V (*promoting*)				
First-pass time	<1	1.16	<1	<1
Regression-path duration	1.64	3.48	<1	<1
First-pass regression proportion	3.94	4.74*	1.13	<1
Second-pass time	4.76*	5.79*	<1	<1
Non-terminal second-pass time	6.21*	6.71*	<1	1.15
Review time	<1	<1	<1	<1
Total time	6.98*	6.39*	<1	2.15
AV & V (*were promoting*)				
First-pass time	<1	<1	<1	<1
Regression-path duration	5.35*	3.62	<1	<1
First-pass regression proportion	7.41*	5.56*	<1	<1
Second-pass time	5.58*	7.08*	<1	<1
Non-terminal second-pass time	5.22*	6.65*	<1	<1
Review time	<1	<1	<1	<1
Total time	5.13*	5.51*	<1	<1
V+1 (*the military*)				
First-pass time	<1	<1	<1	<1
Regression-path duration	3.98	4.80*	<1	<1
First-pass regression proportion	<1	<1	1.52	1.08
Second-pass time	<1	<1	<1	<1
Non-terminal second-pass time	<1	<1	<1	<1
Review time	<1	<1	<1	<1
Total time	<1	<1	<1	<1

*p < .05. **p < .01. ***p < .001.

5.2.1 First-pass measures

At region AV, first-pass time revealed a marginal effect of attractor number by items ($F1(1, 48) = 1.91$; $F2(1, 56) = 3.12$, $p = .08$), suggesting longer RTs for singular-attractor sentences. This measure also revealed a marginal interaction by items between attractor number and grammaticality, suggesting particularly short first-pass times for grammatical plural-attractor sentences ($F1(1, 48) < 1$; $F2(1, 56) = 3.12$, $p = .08$), and a marginal interaction by items between RC type and grammaticality ($F1(1, 48) < 1$; $F2(1, 56) = 3.09$, $p = .08$; grammaticality, RC type, and attractor number x grammaticality x RC type: all F's < 1), suggesting particularly short first-pass times for grammatical SRC sentences.

Analyses separated by RC type revealed a marginal by-items effect of attractor number in SRCs ($F1(1, 48) = 2.77$; $F2(1, 56) = 3.34$, $p = .07$). They also showed a by-items effect of grammaticality ($F1(1, 48) = 1.48$; $F2(1, 56) = 4.27$, $p < .05$; attractor number x grammaticality: both F's < 2), with ungrammatical sentences taking longer than their grammatical counterparts. Tests of the simple effect of grammaticality revealed this effect occurred only for plural-attractor sentences ($F1(1, 48) = 3.53$ $p = .07$; $F2(1, 56) = 8.47$, $p < .01$; singular attractor: both F's < 1), with longer first-pass times for ungrammatical sentences. Tests of the simple effect of attractor number in SRC sentences revealed an effect for grammatical sentences with longer RTs for singular-attractor sentences ($F1(1, 48) = 5.62$, $p < .05$; $F2(1, 56) = 4.88$, $p < .05$; plural attractor: both F's < 1). No statistically reliable results were seen in ORCs (all F's < 2). These results, graphed in Figures 5.1 and 5.2., suggest that processing costs related to indexing ungrammaticality were observed on ungrammatical SRC sentences with plural attractors.

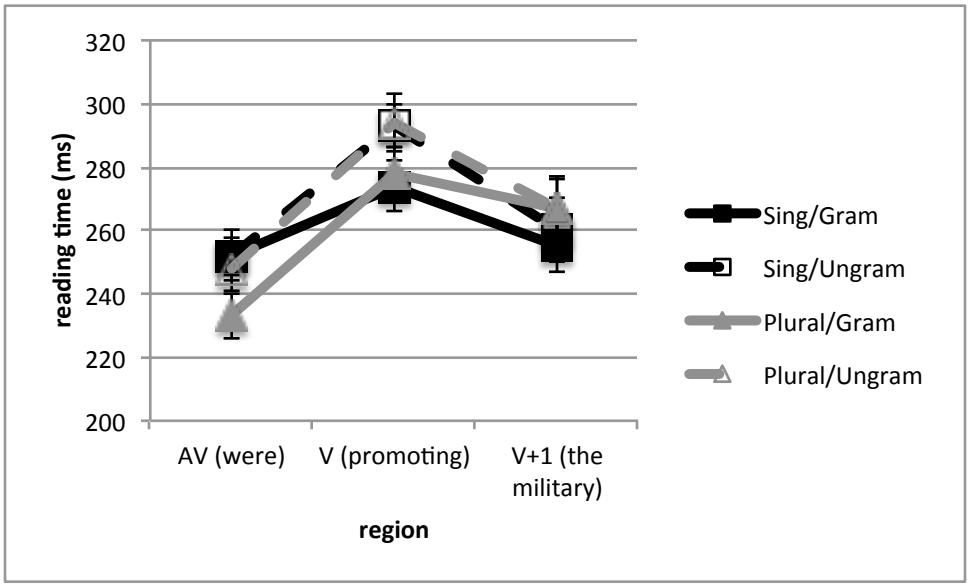


Figure 5.1. Mean first-pass times (by subjects) for grammatical and ungrammatical SRCs with singular and plural attractor variants, Experiment 5. Error bars show ±1 standard error of the mean for repeated measures.

Regression-path duration, shown in Figures 5.3 and 5.4, revealed a main effect of attractor number by items, suggesting longer regression-path durations for singular-attractor sentences ($F1(1, 48) = 1.01$; $F2(1, 56) = 8.37$, $p < .05$; grammaticality, RC type, attractor number x grammaticality, attractor number x RC type, RC type x grammaticality, and attractor number x grammaticality x RC type: all F's < 2.5).

Analyses separated by RC type revealed a marginal effect of attractor number in SRCs ($F1(1, 48) < 1$; $F2(1, 56) = 3.04$, $p = .09$; attractor number and attractor number x grammaticality: all F's < 1), suggesting longer regression-path durations for singular-attractor sentences.

ORC analyses revealed a similar effect of attractor number ($F1(1, 48) = 5.22$, $p < .05$; F2 < 1; grammaticality and attractor number x grammaticality: all F's < 1.5), also suggesting longer RTs for singular-attractor sentences. Tests of the simple effect of atractor number re-

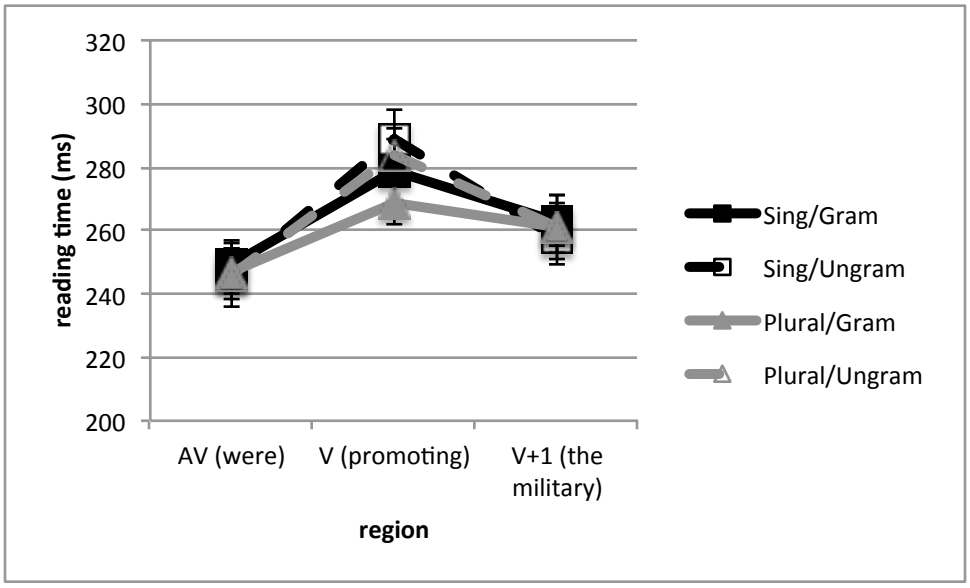


Figure 5.2. Mean first-pass times (by subjects) for grammatical and ungrammatical ORCs with singular and plural attractor variants, Experiment 5. Error bars show ±1 standard error of the mean for repeated measures.

vealed that this effect was only seen for grammatical sentences ($F1(1, 48) < 1$; F2 = 3.31, p = .07; ungrammatical: both F's < 1), with longer RTs for singular-attractor sentences. The results in this region did not yield any effects of grammaticality but suggest that singular-attractor sentences had longer regression-path durations than plural-attractor sentences.

Also in region AV, first-pass regression proportion revealed a marginal by-subjects interaction between attractor number and RC type, suggesting more first-pass regressions for singular-attractor ORC sentences ($F1(1, 48) = 3.16$, p = .08; $F2(1, 56) = 2.35$; attractor number, grammaticality, RC type, attractor number x grammaticality, RC type x grammaticality, and attractor number x grammaticality x RC type: all F's < 2.5).

Analyses separated by RC type did not reveal any statistically reliable results for SRCs (all F's < 1), but revealed a marginal effect of attractor number by subjects in ORCs ($F1(1,$

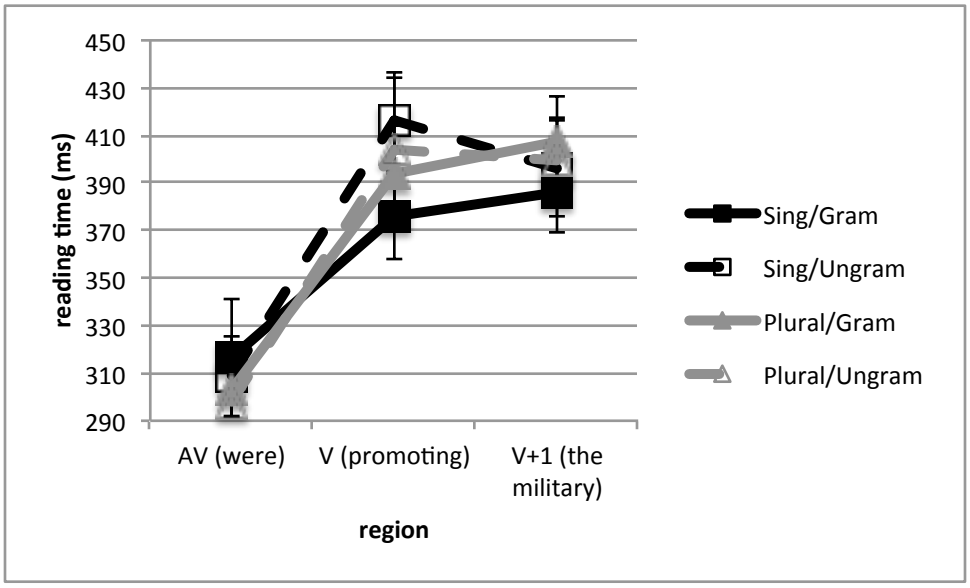


Figure 5.3. Mean regression-path durations (by subjects) for grammatical and ungrammatical SRCs with singular and plural attractor variants, Experiment 5. Error bars show ±1 standard error of the mean for repeated measures.

48) = 3.89, p = . 05; $F2(1, 56) = 2.77$), with a trend towards more first-pass regressions for singular-attractor sentences. ORCs also showed a marginal interaction between grammaticality and attractor number ($F1(1, 48) = 4.28$, $p < .05$; $F2(1, 56) = 3.86$, $p = .05$; grammaticality: both F's < 1), suggesting that, for singular-attractor sentences, grammatical sentences show more first-pass regressions, but for plural-attractor sentences, ungrammatical sentences show more first-pass regressions. This interaction was supported by tests of the simple effects of attractor number and grammaticality. Tests of the simple effect of attractor number revealed an effect for grammatical sentences ($F1(1, 48) = 8.16$, $p < .01$; $F2(1, 56) = 5.57$, $p < .05$; ungrammatical: both F's < 1), with more first-pass regressions for singular-attractor sentences. Tests of the simple effect of grammaticality revealed a marginal by-subjects effect for plural-attractor sentences that suggests more first-pass regressions for ungrammatical sentences ($F1(1, 48) =$

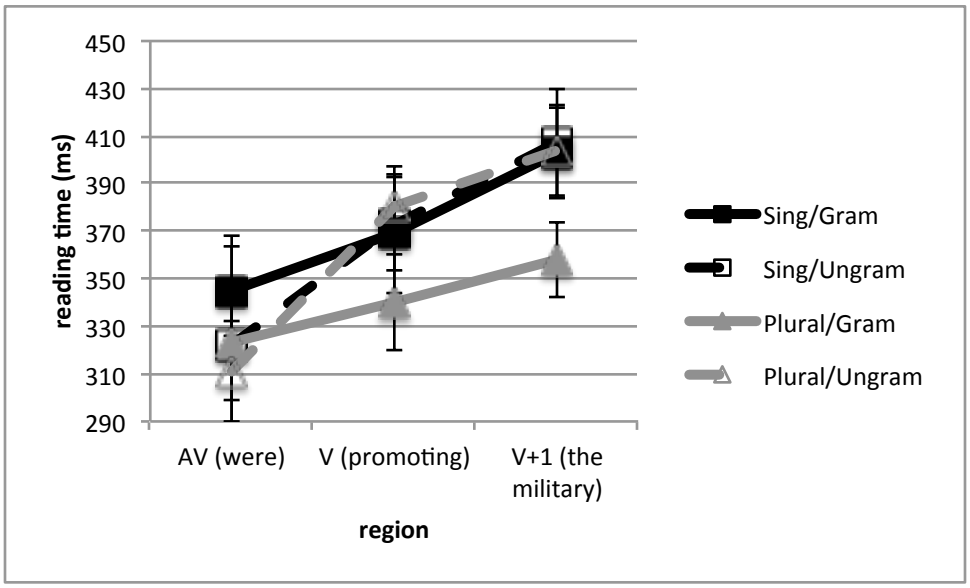


Figure 5.4. Mean regression-path durations (by subjects) for grammatical and ungrammatical ORCs with singular and plural attractor variants, Experiment 5. Error bars show ±1 standard error of the mean for repeated measures.

2.95, $p = .09$; $F2(1, 56) = 2.31$; singular attractor: both F's < 2.5). These results, graphed in Figures 5.5 and 5.6, suggest that, for ORCs, ungrammatical sentences with plural attractors had more first-pass regressions than their grammatical counterparts and that grammatical singular-attractor sentences had the highest incidence of first-pass regressions at the agreeing verb.

Thus, at the agreeing verb, first-pass time indicated processing difficulty for all ungrammatical sentences in SRCs, and first-pass regression proportion indicated more first-pass regressions for plural-attractor sentences in ORCs.

At the content verb (V), first-pass time revealed a main effect of grammaticality, with longer RTs for ungrammatical sentences ($F1(1, 48) = 8.03$, $p < .01$; $F2(1, 56) = 10.03$, $p < .01$;

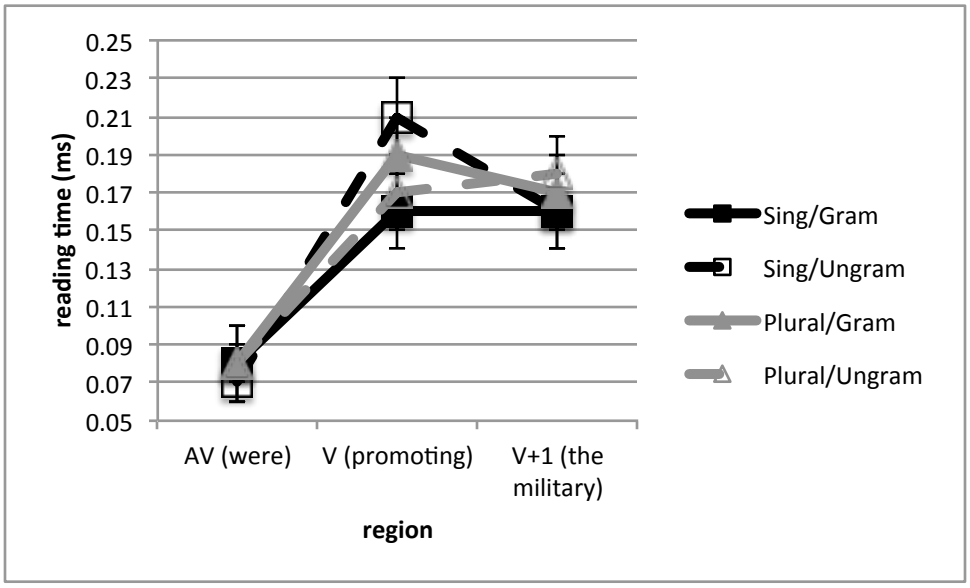


Figure 5.5. Probability of first-pass regression (by subjects) for grammatical and ungrammatical SRCs with singular and plural attractor variants, Experiment 5. Error bars show ±1 standard error of the mean for repeated measures.

attractor number, RC type, attractor number x grammaticality, attractor number x RC type, RC type x grammaticality, and attractor number x grammaticality x RC type: all F's < 2).

Analyses separated by RC type revealed a main effect of grammaticality in SRCs ($F1(1, 48) = 6.83$, $p < .05$; $F2(1, 56) = 5.74$, $p < .05$; attractor number, attractor number x grammaticality: all F's < 1), with longer first-pass times for ungrammatical sentences. Tests of the simple effect of grammaticality further revealed that this effect is seen in singular-attractor sentences ($F1(1, 48) = 4.79$, $p < .05$; $F2(1, 56) = 4.76$, $p < .05$), with longer first-pass times for ungrammatical sentences. They also revealed a marginal by-subjects effect in plural-attractor sentences ($F1(1, 48) = 3.02$, $p = .09$; $F2(1, 56) = 1.83$), suggesting longer first-pass times for ungrammatical sentences. These results indicate that, in SRC sentences, processing costs for

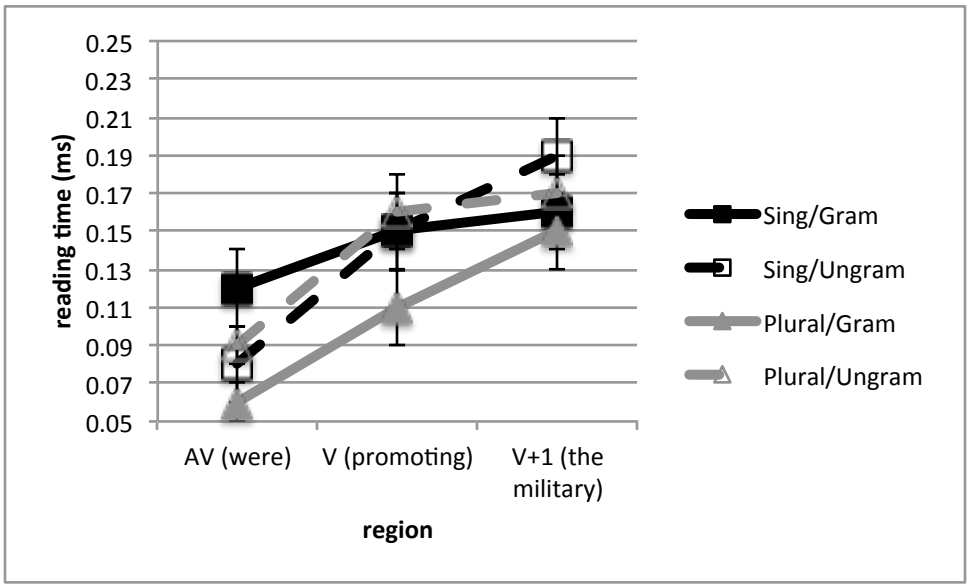


Figure 5.6. Probability of first-pass regression (by subjects) for grammatical and ungrammatical ORCs with singular and plural attractor variants, Experiment 5. Error bars show ±1 standard error of the mean for repeated measures.

ungrammaticality were indexed clearly for singular-attractor sentences, and only marginally for plural-attractor sentences.

ORC sentences revealed a marginal effect of grammaticality at the content verb ($F1(1, 48) = 3.35$, $p = .07$; $F2(1, 56) = 3.26$, $p = .08$; attractor number, attractor number x grammaticality: all F's < 2), with longer first-pass times for ungrammatical sentences. Tests of the simple effect of grammaticality revealed that this effect was seen only marginally by subjects on plural-attractor sentences, suggesting longer first-pass times for ungrammatical sentences ($F1(1, 48) = 3.28$, $p = .08$; $F2(1, 56) = 2.23$; singular attractor: both F's < 1.5). Unlike the SRC results, these results suggest that, in ORCs, processing costs related to indexing ungrammaticality were only present for plural-attractor sentences.

Regression-path duration revealed a marginal effect of grammaticality ($F1(1, 48) = 2.32$; $F2(1, 56) = 7.02$, $p < .05$), suggesting longer RTs for ungrammatical sentences. This measure also revealed a main effect of RC type, with longer regression-path durations in SRC sentences ($F1(1, 48) = 6.57$, $p < .05$; $F2(1, 56) = 6.04$, $p < .05$). Lastly, this measure revealed a three-way interaction between attractor number, grammaticality, and RC type ($F1(1, 48) = 2.96$, p = .09; $F2(1, 56) = 2.90$, = .09; attractor number, attractor number x grammaticality, attractor number x RC type, and RC type x grammaticality all F's < 1.5).

In the analyses separated by RC type, no statistically reliable results were found for SRCs (all F's < 2.5). However, tests of the simple effect of grammaticality revealed a by-items effect for singular-attractor sentences ($F1(1, 48) = 2.69$; $F2(1, 56) = 4.07$, $p < .05$; plural attractor: both F's < 1), suggesting longer regression-path durations for ungrammatical sentences. This finding suggests that processing costs related to indexing ungrammaticality were observed for ungrammatical sentences with singular attractors but not for ungrammatical sentences with plural attractors.

ORCs, on the other hand, continued to show processing difficulty for ungrammatical plural-attractor sentences. A by-items effect of grammaticality ($F1(1, 48) = 1.41$; $F2(1, 56) = 5.43$, $p < .05$; attractor number and attractor number x grammaticality: all F's < 2) showed a trend toward longer RTs for ungrammatical sentences. Tests of the simple effect of grammaticality revealed that this effect was marginal for plural-attractor sentences, suggesting longer regression-path durations for ungrammatical sentences ($F1(1, 48) = 3.17$, $p = .08$; $F2(1, 56) = 6.69$, $p < .05$; singular attractor: both F's < 1). The ORC results differ from the SRC's in that,

for SRC sentences, processing costs related to indexing ungrammaticality were indexed for singular-attractor sentences, but not for plural-attractor sentences. However, ORC sentences revealed processing costs related to indexing ungrammaticality for plural-attractor sentences, but not for singular-attractor sentences.

At the content verb, first-pass regression proportion revealed a marginal effect of grammaticality ($F1(1, 48) = 3.24$, $p = .08$; $F2(1, 56) = 3.56$, $p = .06$), suggesting more first-pass regressions for ungrammatical sentences. There was also an effect of RC type ($F1(1, 48) = 11.24$, $p < .01$; $F2(1, 56) = 10.71$, $p < .01$), with more first-pass regressions for SRCs. Lastly, this measure demonstrated a three-way interaction of grammaticality, attractor number, and RC type ($F1(1, 48) = 7.30$, $p < .01$; $F2(1, 56) = 5.72$, $p < .05$; attractor number, attractor number x grammaticality, attractor number x RC type, and RC type x grammaticality: all F's < 1).

Analyses separated by RC type revealed that SRCs showed a marginal interaction of grammaticality and attractor number ($F1(1, 48) = 3.72$, $p = .06$; $F2(1, 56) = 4.46$, $p < .05$; attractor number and grammaticality: all F's < 1.5), suggesting that ungrammatical singular-attractor sentences had more first-pass regressions than other sentence types. This interaction was supported by tests of the simple effect of grammaticality, which only revealed an effect for singular-attractor sentences ($F1(1, 48) = 5.23$, $p < .05$; $F2(1, 56) = 6.03$, $p < .05$; plural attractor: both F's < 1), showing more first-pass regressions for ungrammatical sentences. The SRC results continue to show that processing costs related to the indexation of ungrammaticality, in the form of regressive eye movements, were only seen on ungrammatical singular-attractor sentences.

Analyses separated by RC type revealed a marginal interaction of grammaticality and attractor number in ORC sentences ($F1(1, 48) = 3.95$, $p = .05$; $F2(1, 56) = 2.84$, $p = .1$; attractor number and grammaticality: all F's < 2.5), suggesting particularly few first-pass regressions for grammatical plural-attractor sentences. This interaction was supported by tests of the simple effects of grammaticality and attractor number. An effect of grammaticality was observed for only plural-attractor sentences ($F1(1, 48) = 7.07$, $p < .05$; $F2(1, 56) = 6.16$, $p < .05$; singular attractor: both F's < 1), with more first-pass regressions for ungrammatical sentences. Furthermore, an effect of attractor number was observed for grammatical sentences, with more first-pass regressions for singular-attractor sentences ($F1(1, 48) = 3.94$, $p = .05$; $F2(1, 56) = 4.74$, $p < .05$; ungrammatical: both F's < 1.5). The results in ORC sentences continue to pattern differently from SRC sentences, with processing costs for ungrammaticality, in the form of regressive eye movements, only being indexed for plural-attractor sentences.

In sum, the content verb continued to show indications of processing difficulty for all ungrammatical SRC sentences under first-pass time, though stronger evidence was seen for singular-attractor sentences. More importantly, regression-path duration and first-pass regression proportion showed evidence of processing difficulty only for singular-attractor SRC sentences. ORC sentences however, showed indications of processing difficulty for only plural-attractor sentences under first-pass time, regression-path duration, and first-pass regression proportion.

The combined verbal region (*were promoting*) revealed a main effect of grammaticality in first-pass time ($F1(1, 48) = 11.51$, $p < .01$; $F2(1, 56) = 21.10$, $p < .001$), with longer first-

pass times for ungrammatical sentences. This region also revealed a marginal effect of RC type, suggesting longer first-pass times for SRCs ($F1(1, 48) = 3.41$, $p = .07$; $F2(1, 56) = 4.86$, $p < .05$; attractor number, attractor number x grammaticality, attractor number x RC type, RC type x grammaticality, and attractor number x grammaticality x RC type: all F's < 2).

Analyses separated by RC type revealed an effect of grammaticality in SRC sentences, with longer first-pass times for ungrammatical sentences ($F1(1, 48) = 7.70$, $p < .01$; $F2(1, 56) = 9.42$, $p < .01$; attractor number, attractor number x grammaticality: all F's < 2). Tests of the simple effect of grammaticality revealed a marginal effect for singular-attractor sentences ($F1(1, 48) = 3.27$, $p = .08$; $F2(1, 56) = 5.13$, $p < .05$), with longer first-pass times for ungrammatical sentences. They also showed an effect for plural-attractor sentences($F1(1, 48) = 5.75$, $p < .05$; $F2(1, 56) = 4.63$, $p < .05$), with longer first-pass times for ungrammatical sentences. These effects, shown in Figures 5.7 and 5.8, indicated that ungrammatical SRC sentences had longer RTs than grammatical SRC sentences, and continue to show that the first-pass time revealed indications of processing difficulty for ungrammaticality on singular- and plural-attractor SRC sentences.

Analyses separated by RC type also revealed an effect of grammaticality in ORC sentences, with longer first-pass times for ungrammatical sentences ($F1(1, 48) = 7.64$, $p < .01$; $F2(1, 56) = 7.09$, $p < .05$; attractor number, attractor number x grammaticality: all F's < 1). Tests of the simple effect of grammaticality revealed a marginal effect for singular- and plural-attractor sentences (singular-attractor sentences: $F1(1, 48) = 3.89$, $p = .05$; $F2(1, 56) = 3.71$, $p = .06$; plural-attractor sentences: $F1(1, 48) = 3.43$, $p = .07$; $F2(1, 56) = 3.97$, $p = .05$),

suggesting longer first-pass times for ungrammatical sentences. Similar to SRC sentences, the results for ORC sentences under first-pass time suggest that processing costs related to indexing grammaticality were observed on all ungrammatical ORC sentences.

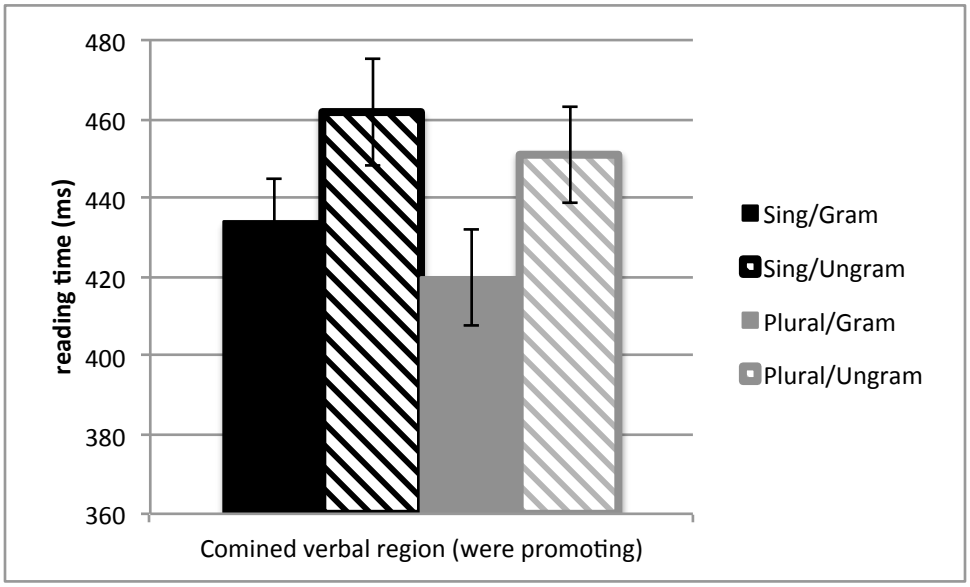


Figure 5.7. Mean first-pass times (by subjects) for grammatical and ungrammatical SRCs with singular and plural attractor variants at the combined verbal region, Experiment 5. Error bars show ±1 standard error of the mean for repeated measures.

Regression-path duration, shown in Figures 5.9 and 5.10, revealed a by-items effect of grammaticality at the combined verbal region ($F1(1, 48) = 2.48$; $F2(1, 56) = 4.73$, $p < .05$), suggesting longer RTs for ungrammatical sentences. This measure also revealed a marginal by-items effect of attractor number, suggesting longer regression-path durations for singular-attractor sentences ($F1$ $(1, 48) = 1.52$; $F2(1, 56) = 3.05$, $p = .09$; RC type, attractor number x grammaticality, attractor number x RC type, RC type x grammaticality, and attractor number x grammaticality x RC type: all F's < 2.5).

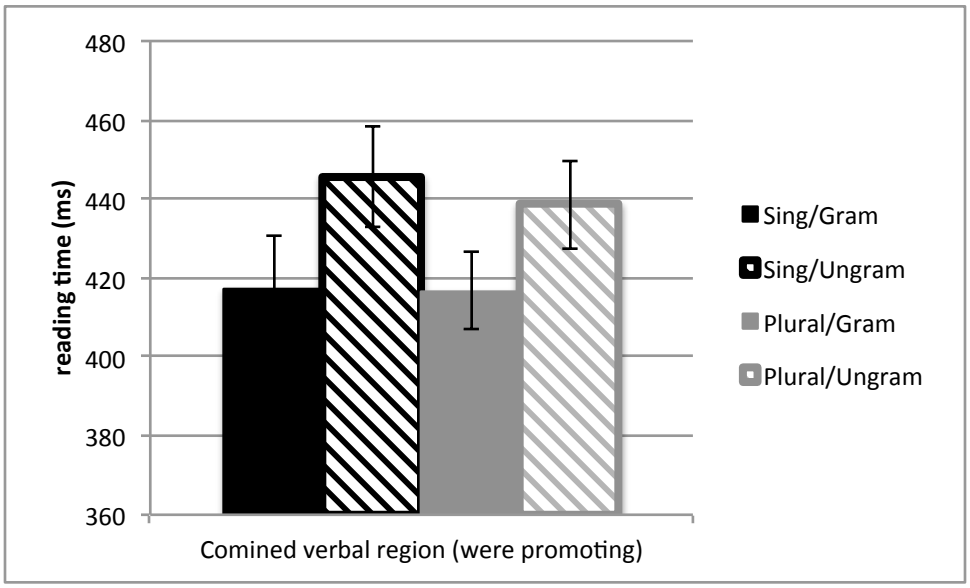


Figure 5.8. Mean first-pass times (by subjects) for grammatical and ungrammatical ORCs with singular and plural attractor variants at the combined verbal region, Experiment 5. Error bars show ±1 standard error of the mean for repeated measures.

Analyses separated by RC type did not reveal any statistically reliable results for SRC sentences (all F's < 2.5); however, ORCs showed a marginal by-items effect of grammaticality ($F1$ (1, 48) = 1.97; $F2$(1, 56) = 3.85, p = .05), suggesting longer regression-path durations for ungrammatical sentences. ORCs also revealed a marginal by-subjects interaction of grammaticality and attractor number ($F1$ (1, 48) = 3.81, p = .05; $F2$(1, 56) = 1.87; attractor number: both F's < 2.5), suggesting particularly short regression-path durations for grammatical plural-attractor sentences. This interaction was supported by tests of the simple effects of grammaticality and attractor number. An effect of grammaticality was revealed for plural-attractor sentences, with longer regression-path durations for ungrammatical sentences ($F1$(1, 48) = 6.82, p < .05; $F2$(1, 56) = 5.23, p < .05; singular attractor: both F's < 1). Furthermore, a marginal effect of attractor number was revealed for grammatical sentences ($F1$(1, 48) = 5.35, p < .05;

$F2(1, 56) = 3.62$, $p = .06$; ungrammatical: both F's < 1), with longer regression-path durations for singular-attractor sentences. These results continue to show that processing costs related to indexing ungrammaticality were observed for plural-attractor sentences in ORC sentences; however, no significant difference was observed for singular-attractor sentences.

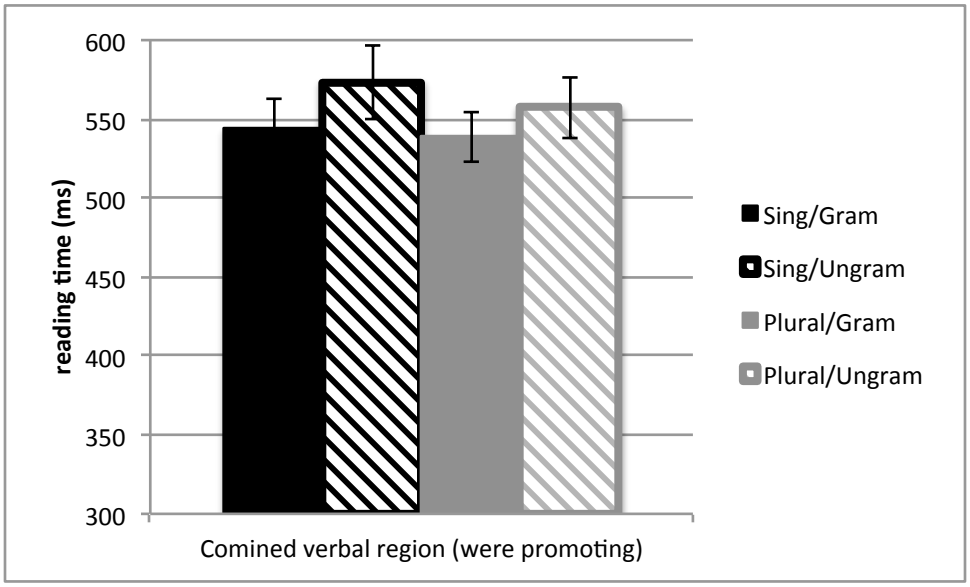


Figure 5.9. Mean regression-path durations (by subjects) for grammatical and ungrammatical SRCs with singular and plural attractor variants at the combined verbal region, Experiment 5. Error bars show ±1 standard error of the mean for repeated measures.

First-pass regression proportion revealed a three-way interaction of grammaticality, attractor number, and RC type at the combined verbal region ($F1(1, 48) = 4.64$, $p < .05$; $F2(1, 56) = 4.26$, $p < .05$; attractor number x grammaticality: $F1(1, 48) = 2.7$; $F2(1, 56) = 1.8$; attractor number, grammaticality, RC type, attractor number x RC type, RC type x grammaticality: all F's < 2).

Analyses separated by RC type revealed a marginal by-subjects effect of attractor number for SRCs ($F1(1, 48) = 3.89$, $p = .05$; $F2(1, 56) = 2.77$), suggesting more first-pass regressions

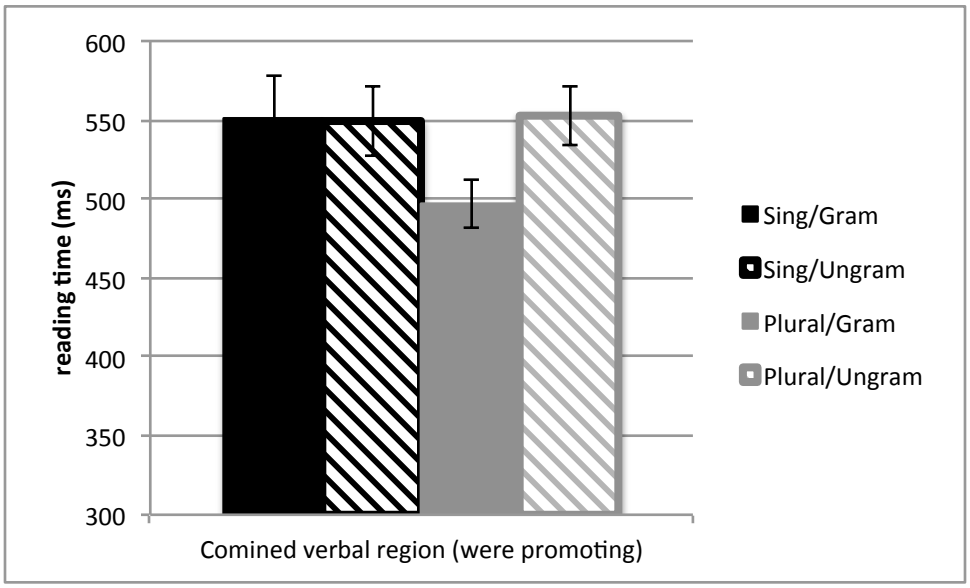


Figure 5.10. Mean regression-path durations (by subjects) for grammatical and ungrammatical ORCs with singular and plural attractor variants at the combined verbal region, Experiment 5. Error bars show ±1 standard error of the mean for repeated measures.

for plural-attractor sentences. SRCs also showed a marginal interaction of grammaticality and attractor number ($F1(1, 48) = 4.28$, $p < .05$; $F2(1, 56) = 3.86$, $p = .05$; grammaticality: both F's < 1), suggesting more first-pass regressions for grammatical plural-attractor sentences. While these results show little difference between grammatical and ungrammatical sentences, they do suggest that grammatical plural-attractor sentences showed more first-pass regressions than other SRC sentence types.

ORCs revealed an interaction of grammaticality and attractor number under first-pass regression proportion ($F1(1, 48) = 5.99$, $p < .05$; $F2(1, 56) = 5.77$, $p < .05$; grammaticality and attractor number: all F's < 1.5), with fewer first-pass regressions for grammatical plural-attractor sentences. Tests of the simple effect of grammaticality revealed a marginal effect for singular- and plural-attractor sentences, suggesting more first-pass regressions for ungram-

matical sentences (singular-attractor sentences: $F1(1, 48) = 2.93$, p = 09; $F2(1, 56) = 2.63$; plural-attractor sentences: $F1(1, 48) = 4.88$, $p < .05$; $F2(1, 56) = 3.73$, $p = .06$). Tests of the simple effect of attractor number revealed an effect for grammatical sentences, with more first-pass regressions for singular-attractor sentences ($F1(1, 48) = 7.41$, $p < .05$; $F2(1, 56) = 5.56$, $p < .05$; ungrammatical: both F's < 1). At the combined verbal region, the effects in the ORC condition suggest that processing costs related to indexing ungrammaticality were observed in ungrammatical plural-attractor sentences, and were only weakly observed for ungrammatical singular-attractor sentences.

To summarize the combined verbal region, first-pass time indicated processing difficulty for all ungrammatical sentences regardless of RC type or attractor number. For ORC sentences, regression-path duration continued to show processing difficulty for only plural-attractor sentences, but first-pass regression proportion suggested processing difficulty for singular- and plural-attractor sentences.

Region V+1 did not reveal any main effects for first-pass time (all F's < 2); however, analyses separated by RC type revealed a by-subjects effect of attractor number in SRCs, suggesting longer first-pass times for plural-attractor sentences ($F1(1, 48) = 4.33$, $p < .05$; $F2(1, 56) = 2.77$; grammaticality, attractor number x grammaticality: all F's < 1). Tests of the simple effect of attractor number revealed this a marginal effect for grammatical sentences, suggesting longer first-pass times for plural-attractor sentences ($F1(1, 48) = 3.48$, $p = .07$; $F2(1, 56) = 3.22$, $p = .08$; ungrammatical: both F's 1). No statistically reliable results were found for ORC sen-

tences (all F's < 1). These results suggest that, for SRC sentences, grammatical plural-attractor sentences had longer RTs than grammatical singular-attractor sentences.

Regression-path duration did not show any main effects at this region either (attractor number x RC type: $F1(1, 48) = 2.80$; $F2(1, 56) = 2.64$; all other F's < 2.5). Furthermore, analyses separated by RC type in this region revealed no significant results for SRCs (all F's < 1.5). However, ORCs showed a marginal by-items effect of grammaticality ($F1(1, 48) = 1.96$; $F2(1, 56) = 3.81$, $p = .06$), suggesting longer regression-path durations for ungrammatical sentences. ORCs also showed a marginal by-items interaction of grammaticality and attractor number ($F1(1, 48) = 2.24$; $F2(1, 56) = 2.87$, $p = .1$; attractor number: both F's < 2.5), suggesting shorter regression-path durations for grammatical plural-attractor sentences. This interaction was supported by tests of the simple effects of grammaticality and attractor number. An effect of grammaticality was observed for plural-attractor sentences, with longer regression-path durations for ungrammatical sentences ($F1(1, 48) = 6.62$, $p < .05$; $F2(1, 56) = 8.17$, $p < .01$; singular attractor both F's < 1). Furthermore, tests of the simple effect of attractor number showed an effect for grammatical sentences, with longer regression-path durations for singular-attractor sentences sentences ($F1(1, 48) = 3.98$, $p = .05$; $F2(1, 56) = 4.80$, $p < .05$; singular attractor both F's < 1). These results continue to suggest that, for ORCs, processing costs related to indexing ungrammaticality were observed for ungrammatical plural-attractor sentences and also suggest that grammatical plural-attractor sentences were suggested to show particularly short regression-path durations.

Finally, at region V+1, first-pass regression proportion showed a by-items effect of grammaticality, suggesting more first-pass regressions for ungrammatical sentences ($F1(1, 48) = 2.08$; $F2(1, 56) = 4.27$, $p < .05$; grammaticality, RC type, attractor number x grammaticality, attractor number x RC type, RC type x grammaticality, and attractor number x grammaticality x RC type: all F's < 2.5).

Analyses separated by RC type revealed no significant results for SRC sentences (all F's < 1.5), but did reveal a marginal effect of grammaticality in ORC sentences ($F1(1, 48) = 1.77$; $F2(1, 56) = 4.53$, $p < .05$; attractor number and attractor number x grammaticality: all F's < 2), suggesting more first-pass regressions for ungrammatical sentences. Similar to regression-path duration, these results suggest that ungrammatical ORC sentences had more first-pass regressions their grammatical counterparts.

5.2.2 Second-pass measures

In SRC sentences early reading measures showed somewhat conflicting results. First-pass time suggested processing costs related to indexing ungrammaticality for both singular- and plural-attractor sentences, but regression-path duration and first-pass regression proportion only indicated processing difficulty for ungrammatical singular-attractor sentences. ORC sentences however, followed a different pattern of results. While first-pass time indicated processing difficulty for all ungrammatical sentences, regression-path duration and first-pass regression proportion indicated processing difficulty only for ungrammatical plural-attractor sentences.

Late reading measures continued to show evidence of processing difficulty for all ungrammatical SRC sentences, with indications of attenuation for plural-attractor sentences. These reading measures also continued to show clear evidence of processing difficulty for ungrammatical ORC sentences with plural attractors, with only weak indications of processing difficulty for ungrammatical ORC sentences with singular attractors. At the agreeing verb, second-pass time, graphed in Figures 5.11 and 5.12, showed a main effect of grammaticality, with longer RTs for ungrammatical sentences ($F1(1, 48) = 9.34$, $p < .01$; $F2(1, 56) = 13.37$, $p < .001$; attractor number, RC type, attractor number x grammaticality, attractor number x RC type, RC type x grammaticality, and attractor number x grammaticality x RC type: all F's < 2).

Analyses separated by RC type revealed a marginal effect of grammaticality in SRCs ($F1(1, 48) = 3.78$, $p = .06$; $F2(1, 56) = 4.56$, $p < .05$; attractor number and attractor number x grammaticality: all F's < 1), suggesting longer second-pass times for ungrammatical sentences. These results suggest that processing costs related to indexing ungrammaticality are present for all ungrammatical sentences in SRC sentences.

ORCs also showed an effect of grammaticality ($F1(1, 48) = 11.46$, $p < .01$; $F2(1, 56) = 9.99$, $p < .01$), with longer second-pass times for ungrammatical sentences. ORCs also revealed a marginal interaction of grammaticality and attractor number ($F1(1, 48) = 3.34$, $p = .07$; $F2(1, 56) = 2.84$, $p = .1$; attractor number: both F's < 2), suggesting particularly short second-pass times for grammatical sentences with plural attractors. This interaction is supported by tests of the simple effects of grammaticality and attractor number. An effect of grammaticality was

observed for plural-attractor sentences, with longer second-pass times for ungrammatical sentences ($F1(1, 48) = 13.56$, $p < .001$; $F2(1, 56) = 11.57$, $p < .01$; singular attractor: both F's < 1.5). An effect of attractor number was observed for grammatical sentences ($F1(1, 48) = 5.23$, $p < .05$; $F2(1, 56) = 4.10$, $p < .05$; ungrammatical: both F's < 1), with longer RTs for singular-attractor sentences. These results suggest that, for ORCs, processing costs related to indexing ungrammaticality are present for plural-attractor sentences.

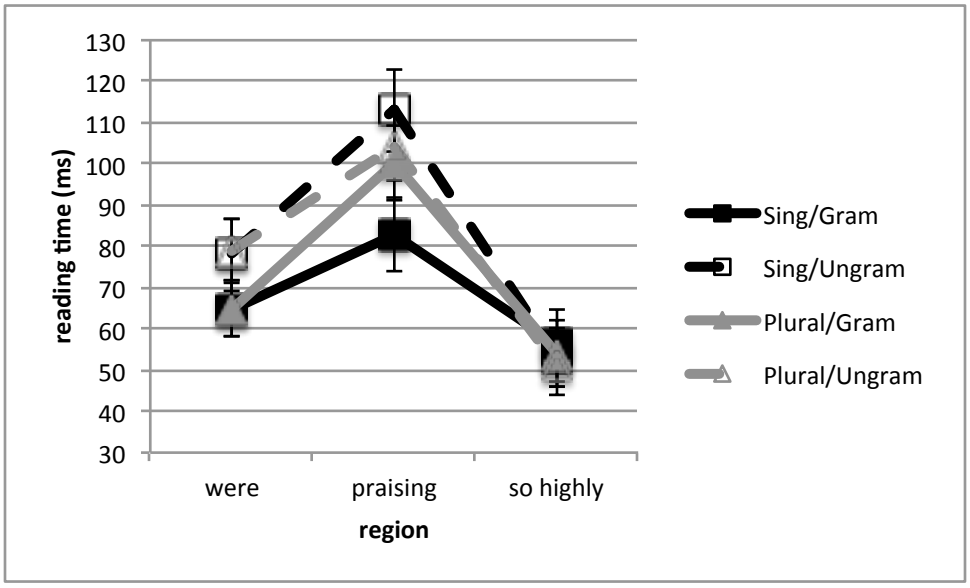


Figure 5.11. Mean second-pass times (by subjects) for grammatical and ungrammatical SRCs with singular and plural attractor variants, Experiment 5. Error bars show ±1 standard error of the mean for repeated measures.

Non-terminal second-pass time revealed a different pattern of results for SRCs, shown in Figures 5.13 and 5.14. This measure revealed a main effect of grammaticality ($F1(1, 48) = 8.74$, $p < .01$; $F2(1, 56) = 14.46$, $p < .001$), with longer RTs for ungrammatical sentences. This measure also revealed a marginal effect of RC type, suggesting longer non-terminal second-pass times for SRCs ($F1(1, 48) = 4.78$, $p < .05$; $F2(1, 56) = 3.48$, $p = .07$; attractor number,

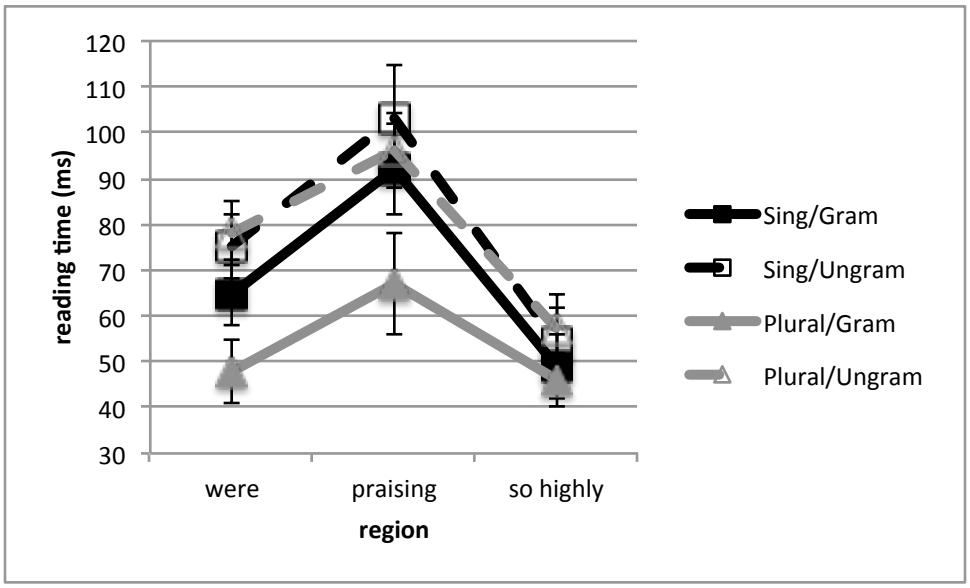


Figure 5.12. Mean second-pass times (by subjects) for grammatical and ungrammatical ORCs with singular and plural attractor variants, Experiment 5. Error bars show ±1 standard error of the mean for repeated measures.

attractor number x grammaticality, attractor number x RC type, RC type x grammaticality, and attractor number x grammaticality x RC type: all F's < 1.5).

Analyses separated by RC type revealed an effect of grammaticality in SRCs ($F1(1, 48) = 4.96$, $p < .05$; $F2(1, 56) = 5.38$, $p < .05$; attractor number and attractor number x grammaticality: all F's < 1), with longer non-terminal second-pass times for ungrammatical sentences. Tests of the simple effect of grammaticality revealed that this effect was only significant for singular-attractor sentences ($F1(1, 48) = 4.27$, $p < .05$; $F2(1, 56) = 4.69$, $p < .05$; plural attractor: both F's < 1.5), with longer non-terminal second-pass times for ungrammatical sentences. These results indicated that SRCs demonstrated processing costs related to ungrammaticality for singular-attractor sentences but not for plural-attractor sentences.

ORCs also revealed an effect of grammaticality, with longer non-terminal second-pass times for ungrammatical sentences ($F1(1, 48) = 7.35$, $p < .01$; $F2(1, 56) = 7.46$, $p < .01$; attractor number and attractor number x grammaticality: all F's < 1.5). However, tests of the simple effect of grammaticality revealed it only occurred in plural-attractor sentences, with longer non-terminal second-pass times for ungrammatical sentences ($F1(1, 48) = 6.47$, $p < .05$; $F2(1, 56) = 6.83$, $p < .05$; singular attractor: both F's < 2.5). Unlike SRCs, these results indicated that ORCs demonstrated processing costs related to ungrammaticality for plural-attractor sentences but not for singular-attractor sentences.

Review time, shown in Figures 5.15 and 5.16, revealed a by-subjects interaction between attractor number and grammaticality at the agreeing verb, suggesting shorter review times for grammatical plural-attractor sentences ($F1(1, 48) = 5.10$, $p < .05$; $F2(1, 56) = 2.56$; attractor number, grammaticality, RC type, attractor number x RC type, RC type x grammaticality, and attractor number x grammaticality x RC type: all F's < 2.5).

Analyses separated by RC type revealed no statistically reliable results for SRC sentences (all F's < 1.5). However, ORCs showed a marginal by-subjects interaction of grammaticality and attractor number, suggesting particularly short review times for grammatical plural-attractor sentences ($F1(1, 48) = 3.35$, $p = .07$; $F2(1, 56) = 2.25$; grammaticality: $F1(1, 48) = 2.4$; $F2(1, 56) = 2.56$; attractor number: both F's < 1). This interaction was supported by tests of the simple effect of grammaticality which revealed an effect for plural-attractor sentences, with longer review times for ungrammatical sentences ($F1(1, 48) = 4.67$, $p < .05$; $F2(1, 56) = 5.05$, $p < .05$: singular attractor: both F's < 1). These results continue to suggest that,

in ORCs, processing costs for ungrammaticality were seen on ungrammatical plural-attractor sentences.

Total time, Figures 5.17 and 5.18, revealed a by-items effect of grammaticality, suggesting longer RTs for ungrammatical sentences ($F1(1, 48) = 2.6$; $F2(1, 56) = 6.78$, $p < .05$; attractor number, RC type, attractor number x grammaticality, attractor number x RC type, RC type x grammaticality, and attractor number x grammaticality x RC type: all F's < 2.5).

Analyses separated by RC type revealed a marginal effect of grammaticality in SRCs ($F1(1, 48) = 1.95$; $F2(1, 56) = 4.67$, $p < .05$; attractor number and attractor number x grammaticality: all F's < 1), suggesting longer total times for ungrammatical sentences. Tests of the simple effect of grammaticality revealed that this effect is only seen for plural-attractor sentences ($F1(1, 48) = 4.41$, $p < .05$; $F2(1, 56) = 4.89$, $p < .05$; singular attractor: both F's < 1), with longer RTs for ungrammatical sentences. No statistically reliable results were found for ORCs (attractor number: $F1(1, 48) = 2.54$; $F2(1, 56) = 2.38$; grammaticality and attractor number x grammaticality: all F's < 2). These results suggest SRC sentences showed processing difficulty for ungrammatical sentences with plural attractors.

SRCs at the agreeing verb indicated processing difficulty for ungrammatical plural-attractor sentences under second-pass time and total time, but non-terminal second-pass time showed some indications of attenuated processing difficulty for ungrammatical plural-attractor sentences. ORCs however, showed consistent indications of processing difficulty for ungrammatical plural-attractor sentences under all late measures in this region.

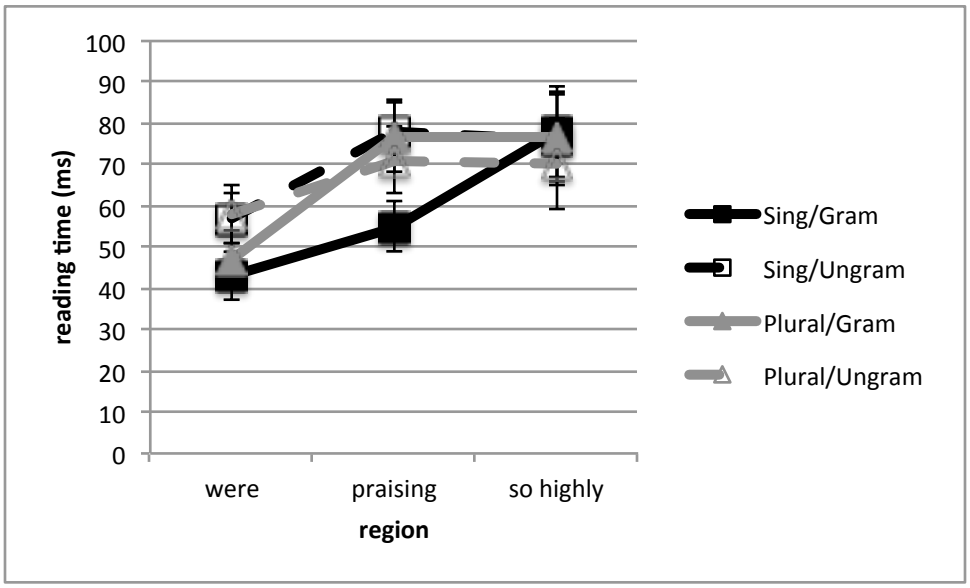


Figure 5.13. Mean non-terminal second-pass times (by subjects) for grammatical and ungrammatical SRCs with singular and plural attractor variants, Experiment 5. Error bars show ±1 standard error of the mean for repeated measures.

At the content verb (*promoting*), second-pass time revealed a main effect of grammaticality ($F1(1, 48) = 11.72$, $p < .01$; $F2(1, 56) = 10.06$, $p < .05$), with longer second-pass times for ungrammatical sentences. This measure also showed a marginal effect of RC type ($F1(1, 48) = 3.65$, $p = .06$; $F2(1, 56) = 3.63$, $p = .06$), suggesting longer second-pass times for SRCs. A marginal by-items interaction between attractor number and RC type was also seen ($F1(1, 48) = 2.62$; $F2(1, 56) = 3.25$, $p = .08$), suggesting particularly short second-pass times for plural-attractor ORC sentences. Lastly, this measure showed a marginal three-way interaction of attractor number, grammaticality, and RC type ($F1(1, 48) = 3.59$, $p = .06$; $F2(1, 56) = 4.41$, $p < .05$; attractor number, attractor number x grammaticality, and RC type x grammaticality: all F's < 1.5).

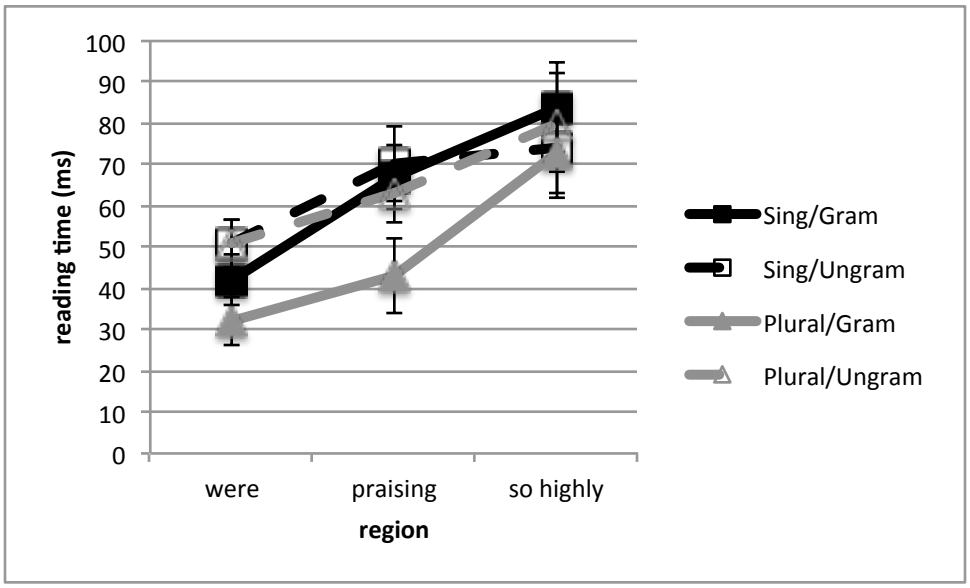


Figure 5.14. Mean non-terminal second-pass times (by subjects) for grammatical and ungrammatical ORCs with singular and plural attractor variants, Experiment 5. Error bars show ±1 standard error of the mean for repeated measures.

Analyses separated by RC type revealed an effect of grammaticality in SRCs, with longer second-pass times for ungrammatical sentences ($F1(1, 48) = 6.28$, $p < .05$; $F2(1, 56) = 5.51$, $p < .05$; attractor number x grammaticality: $F1(1, 48) = 2.58$; $F2(1, 56) = 2.49$; attractor number: both F's < 1). Tests of the simple effect of grammaticality revealed that this effect is only reliable for singular-attractor sentences, with longer second-pass times for ungrammatical sentences ($F1(1, 48) = 6.97$, $p < .05$; $F2(1, 56) = 8.02$, $p < .01$; plural attractor: both F's < 1). These results indicated that, for SRCs, second-pass time showed processing costs related to indexing ungrammaticality for singular-attractor sentences but not for plural-attractor sentences.

ORCs also showed an effect of grammaticality, with longer second-pass times for ungrammatical sentences ($F1(1, 48) = 5.99$, $p < .05$; $F2(1, 56) = 6.03$, $p < .05$). However, tests

of the simple effect of grammaticality showed that this effect only occurred for plural-attractor sentences ($F1(1, 48) = 6.72$, $p < .05$; $F2(1, 56) = 6.41$, $p < .05$; singular attractor: both F's < 1.5), with longer second-pass times for ungrammatical sentences. ORCs also revealed a marginal effect of attractor number, with longer second-pass times for singular-attractor sentences ($F1(1, 48) = 3.20$, $p = .08$; $F2(1, 56) = 4.59$, $p < .05$; attractor number x grammaticality: both F's < 1.5). Tests of the simple effect of attractor number revealed this effect only occurred on grammatical sentences ($F1(1, 48) = 4.76$, $p < .05$; $F2(1, 56) = 5.79$, $p < .05$; ungrammatical: both F's < 1), with longer second-pass times for singular-attractor sentences. These results indicated that ORC sentences showed processing costs for ungrammaticality for plural-attractor sentences, but not for singular-attractor sentences.

Non-terminal second-pass time revealed a main effect of grammaticality at the content verb ($F1(1, 48) = 4.32$, $p < .05$; $F2(1, 56) = 5.88$, $p < .05$), with longer RTs for ungrammatical sentences. This measure also revealed a marginal effect of RC type, with a trend towards longer non-terminal second-pass times for SRCs ($F1(1, 48) = 3.93$, $p = .05$; $F2(1, 56) = 4.59$, $p < .05$). An interaction between attractor number and RC type was also observed, with particularly short non-terminal second-pass times for plural-attractor ORC sentences ($F1(1, 48) = 6.07$, $p < .05$; $F2(1, 56) = 5.07$, $p < .05$). Lastly, non-terminal second-pass time showed a three-way interaction of attractor number, grammaticality, and RC type ($F1(1, 48) = 7.85$, $p < .01$; $F2(1, 56) = 4.64$, $p < .05$; attractor number, attractor number x grammaticality, and RC type x grammaticality: all F's < 1).

Analyses separated by RC type revealed a by-subjects interaction of grammaticality and attractor number in SRCs ($F1(1, 48) = 4.27$, $p < .05$; $F2(1, 56) = 2.98$, $p = .09$; attractor number and grammaticality: both F's < 2.5), suggesting shorter non-terminal second-pass times for grammatical singular-attractor sentences. Tests of the simple effects of grammaticality and attractor number supported this interaction. Tests of the simple effect of grammaticality showed an effect for singular-attractor sentences, with longer non-terminal second-pass times for ungrammatical sentences ($F1(1, 48) = 6.84$, $p < .05$; $F2(1, 56) = 4.73$, $p < .05$; plural attractor: both F's < 1). Tests of the simple effect of attractor number showed an effect for grammatical sentences, with longer non-terminal second-pass times for plural-attractor sentences ($F1(1, 48) = 5.46$, $p < .05$; $F2(1, 56) = 3.09$, $p = .08$; ungrammatical: both F's < 1). These results suggest that, for SRCs, processing costs related to indexing ungrammaticality were only observed on singular-attractor sentences.

Analyses separated by RC type revealed that ORCs contained an effect of attractor number, with longer non-terminal second-pass times for singular-attractor sentences ($F1(1, 48) = 4.20$, $p < .05$; $F2(1, 56) = 6.70$, $p < .05$). Tests of the simple effect of attractor number showed it only occurring in grammatical sentences, with longer non-terminal second-pass times for singular-attractor sentences ($F1(1, 48) = 6.21$, $p < .05$; $F2(1, 56) = 6.71$, $p < .05$; plural attractor: both F's < 1.5). ORCs also revealed a marginal effect of grammaticality, with longer non-terminal second-pass times for ungrammatical sentences ($F1(1, 48) = 3.12$, $p = .08$; $F2(1, 56) = 4.22$, $p < .05$; attractor number x grammaticality: both F's < 2.5). Tests of the simple effect of grammaticality revealed this effect only occurred in plural-attractor sentences, with

longer non-terminal second-pass times for ungrammatical sentences ($F1(1, 48) = 4.82$, $p < .05$; $F2(1, 56) = 5.62$, $p < .05$). As previous measures for ORC sentences have shown, these results show ORC sentences displayed processing costs for ungrammaticality for plural-attractor sentences, but not for singular-attractor sentences.

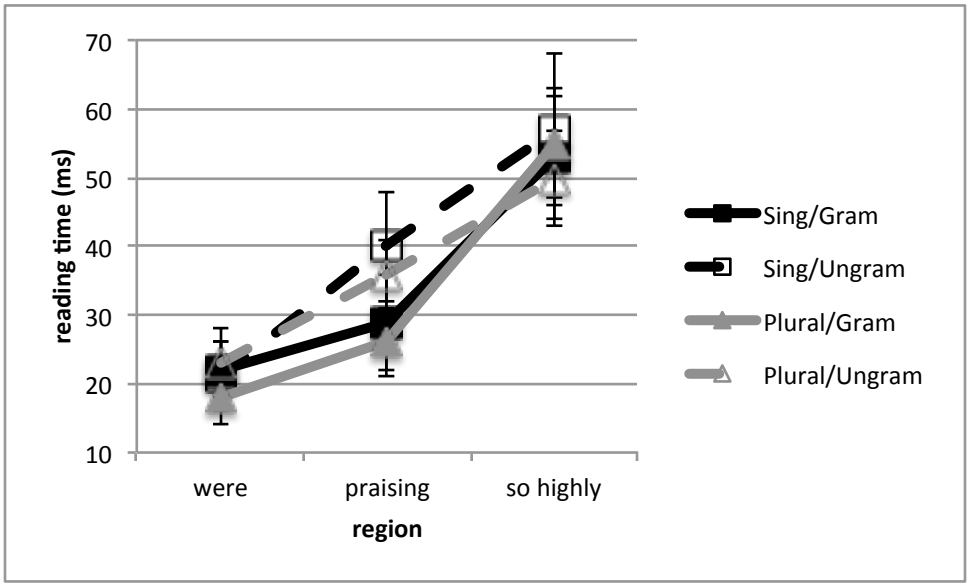


Figure 5.15. Mean review times (by subjects) for grammatical and ungrammatical SRCs with singular and plural attractor variants, Experiment 5. Error bars show ±1 standard error of the mean for repeated measures.

Also at the content verb, review time revealed a main effect of grammaticality, with longer RTs for ungrammatical sentences ($F1(1, 48) = 10.96$, $p < .01$; $F2(1, 56) = 7.62$, $p < .01$; attractor number, RC type, attractor number x grammaticality, attractor number x RC type, RC type x grammaticality, attractor number x grammaticality x RC type: all F's < 1).

Analyses separated by RC type revealed that SRCs showed an effect of grammaticality, with longer review times for ungrammatical sentences ($F1(1, 48) = 6.27$, $p < .05$; $F2(1, 56) = 6.93$, $p < .05$; attractor number attractor number x grammaticality: all F's < 1.5). Tests of the

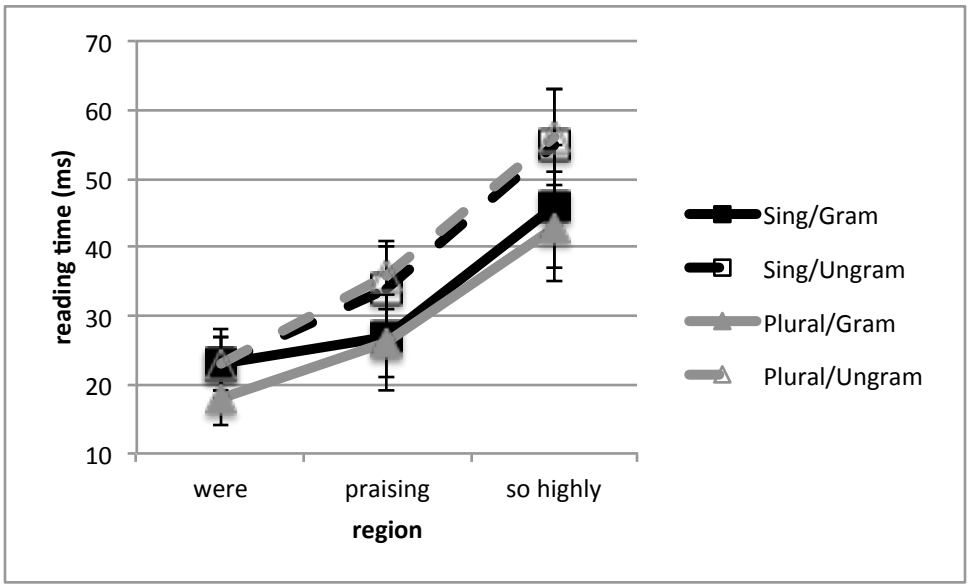


Figure 5.16. Mean review times (by subjects) for grammatical and ungrammatical ORCs with singular and plural attractor variants, Experiment 5. Error bars show ±1 standard error of the mean for repeated measures.

simple effect of grammaticality revealed it to be marginal for singular- and plural-attractor sentences (singular-attractor sentences: $F1(1, 48) = 2.32$; $F2(1, 56) = 2.92$, $p = .09$; plural-attractor sentences: $F1(1, 48) = 4.90$, $p < .05$; $F2(1, 56) = 3.43$, $p = .07$), with longer review times for ungrammatical sentences. Unlike the previous measures at this region, these results suggest that processing costs related to indexing ungrammaticality are observed on all ungrammatical SRC sentence types

Analyses separated by RC type also indicated a marginal effect of grammaticality for ORCs ($F1(1, 48) = 3.06$, $p = .09$; $F2(1, 56) = 3.09$, $p < .08$; attractor number and attractor number x grammaticality: all F's < 1), with longer review times for ungrammatical sentences. Similar to the SRC results, these results suggest that processing costs related to indexing ungrammaticality are observed on all ungrammatical ORC sentence types.

Also at the content verb, total time showed a marginal effect of attractor number and a main effect of grammaticality. The effect of attractor number ($F1(1, 48) = 2.32$; $F2(1, 56) = 3.26$, $p = .08$), suggested longer total times for singular-attractor sentences. The effect of grammaticality ($F1(1, 48) = 18.48$, $p < .001$; $F2(1, 56) = 16.84$, $p < .001$), showed longer total times for ungrammatical sentences. This measure also revealed a main effect of RC type, with longer total times for SRCs ($F1(1, 48) = 4.20$, $p < .05$; $F2(1, 56) = 4.82$, $p < .05$); as well as a marginal interaction between attractor number and RC type, suggesting particularly short total times for plural-attractor ORC sentences ($F1(1, 48) = 3.37$, $p = .07$; $F2(1, 56) = 3.44$, $p = .07$). Finally, there was a three-way interaction of attractor number, grammaticality, and RC type that was significant by items ($F1(1, 48) < 1$; $F2(1, 56) = 5.28$, $p < .05$; attractor number x grammaticality and RC type x grammaticality: all F's < 1).

Analyses separated by RC type revealed that SRCs showed an effect of grammaticality, with longer total times for ungrammatical sentences ($F1(1, 48) = 9.72$, $p < .01$; $F2(1, 56) = 8.87$, $p < .01$). This measure also revealed a marginal interaction of attractor number and grammaticality in SRCs ($F1(1, 48) = 3.73$, $p = .06$; $F2(1, 56) = 3.90$, $p = .05$; attractor number: both F's < 1), suggesting singular-attractor sentences show longer RTs for their ungrammatical forms, but plural-attractor sentences do not. Tests of the simple effect of grammaticality revealed an effect only for singular-attractor sentences ($F1(1, 48) = 11.38$, $p < .01$; $F2(1, 56) = 15.97$, $p < .001$; plural attractor: both F's < 1), with longer total times for ungrammatical sentences. Furthermore, tests of the simple effect of attractor number revealed a marginal effect for grammatical sentences, suggesting longer total times for plural-attractor sentences ($F1(1,$

48) = 2.87, p = .10; $F2(1, 56)$ = 2.29; ungrammatical: both F's < 2). Like second-pass time and non-terminal second-pass time, these results show that, for SRCs, processing costs related to indexing ungrammaticality were only observed for singular-attractor sentences.

ORCs revealed effects of attractor number and grammaticality. The effect of attractor number ($F1(1, 48) = 5.86$, $p < .05$; $F2(1, 56) = 8.74$, $p < .01$), showed longer total times for singular-attractor sentences. Tests of the simple effect of attractor number revealed it occurred for grammatical sentences ($F1(1, 48) = 6.98$, $p < .05$; $F2(1, 56) = 6.39$, $p < .05$; ungrammatical: both F's < 2.5), with longer RTs for singular-attractor sentences. The effect of grammaticality ($F1(1, 48) = 10.18$, $p < .01$; $F2(1, 56) = 9.18$, $p < .01$; attractor number x grammaticality: all F's < 1), showed longer total times for ungrammatical sentences. Tests of the simple effect of grammaticality revealed a marginal effect for singular-attractor sentences ($F1(1, 48) = 2.25$; $F2(1, 56) = 3.31$, $p = .07$), as well as a significant effect for plural-attractor sentences ($F1(1, 48) = 9.56$, $p < .01$; $F2(1, 56) = 7.13$, $p < .01$), with longer total times for ungrammatical sentences. ORC sentences showed that processing costs for ungrammaticality were clearly observed for plural-attractor sentences and suggested for singular-attractor sentences.

In sum, region V (*praising*) indicated clear processing difficulty related to indexing ungrammaticality for singular-attractor sentences in SRCs under second-pass time, non-terminal second-pass time, and total time, but did not indicate processing difficulty for plural-attractor SRC sentences. For ORCs however, these measures clearly indicated processing difficulty related to indexing ungrammaticality for plural-attractor sentences and only suggested processing

difficulty for singular-attractor sentences. Lastly, review time indicated processing difficulty for all ungrammatical sentences at the content verb.

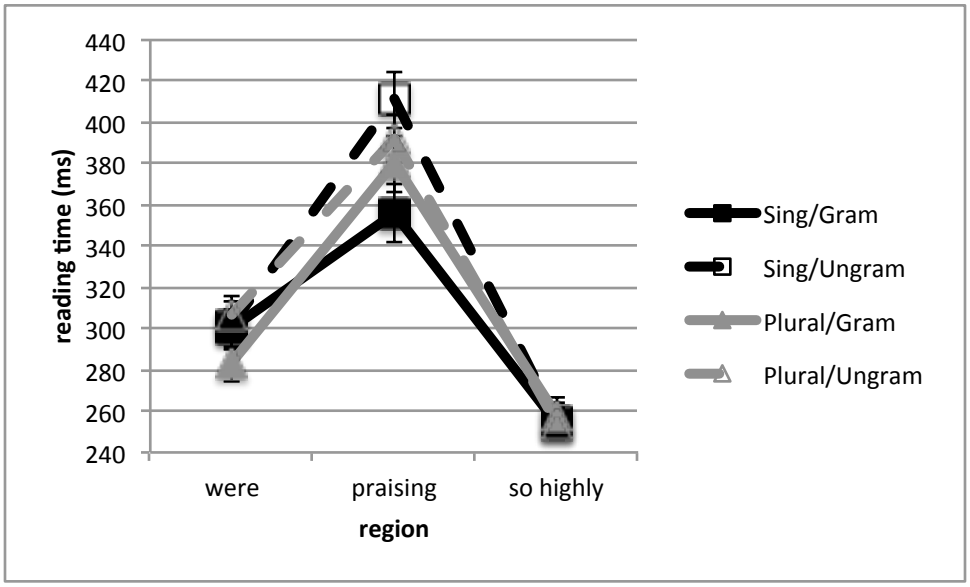


Figure 5.17. Mean total times (by subjects) for grammatical and ungrammatical SRCs with singular and plural attractor variants, Experiment 5. Error bars show ±1 standard error of the mean for repeated measures.

The combined verbal region revealed a main effect of grammaticality in second-pass time, Figures 5.19 and 5.20, with longer RTs for ungrammatical sentences ($F1(1, 48) = 10.31$, $p < .01$; $F2(1, 56) = 8.93$, $p < .01$). This measure also revealed a marginal interaction of attractor number and RC type, suggesting particularly short second-pass times for plural attractor ORC sentences ($F1(1, 48) = 2.96$, p = .09; $F2(1, 56) = 3.31$, $p = .07$). Finally, a marginal three-way interaction of attractor number, grammaticality, and RC type was found ($F1(1, 48) = 2.49$; $F2(1, 56) = 3.08$, $p = .08$; attractor number, RC type, attractor number x grammaticality, and RC type x grammaticality: all F's < 2.5).

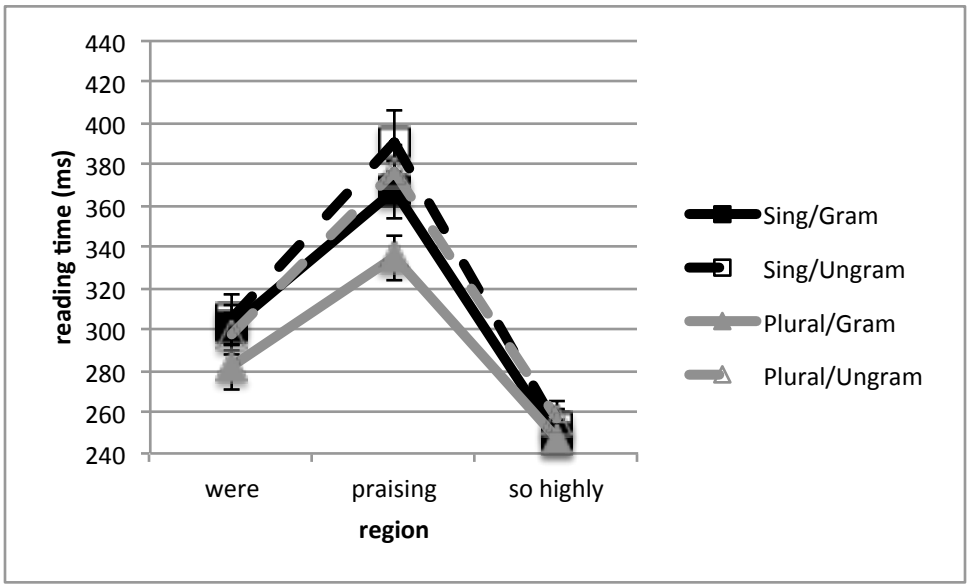


Figure 5.18. Mean total times (by subjects) for grammatical and ungrammatical ORCs with singular and plural attractor variants, Experiment 5. Error bars show ±1 standard error of the mean for repeated measures.

Analyses separated by RC type revealed a marginal effect of grammaticality in SRCs, suggesting longer second-pass times for ungrammatical sentences ($F1(1, 48) = 3.49$, $p = .07$; $F2(1, 56) = 4.01$, $p = .05$; attractor number and attractor number x grammaticality: all F's < 1.5). These results indicate that when the agreeing verb and content verb are combined, SRCs were suggested to show processing costs related to indexing ungrammaticality for both singular- and plural-attractor sentences.

ORCs showed an effect of grammaticality ($F1(1, 48) = 8.53$, $p < .01$; $F2(1, 56) = 6.91$, $p < .05$), with longer second-pass times for ungrammatical sentences. ORCs also revealed a marginal interaction of grammaticality and attractor number ($F1(1, 48) = 3.96$, $p = .05$; $F2(1, 56) = 4.81$, $p < .05$), suggesting particularly short second-pass times for grammatical sentences with plural attractors. This interaction was supported by tests of the simple effects of gram-

maticality and attractor number. The effect of grammaticality only occurred on plural-attractor sentences, with longer second-pass times for ungrammatical sentences ($F1(1, 48) = 13.69$, $p < .001$; $F2(1, 56) = 12.10$, $p < .001$; singular attractor: both F's < 1). The effect of attractor number only occurred on grammatical sentences, with longer RTs for singular-attractor sentences ($F1(1, 48) = 5.58$, $p < .05$; $F2(1, 56) = 7.08$, $p < .05$; ungrammatical: both F's < 1). These results continue to show that, for ORCs, processing costs related to indexing ungrammaticality were observed for plural-attractor sentences but not for singular-attractor sentences.

Non-terminal second-pass time revealed a marginal effect of grammaticality at the combined verbal region ($F1(1, 48) = 3.71$, $p = .06$; $F2(1, 56) = 4.12$, $p < .01$), with longer non-terminal second-pass times for ungrammatical sentences. This measure also revealed an interaction of attractor number and RC type, showing particularly short non-terminal second-pass times for plural attractor ORC sentences ($F1(1, 48) = 7.48$, $p < .01$; $F2(1, 56) = 5.74$, $p < .05$). Lastly, this measure revealed a marginal three-way interaction of attractor number, grammaticality, and RC type ($F1(1, 48) = 3.37$, $p = .07$; $F2(1, 56) = 2.92$, $p = .09$; attractor number, RC type, attractor number x grammaticality, RC type x grammaticality: all F's < 1).

Analyses separated by RC type showed a marginal by-subjects effect of attractor number in SRCs, with longer non-terminal second-pass times for plural attractor sentences ($F1(1, 48) = 4.02$, $p = .05$; $F2(1, 56) = 2.65$; grammaticality and attractor number x grammaticality: all F's < 1.5). Tests of the simple effect of attractor number revealed this only marginally appeared on grammatical sentences, with longer non-terminal second-pass times for plural-attractor sentences ($F1(1, 48) = 3.59$, $p = .06$; $F2(1, 56) = 3.05$, $p < .09$). These results do not

indicate differences in grammaticality but suggest that, for SRCs, grammatical plural-attractor sentences had longer RTs than their singular-attractor counterparts.

ORCs showed marginal effects of attractor number and grammaticality. The effect of attractor number ($F1(1, 48) = 3.10$, $p = .08$; $F2(1, 56) = 3.77$, $p = .06$), suggested longer RTs for singular-attractor sentences. The effect of grammaticality ($F1(1, 48) = 3.59$, $p = .06$; $F2(1, 56) = 3.26$, $p = .08$), suggested longer RTs for ungrammatical sentences. ORCs also showed a marginal interaction of attractor number and grammaticality, suggesting particularly short non-terminal second-pass times for grammatical sentences with plural attractors ($F1(1, 48) = 3.50$, $p = .07$; $F2(1, 56) = 3.48$, $p = .07$). Tests of the simple effects of grammaticality and attractor number supported this interaction. The effect of grammaticality only occurs on plural-attractor sentences, with longer non-terminal second-pass times for ungrammatical sentences ($F1(1, 48) = 7.61$, $p < .01$; $F2(1, 56) = 8.52$, $p < .01$; singular attractor: both F's < 1). The effect of attractor number only occurs on grammatical sentences, with longer non-terminal second-pass times for singular-attractor sentences ($F1(1, 48) = 5.22$, $p < .05$; $F2(1, 56) = 6.65$, $p < .05$; ungrammatical: both F's < 1). These results continue to show that, for ORCs, processing difficulty was observed on ungrammatical sentences with plural attractors but not for sentences with singular attractors.

Review time revealed a main effect of grammaticality at the combined verbal region, with longer review times for ungrammatical sentences ($F1(1, 48) = 8.91$, $p < .01$; $F2(1, 56) = 6.25$, $p < .05$; attractor number, RC type, attractor number x grammaticality, attractor number

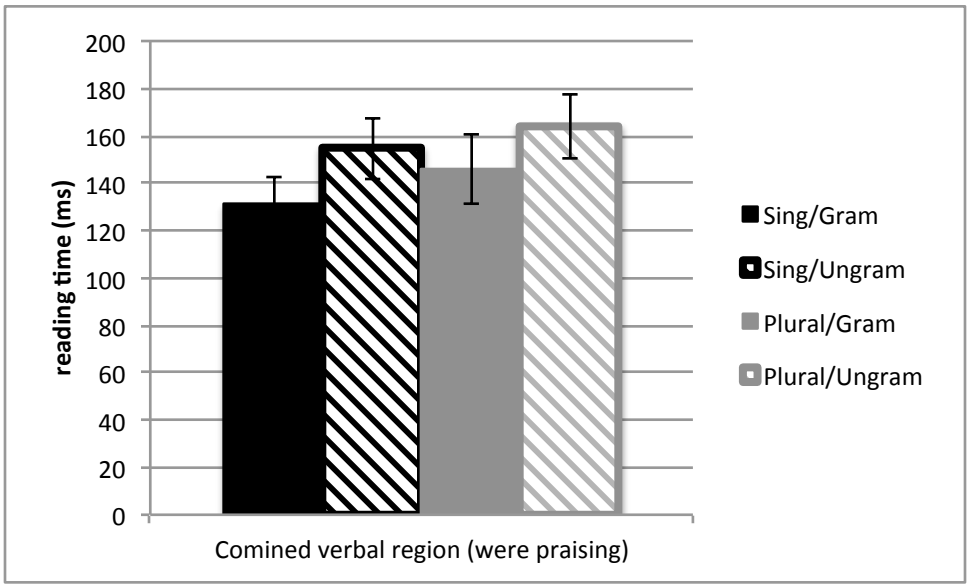


Figure 5.19. Mean second-pass times (by subjects) for grammatical and ungrammatical SRCs with singular and plural attractor variants at the combined verbal region, Experiment 5. Error bars show ±1 standard error of the mean for repeated measures.

x RC type, RC type x grammaticality, and attractor number x grammaticality x RC type: all F's < 1.5).

Analyses separated by RC type revealed a marginal effect of grammaticality in SRCs, suggesting longer review times for ungrammatical sentences ($F1(1, 48) = 3.14$, $p = .08$; $F2(1, 56) = 4.25$, $p < .05$; attractor number and attractor number x grammaticality: all F's < 1). Tests of the simple effect of grammaticality revealed this effect only in plural-attractor sentences ($F1(1, 48) = 3.93$, $p = .05$; $F2(1, 56) = 3.53$, $p = .07$; singular attractor: both F's < 1), suggesting longer review times for ungrammatical sentences. These results indicate that processing difficulty was only observed for ungrammatical SRC sentences with plural attractors.

ORCs also showed a marginal effect of grammaticality ($F1(1, 48) = 4.50$, $p < .05$; $F2(1, 56) = 3.69$, $p = .06$; attractor number and attractor number x grammaticality: all F's < 1.5),

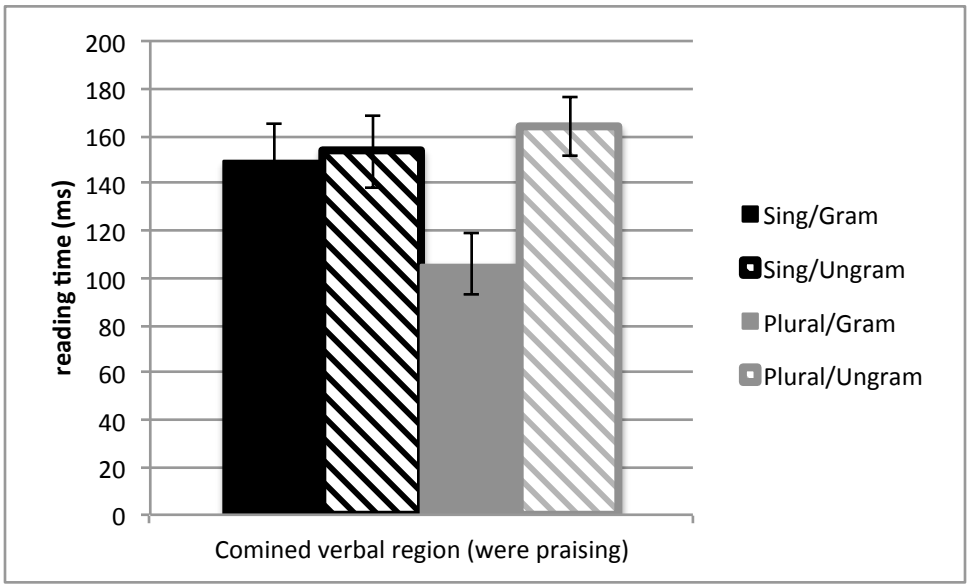


Figure 5.20. Mean second-pass times (by subjects) for grammatical and ungrammatical ORCs with singular and plural attractor variants at the combined verbal region, Experiment 5. Error bars show ±1 standard error of the mean for repeated measures.

suggesting longer review times for ungrammatical sentences. Tests of the simple effect of grammaticality revealed this effect is only in plural-attractor sentences ($F1(1, 48) = 4.03$, $p = .05$; $F2(1, 56) = 4.32$, $p < .05$; singular attractor: both F's < 1), suggesting longer review times for ungrammatical sentences. Similar to the SRC results, these results indicate that processing difficulty was only observed for ungrammatical ORC sentences with plural attractors.

Total time, Figures 5.21 and 5.22, revealed a main effect of grammaticality at the combined verbal region ($F1(1, 48) = 22.87$, $p < .001$; $F2(1, 56) = 25.93$, $p < .001$), with longer total times for ungrammatical sentences. This measure also revealed a marginal effect of RC type, suggesting longer total times for SRCs ($F1(1, 48) = 3.79$, $p = .06$; $F2(1, 56) = 3.69$, $p = .06$; attractor number, attractor number x grammaticality, attractor number x RC type, RC type x grammaticality, and attractor number x grammaticality x RC type: all F's < 2).

Analyses separated by RC type revealed an effect of grammaticality in SRCs ($F1(1, 48) = 11.43$, $p < .01$; $F2(1, 56) = 12.54$, $p < .001$; attractor number and attractor number x grammaticality: all F's < 1), with longer total times for ungrammatical sentences. Tests of the simple effect of grammaticality revealed that this effect occurred for both singular- and plural-attractor sentences (singular-attractor sentences: $F1(1, 48) = 6.23$, $p < .05$; $F2(1, 56) = 8.28$, $p < .01$; plural-attractor sentences: $F1(1, 48) = 6.10$, $p < .05$; $F2(1, 56) = 4.67$, $p < .05$), with ungrammatical sentences showing longer total times. Similar to second-pass time, these results show that, for SRCs, processing costs related to indexing ungrammaticality were observed on both singular-and plural-attractor sentences.

Analyses separated by RC type revealed an effect of grammaticality in ORCs ($F1(1, 48) = 18.01$, $p < .001$; $F2(1, 56) = 14.74$, $p < .001$), with longer total times for ungrammatical sentences. A marginal effect of attractor number was also found in ORCs ($F1(1, 48) = 2.48$; $F2(1, 56) = 3.32$, $p = .07$), suggesting longer total times for singular-attractor sentences. Lastly, ORCs revealed a marginal interaction of grammaticality and attractor number ($F1(1, 48) = 2.23$, $p < .01$; $F2(1, 56) = 3.29$, $p = .08$), suggesting particularly short total times for grammatical sentences with plural attractors. This interaction was supported by tests of the simple effect of attractor number which showed an effect of attractor number for grammatical sentences ($F1(1, 48) = 5.13$, $p < .05$; $F2(1, 56) = 5.51$, $p < .05$; ungrammatical: both F's < 1), with longer total times for singular-attractor sentences. Tests of the simple effect of grammaticality revealed a marginal effect for singular-attractor sentences ($F1(1, 48) = 2.73$, $p = .11$; $F2(1, 56) = 3.96$, $p = .05$) and significant effect for plural-attractor sentences ($F1(1, 48) = 16.11$, $p < .001$; $F2(1,$

56) = 16.58, $p < .001$), with longer RTs for ungrammatical sentences. These results show that, for ORCs, processing costs related to indexing ungrammaticality were observed on both singular- and plural-attractor sentences, with stronger evidence for plural-attractor sentences.

Thus, at the combined verbal region, SRCs showed evidence that ungrammaticality was indexed for singular- and plural-attractor sentences under second-pass time and total time. For ORCs, second-pass time and non-terminal second-pass time showed evidence that ungrammaticality was indexed only for plural-attractor sentences, and total time showed evidence for both singular- and plural-attractor sentences. Finally, review time showed processing difficulty related to indexing ungrammaticality for only plural-attractor sentences in both SRCs and ORCs.

At the post-verbal adverb (V+1), no statistically reliable main effects were observed (all F's < 2.5). Analyses separated by RC type also showed that no statistically reliable results were observed in SRC sentences (all F's < 1). However, ORC sentences revealed a marginal effect of grammaticality for review time, suggesting longer RTs for ungrammatical sentences($F1(1, 48) = 2.85$, $p = .1$; $F2(1, 56) = 2.4$).

5.3 Discussion

The results of Experiment 5 revealed processing difficulty for ungrammatical sentences with singular and plural attractors as early as first-pass time. These effects occurred in both SRC and ORC sentences and indicated processing costs related to indexing ungrammaticality for all ungrammatical sentences. For SRCs, first-pass time revealed a marginal effect of grammaticality at the agreeing verb that only occurred in plural-attractor sentences, and marginal

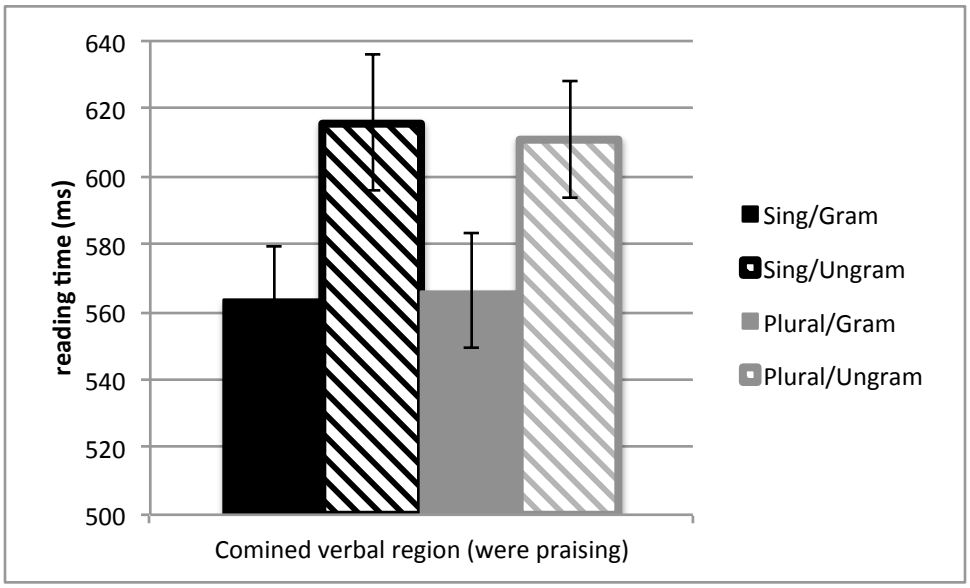


Figure 5.21. Mean total times (by subjects) for grammatical and ungrammatical SRCs with singular and plural attractor variants at the combined verbal region, Experiment 5. Error bars show ±1 standard error of the mean for repeated measures.

effects of grammaticality at the content verb and the combined verbal region for both singular- and plural-attractor sentences, indicating that all ungrammatical SRC sentences showed processing costs related to indexing ungrammaticality. ORC sentences demonstrated similar results under first-pass time, showing a marginal effect of grammaticality at the content verb for plural-attractor sentences and a marginal effect of grammaticality at the combined verbal region for both singular- and plural-attractor sentences. As with SRCs, these effects suggest that ungrammaticality was indexed for all ungrammatical sentences under first-pass time. Importantly, the effects described under first-pass time occur on ungrammatical plural-attractor sentences, showing that attraction effects were not present for either RC type under this measure. However, this pattern of results was not maintained under all other reading measures, and the profiles of SRC and ORC sentences diverged under these measures. Specifically, SRCs

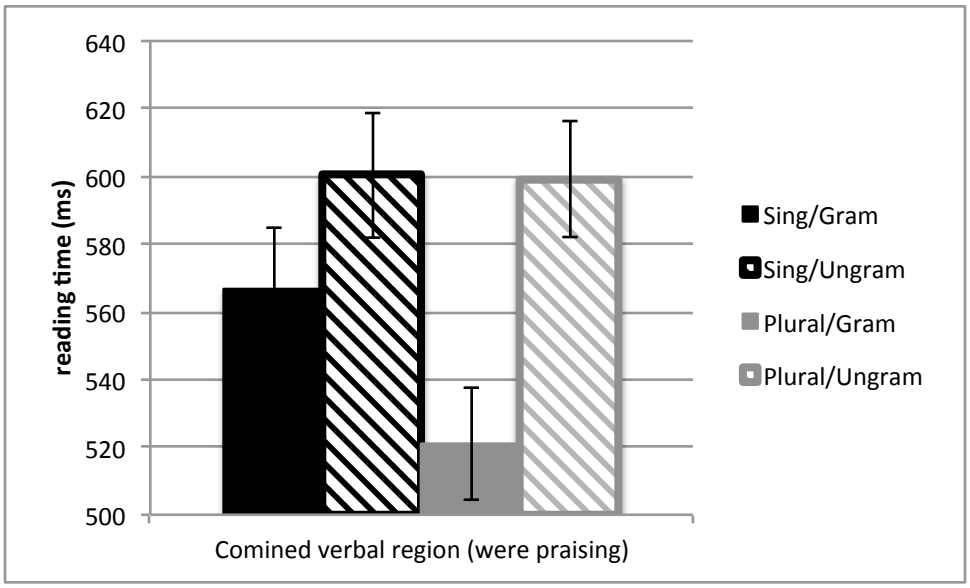


Figure 5.22. Mean total times (by subjects) for grammatical and ungrammatical ORCs with singular and plural attractor variants at the combined verbal region, Experiment 5. Error bars show ±1 standard error of the mean for repeated measures.

showed evidence of attraction effects, but ORCs showed processing difficulty for ungrammatical plural-attractor sentences, with minor indications of processing difficulty for singular-attractor sentences.

5.3.1 Subject-extracted relative clauses

As discussed above, the results for SRC sentences showed processing difficulty related to the indexation of ungrammaticality on all ungrammatical sentences under first-pass time. However, first-pass regression proportion and second-pass measures yielded evidence of attraction effects for ungrammatical plural-attractor sentences at region V (*promoting*). These were most clearly shown in the interactions of grammaticality and attractor number under first-pass regression proportion and non-terminal second-pass time. As Table 5.8 shows, tests of

the simple effect of grammaticality under these measures revealed that processing difficulty related to indexing ungrammaticality only occurred on singular-attractor sentences, indicating that ungrammatical plural-attractor sentences showed attenuated processing difficulty consistent with attraction effects. Second-pass time and total time showed a comparable pattern of results. While these measures revealed main effects of grammaticality without interactions, tests of the simple effect of grammaticality revealed that processing difficulty only occurred in ungrammatical singular-attractor sentences, further indicating attenuated processing difficulty for ungrammatical plural-attractor sentences. In fact, at the content verb, it was not until review time that processing difficulty was once again revealed for ungrammatical plural-attractor sentences. This measure showed an effect of grammaticality that was only observed for plural-attractor sentences, indicating processing difficulty for these sentences.

Thus, the results at *promoting* indicate that attraction effects are evident for SRC sentences with the attractor noun occurring as the object of the intervening SRC. However, they differ from the results in Experiment 4 in two important ways. First, these effects did not appear until after first-pass time, indicating that these intervening SRC constructions did not yield an illusion of grammaticality. Instead, they showed an attenuation of processing costs related to indexing ungrammaticality at region V (*promoting*). Secondly, these effects are not as strong as those in Experiment 4. This is evident by the lack of strong interactions within the regions showing attraction effects, and is further evident in the combined verbal region. At this region, there was no evidence of attraction effects, but rather, first-pass time and total time showed main effects of grammaticality for singular- and plural-attractor sentences, indicating

processing difficulty for all ungrammatical SRC sentences. Furthermore, this region also revealed marginal effects of grammaticality under second-pass time and review time, suggesting that processing costs related to indexing ungrammaticality were observed on all ungrammatical SRC sentences.

Although the profile of attenuation found in Experiment 5 is less pronounced than that of Experiment 4, this profile of attenuation is consistent with Dillon et al. (2013) discussed above. In fact, Experiment 5 almost directly replicates the findings of Dillon and colleagues (2013). They reported processing difficulty at the critical region for ungrammatical sentences with both singular and plural attractors under first-pass time, first-pass regression proportion, and total time, with only total time indicating evidence of attraction effects. Furthermore, an interaction consistent with agreement attraction was observed under first-pass regression proportion, but the planned comparisons to resolve this interaction yielded no statistically reliable results. Correspondingly, Experiment 5 also revealed processing difficulty for ungrammatical sentences under first-pass time, first-pass regression proportion, and total time, and showed an attenuation of this processing difficulty for ungrammatical sentences with plural attractors under first-pass regression proportion and total time. In addition, first-pass regression proportion revealed an interaction consistent with agreement attraction, and tests of the simple effect of grammaticality indicated processing difficulty only for ungrammatical singular-attractor sentences. Thus, the results of Experiment 5 replicate Dillon et al.'s (2013) findings with the slight exception that the results under first-pass regression proportion in Experiment 5 showed clearer indications of agreement attraction.

5.3.2 Object-extracted relative clauses

While SRC sentences demonstrated evidence of agreement attraction at region V (*promoting*), ORC sentences did not indicate any evidence of attraction effects. Rather, these sentences showed clear indications of processing difficulty for ungrammatical plural-attractor sentences in all regions and under all measures. This was shown at region AV (*were*) by effects of grammaticality under second-pass time and non-terminal second-pass time, indicating processing difficulty for ungrammatical plural-attractor sentences. At region V (*promoting*), first-pass time, second-pass time, and total time revealed effects of grammaticality, further indicating processing difficulty for ungrammatical plural-attractor sentences. Marginal effects of grammaticality under non-terminal second-pass time and review time also showed processing difficulty for ungrammatical plural-attractor sentences. Finally, at the combined verbal region, all measures indicated processing difficulty for ungrammatical plural-attractor sentences. Thus, unlike SRC sentences, ungrammatical plural-attractor ORC sentences yielded processing costs related to indexing ungrammaticality, without any indications of agreement attraction.

Recall that if the structural position of the attractor noun influences attraction effects, it was predicted that ORC sentences would show more robust attraction effects since the attractor noun is in the subject position. However, only SRC sentences, with attractors occurring in the object position, showed evidence of attraction effects. This pattern of results clearly runs contrary to the prediction above, which might suggest that the structural position of the attractor noun does not influence agreement attraction. Importantly however, ORC sentences were predicted to demonstrate agreement attraction regardless of whether or not the structural

position of the attractor noun influences agreement attraction. In either case, attraction effects should still be affected by the intervening plural attractor in ORC sentences, as it occurs in the subject position and contains a plural number feature. Moreover, the lack of attraction effects in ORC sentences is in direct contrast with the strong attraction effects in Experiment 4 as seen by (27).

(27) a. *The **musicians** that the *reviewer* were praising so highly won…

b. *The *Marine* that the **officers** saved last week were promoting the military…

The sentences in (27) demonstrate that in both cases the attractor noun matches the verb's number and occurs in the subject position, with *musicians* occuring as the subject of *won* in (27a) and *officers* as the subject of *saved* in (27b). It is unclear then, why (27a) elicited attraction effects, but (27b) did not. The fact that the attractor in (27b) intervenes between the subject and the verb should not prohibit attraction effects, as previous work has demonstrated intervening attractors are capable of eliciting processing attenuation consistent with agreement attraction.

One possible explanation for this pattern of results could be that agreement is preferentially controlled by the NP located in the highest position within the structural representation. Under such an account, cases of long-distance agreement attraction, as in (27a), would give rise to an illusion of grammaticality because, between the possible controlling nouns *musicians* and *reviewer*, the attractor noun (*musicians*) is structurally higher than the controlling subject (*reviewer*). In intervening RC cases, however, the controlling subject (*Marine*) is structurally

higher than the attractor noun (*officers*), which might help readers index these sentences as ungrammatical. Although an account along these lines might be able to explain the different pattern of results for (27a) and (27b), it would seem to predict that SRC sentences such as (28) should not show any evidence of agreement attraction.

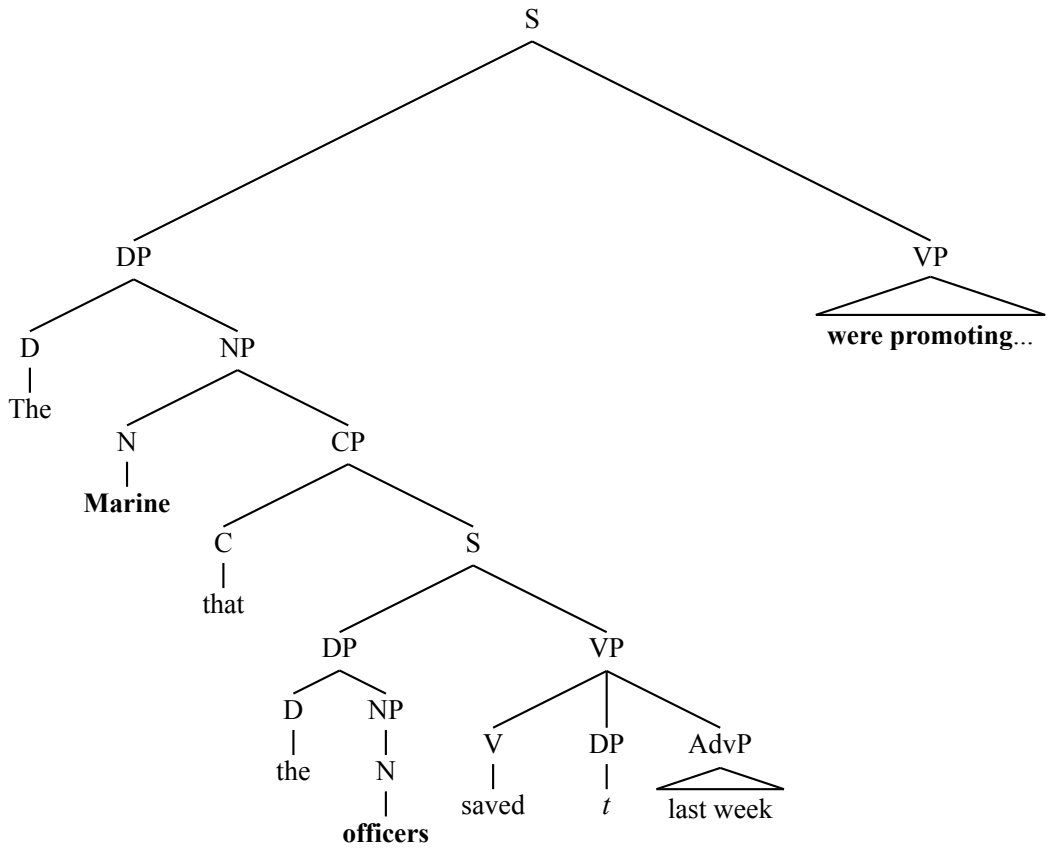
(28) *The *Marine* that saved the **officers** last week were promoting the military…

In sentences like (28), the controlling subject (*Marine*) is the highest NP in the structural representation so its features should be retrieved for agreement computation, leading readers to index these sentences as ungrammatical. However, the results of Experiment 5 indicated that readers showed an attenuation of processing difficulty consistent with agreement attraction in these sentences, suggesting that the attractor noun's features (*officers*) were retrieved during agreement computation. Furthermore, cases of attraction involving PPs modifying the subject have been shown to elicit agreement attraction errors. Importantly, in these sentences, such as **The key to the cabinets are*…, the attractor noun (*cabinets*) is structurally lower than the controlling subject (*key*), but these sentences show processing attenuation in comprehension studies.

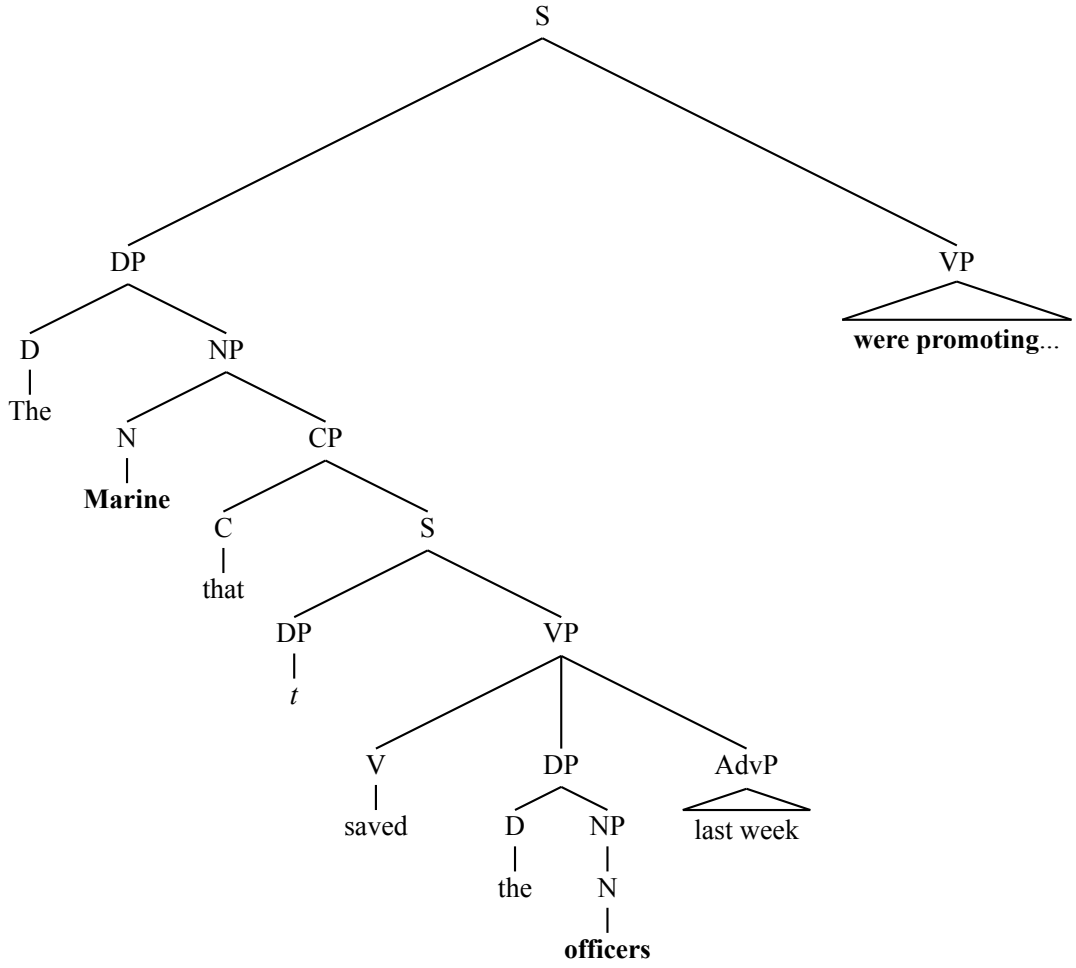
A second explanation for these results might consider operations that occur prior to agreement computation. One might imagine that these operations could affect how salient a possible controller's features are to subsequent retrieval processes. Specifically, if a possible controlling noun has been encoded as a subject for a verb, this operation could decrease the visibility of that noun's features for agreement processing that occurs later in the sentence.

This would be especially relevant for ORC sentences, in which the attractor noun occurs as the RC subject, as in (29a). In these sentences, once the reader reaches the RC verb (*saved*), the RC subject (*officers*) would be encoded as the controlling subject for that verb. As a result, the features of *officers*, having already been matched to the verb *saved*, would no longer be relevant for the search process initiated at the main clause verb (*were*). This would mean that the only possible controller for the agreement computation at the main clause verb would be *Marine*, and when *Marine's* features are retrieved for agreement computation, the mismatch in number would result in processing difficulty for the sentence.

(29) a. ORC/Plural attractor/Ungrammatical



b. SRC/Plural attractor/Ungrammatical



However, in SRC sentences as in (29b), the RC verb and the main clause verb are both controlled by the same subject (*Marine*). When the reader reaches the RC, *Marine* is integrated into the subject position of the RC to resolve the filler-gap dependency created by the RC subject's extraction (Stowe, 1986; Traxler & Pickering, 1996). Once this integration has occurred, the *t* position inside the RC would contain the necessary properties to act as the RC subject, leaving both the main clause subject (*Marine*) and the attractor noun (*officers*) as relevant controllers for retrieval during agreement computation at the main clause verb (*were*). Since

the features of the attractor noun would still be salient during retrieval, agreement attraction effects, as seen in Experiment 5, would be predicted for these sentences.

Importantly, sentences with long-distance attractors, as in (30), are also predicted to show attraction effects under this account.

(30) *The musicians that the reviewer were praising so highly won the prestigious award.

In these cases neither the attractor noun (*musicians*) nor the controlling subject (*reviewer*) have been encoded as the subject of a verb when the search process at *were* is initiated, meaning both *musicians* and *reviewer* would be relevant controllers during retrieval-based agreement processing. Thus, in the cases of (29b) and (30), the attractor nouns have not been encoded as the subject of a previous verb in the sentence, so they are still salient during retrieval processes.

Although this is an intriguing idea, it would seem to run into problems with at least one sentence type – sentences with coordinated VPs. In order to account for agreement that would occur in these sentences, such as in *The students were sitting in the cafeteria and were eating their lunches.*, it would be necessary to assume that the nouns remain relevant to agreement processing until the clause in which the noun occurs is closed. This would allow retrieval processes for both verbs in the coordinated VP to access *students* as the relevant controller for agreement computation. However, once the noun has been encoded as a subject and the clause is closed, any further verbs in the sentence would treat that noun as irrelevant to agreement computation.

Interestingly, if it is assumed that attractor nouns which have been encoded as subjects are deemed irrelevant to retrieval processes in later clauses, then it would appear that the retrieval processes responsible for agreement computation are indeed sensitive to structural information on the noun. Namely, the retrieval process is capable of ignoring the features of a noun that has already been encoded as the subject of a verb in a previous clause in the sentence. However, these results do not have clear implications as to whether the structural position of the attractor noun modulates attraction effects. The relevant comparison between ORC and SRC sentences is not available because the attractor nouns in ORC sentences are ignored during the agreement computation at the main clause verb *were*. However, though it is not a straightforward comparison, the attraction effects observed in Experiment 5 can be compared to the effects observed in Experiment 4. Recall that in Experiment 4, the attractor noun (*musicians*) occurred as the main clause subject, and in the SRC sentences of Experiment 5, the attractor noun (*officers*) occurred as the RC object. Thus, a comparison of these two sentence types could yield insight into whether the structural position of the attractor noun influences agreement attraction.

5.3.3 Illusion vs. Attenuation

Throughout the five experiments in this dissertation, only Experiment 4 indicated an illusion of grammaticality. The self-paced reading experiments and Experiment 5 all indicated attenuated processing difficulty for ungrammatical plural-attractor sentences, but no illusion of grammaticality. While both of these patterns reflect the influence of agreement attraction effects, it is important to understand why there is a difference in the profiles of attraction.

As discussed in Chapter 3, the difference between Experiments 1-3 and Experiment 4 was methodological. The motivation for using eye tracking was to gain access to the time-course of agreement processing in a way that self-paced reading was unable to reveal (Rayner, 1998; Rayner et al., 1989; Witzel et al., 2012). Eye tracking yielded results that demonstrated an illusion of grammaticality from the initial stages of processing until review time, which was suggested to reflect late stage review processes that occur after an initial sentence parse. During a self-paced reading study, these different time-course measures are not available for analysis and are conflated into one RT associated with a button push. Since self-paced reading represents early and late reading measures with a single RT, it could cause an illusion of grammaticality to be represented through a pattern of attenuation.

The difference between Experiments 4 and 5, however, is not one of methodology, as both are eye tracking studies, but rather materials. Experiment 4 used cases of long-distance agreement attraction with an ORC attached to the attractor noun as in (31). In these sentences, the main clause subject (*musicians*) acts as an attractor noun for subject-verb agreement occurring within the RC (*reviewer were praising*).

(31) Plural attractor/ungrammatical

*The musicians that the reviewer were praising so highly won the prestigious award.

Experiment 5 however, used materials with the attractor noun occurring within an invervening RC and the subject-verb agreement occurring in the main clause as in (32). In these sentences, the main clause subject (*Marine*) is the controlling subject for the main clause agreeing verb

(*were*) and the attractor noun (*officers*) is embedded in either the subject or the object position of the RC (only SRC items are considered for this comparison).

(32) SRC/Plural attractor/ungrammatical

*The Marine that saved the officers last week were promoting the military very forcefully.

A comparison of the attraction effects between (31) and (32) might suggest that attractors in the subject position exert more influence on agreement computation. This is supported by the illusion of grammaticality found in Experiment 4 with the attractor noun in the subject position. In comparison, the SRC items in Experiment 5 showed initial indications of processing difficulty with an attenuation of processing difficulty under first-pass regression proportion and second-pass measures. Thus, the lack of an illusion of grammaticality for SRC items, with an attractor in the object position, might suggest that agreement processing is sensitive to the structural position of the attractor noun.

However, this comparison relies on comparing two different attraction paradigms with different structural properties. Furthermore, previous work with intervening RC sentences has suggested that attractors occurring inside an RC give rise to weaker attraction effects than attractors occurring as objects of prepositions in the main clause. Specifically, Bock and Cutting (1992) compared responses to preambles like *The editor of the history books...* to responses to preambles like *The editor who rejected the books....* They found that head nouns with PP modifiers resulted in the production of more incorrect verbs than those with RC modifiers

and argued that the asymmetry of produced errors occurred because an RC boundary creates more structural information between the head noun and the attractor noun. While these results should not be taken to suggest that agreement attraction is clause bounded, the weaker profile of agreement attraction in Experiment 5 could be explained if it is assumed that an attractor noun is less effective when it is located in an embedded clause than when it is located in a main clause.

Thus, further research into whether the structural position of an attractor influences agreement attraction is necessary. One line of investigation that might lead to clear results is to return to the long-distance paradigm. Specifically, long-distance agreement attraction when the attractor occurs as a main clause subject, as in (31), could be compared to long-distance agreement attraction when the attractor occurs as a main clause object, as in (33).

(33) The record label hired the musician(s) that the reviewer(s) were praising so highly.

By comparing (33) to the long-distance cases examined in Experiment 4, the same manipulation of structural position examined in Experiment 5 is possible. Furthermore, these sentences provide a case where the attractor element is in the object position but is also part of the main clause, eliminating the possibility that an attractor embedded inside an RC has reduced effectiveness. Thus, if the structural position of the attractor noun does influence its effectiveness as an attractor, the sentences with attractors as subjects should show stronger attraction effects than sentences with attractors as objects. However, if the structural position of the attractor noun does not modulate agreement computation, there should be comparable agreement at-

traction in sentences from Experiment 4 and those in (33). The latter result might also suggest that the weaker effects seen in the SRC sentences of Experiment 5 are related to embedding the attractor noun inside an RC.

CHAPTER 6

CONCLUSION

The major goal of this dissertation was to investigate the nature of memory retrieval in agreement computation. This was done by examining possible cues that initiate retrieval, the time course of memory retrieval, and whether the structural position of the attractor noun influences retrieval processes during agreement processing. In order to investigate the first two issues, this dissertation used the paradigm of long-distance agreement attraction because it strongly favors a memory retrieval account.

Three self-paced reading experiments, Experiments 1-3, investigated whether long-distance attraction effects were observed across multiple agreement targets. If these effects represent core properties of agreement processing, then they should be observed regardless of the agreement target. Experiment 1 demonstrated evidence of agreement attraction in the form of attenuated processing difficulty for ungrammatical plural-attractor sentences when the verbal agreement target was an inflected main verb (*praise-s/-∅*). Experiments 2 & 3 demonstrated evidence of agreement attraction in the form of attenuated processing difficulty for ungrammatical plural-attractor sentences when the agreement target was a free auxiliary (*was/were*). The results of these three experiments confirm that long-distance agreement attraction occurs across multiple verb agreement targets, indicating that these effects reflect core properties of subject-verb agreement computation. These results also support the claim that memory re-

trieval processes are involved in agreement processing. However, these results did not provide clear evidence whether memory retrieval processes are part of core agreement processing. An investigation into the time course of agreement processing was necessary for such evidence.

Experiment 4 investigated the time course of memory retrieval. This experiment employed eye tracking to examine long-distance agreement attraction in early and late reading measures. It was predicted that if long-distance attraction effects were seen in early measures, this would indicate that these effects influence the earliest stages of agreement processing. However, if long-distance attraction effects occurred only in late measures, this would indicate that these effects are not present during early agreement processing and would suggest that they influence late stage processing attributed to recovery mechanisms. Experiment 4 revealed agreement attraction effects, in the form of an illusion of grammaticality, for ungrammatical plural-attractor sentences in early measures of agreement processing with indications that ungrammaticality was recognized only under the very latest stages of processing. These results indicated that long-distance attraction effects influence the earliest stages of agreement processing and also suggest that memory retrieval processes are involved at the earliest stages of agreement processing. The late recognition of ungrammaticality for ungrammatical plural-attractor sentences in review time was suggested to indicate a review or checking process that occurs after the sentences is parsed, meaning that ungrammaticality for plural-attractor sentences was only recognized during the final stage of processing. Taken together, Experiments 1-4 provide evidence that memory retrieval processes are involved in core agreement processing, with Experiments 1-3 showing that long-distance agreement attraction occurred across

multiple agreeing verbs, and Experiment 4 showing long-distance attraction effects at earliest stages of agreement processing.

Experiment 5 examined whether the structural position of the attractor noun affects its ability to influence agreement computation. Specifically, this experiment investigated whether an attractor which is a syntactic object exerts the same amount of influence as an attractor which is a syntactic subject. Since the long-distance agreement paradigm employed in Experiments 1-4 placed the attractor noun in the subject position, it provided no insight into this question (**The musicians that the reviewer were praising…*). Experiment 5 used an intervening attraction paradigm with subject-verb agreement occurring in the main clause and the attractor noun occurring as either the subject or object of an intervening RC, (34). If the structural position of the attractor noun influenced agreement attraction, then ungrammatical ORC sentences with plural attractors would show stronger attraction effects than their SRC counterparts. However, if the structural position of the attractor noun did not influence agreement attraction, then ungrammatical sentences with plural attractors in both SRC and ORC conditions would show comparable effects of agreement attraction.

(34) a. SRC / Plural attractor / ungrammatical

*The Marine that saved the officers last week were promoting the military very forcefully.

b. ORC / Plural attractor / ungrammatical

*The Marine that the officers saved last week were promoting the military very forcefully.

Experiment 5 demonstrated attraction effects, in the form of attenuated processing difficulty, for SRC sentences and no evidence of attraction effects for ORC sentences. In fact, ORC sentences demonstrated strong indications of processing difficulty for ungrammatical plural-attractor sentences.

The lack of attraction effects in ORC sentences paired with the evidence of attraction effects in SRC sentences and long-distance cases suggested that the agreement processor is sensitive to structural information on the attractor noun. Namely, it is capable of ignoring the features of an attractor noun, if that noun has been encoded as the subject of a verb in a previous clause in the sentence. Thus, in (34b), during the retrieval processes triggered by *were*, the only available match would be the main clause subject (*Marine*), resulting in a number mismatch between the verb and its controlling noun, and causing processing difficulty at and after the agreeing verb *were*. Importantly, this process would have no effect on either SRC agreement computation or long-distance agreement computation, maintaining the possibility of attraction effects to occur in these sentence types.

Lastly, the results of the five experiments varied with respect to their strength and timing. Experiments 1-4 examined long-distance agreement attraction, with the clearest and most persistent evidence for attraction effects occurring in Experiment 4, in the form of an illusion of grammaticality for ungrammatical plural-attractor sentences. However, Experiments 1-3 showed attenuation of processing difficulty for ungrammatical plural-attractor sentences, which varied in strength and timing. The differences between Experiments 1-3 and Experiment 4 were suggested to be due to the difference in methodology. Specifically, eye tracking

measures can represent reading times associated with different stages of sentence processing, however, in self-paced reading, early and late reading measures would be represented by the same RT causing a possible illusion of grammaticality to be represented through a pattern of attenuation.

Experiment 5's results also varied from the illusion of grammaticality seen in Experiment 4. Though evidence of attraction effects was seen for SRC sentences, these sentences also indicated that ungrammaticality was indexed for plural-attractor sentences. Here, the relevant difference between the two experiments involves the materials. Experiment 4 used cases of long-distance agreement attraction with an ORC attached to the attractor noun as in (35). In these sentences, the main clause subject (*musicians*) acts as an attractor noun for subject-verb agreement occurring within the RC (between *reviewer were praising*).

(35) Plural attractor/ungrammatical

*The musicians that the reviewer were praising so highly won the prestigious award.

Experiment 5, however, used materials with intervening agreement attraction with the attractor noun occurring within the RC and the subject-verb agreement occurring in the main clause as was seen in (34a). In these sentences, the main clause subject (*Marine*) is the controlling subject for the main clause agreeing verb (*were*) and the attractor noun (*officers*) is embedded in either the subject or the object position of the RC; however, here only SRC items are considered.

One account of the differences between these experiments develops straightforwardly out the the memory retrieval model. Specifically, the processor searches through working

memory looking for a controlling noun/NP to check its agreement features. When considering possible controllers, the subject-verb agreement processor looks for a noun/NP that matches the agreement target in terms of number features (plural), its encoding in a compatible structural position (subject), and its occurrence in the same clause. Thus, instances like long-distance attraction, in which the attractor noun matches with respect to both number and structural position, would be predicted to show stronger attraction effects. However, instances like intervening SRC constructions, in which the attractor noun matches only with respect to number features, would be predicted to show weaker attraction effects.

Alternatively, previous work with intervening RC sentences has suggested that this structure provides weaker attraction effects than other structural relationships, such as attractors occurring as objects of prepositions. Bock and Cutting (1992) found that head nouns with PP modifiers resulted in the production of more incorrect verbs than those with RC modifiers, and argued that the asymmetry of produced errors occurred because an RC boundary creates more structural information between the head noun and the attractor noun. While these results do not suggest that agreement attraction is clause bounded, the weaker profile of agreement attraction in Experiment 5 suggests that the attractor noun is less effective when it is located in the embedded clause rather than the main clause. Unfortunately, the data in this dissertation do not delineate between these two accounts. A future study using long-distance agreement with attractors occurring as the object of the main clause verb, as in (36), could shed light onto this issue.

(36) The record label hired the musician(s) that the reviewer(s) were praising so highly.

By comparing the attraction profiles of sentence type (36), with the attraction profile for the long-distance cases used in Experiments 1-4, one could determine if the structural position of the attractor noun influences its effect on agreement processing and possibly whether attractors within embedded clauses give rise to weaker attraction effects.

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APPENDIX A

Experiment 1: Experimental Items

The following list contains experimental items used in Experiment 1. Each of these items was manipulated for attractor number (singular, plural) and grammaticality (grammatical, ungrammatical) as given in (1).The main-clause subject acted as the attractor, it appeared both as singular, as in (1a) and (1b), and plural, as in (1c) and (1d). The relative clause verb was manipulated for grammaticality; the grammatical sentences are exemplified in (1a) and (1c) and the ungrammatical sentences are exemplified in (1b) and (1d).

(1) a. Singular attractor / grammatical
The musician that the reviewer praises so highly won the prestigious award.

b. Singular attractor / ungrammatical
*The musician that the reviewer praise so highly won the prestigious award.

c. Plural attractor / grammatical
The musicians that the reviewer praises so highly won the prestigious award.

d. Plural attractor / ungrammatical
*The musicians that the reviewer praise so highly won the prestigious award.

(2) The Marine that the officer trains on base went on leave last weekend.

(3) The patient that the doctor checks on daily tried an experimental treatment.

(4) The volunteer that the director relies on completely finished the important project.

(5) The runner that the driver passes every morning waved to say hello.

(6) The player that the coach describes very favorably arrived to practice early.

(7) The teenager that the farmer hires every summer picked fruit in the morning.

(8) The accountant that the administrator depends on completely balanced the books on time.

(9) The colleague that the researcher spends time with created very inventive machines.

(10) The supervisor that the counselor reports to weekly provided advice and support.

(11) The customer that the waitress treats quite badly decided to leave the restaurant.

(12) The dancer that the director praises so profusely performed in the Broadway musical.

(13) The industrialist that the activist criticizes each evening profited from creating pollution.

(14) The politician that the publicist assists every week expected a check yesterday.

(15) The actor that the producer considers quite talented performed for a long time.

(16) The firefighter that the ranger keeps on hand advised about forest fires.

(17) The overseer that the worker obeys so diligently fired anyone that mentioned unions.

(18) The lawyer that the candidate consults every morning discussed the recent poll.

(19) The landlord that the tenant pays so reluctantly took trips on weekends.

(20) The comedian that the prisoner watches so intently saw humor in everything.

(21) The pilot that the smuggler argues with angrily smoked on the balcony.

(22) The orphan that the nun tutors in algebra struggled with the subject.

(23) The columnist that the reader complains about frequently criticized the governor without evidence.

(24) The cheerleader that the choreographer works out with spent all year training.

(25) The therapist that the survivor meets with weekly studied at Harvard University.

(26) The sculptor that the donor supports so generously held several acclaimed exhibitions.

(27) The author that the librarian recommends to students sold well in India.

(28) The news anchor that the viewer disagrees with regularly reported the story irresponsibly.

(29) The journalist that the editor appreciates the most turned the story in promptly.

(30) The skateboarder that the kid admires so passionately signed autographs for fans.

(31) The rancher that the cowboy steals money from checked the accounts carefully.

(32) The receptionist that the boss gives small projects failed to perform well.

(33) The chef that the gourmet visits every week came up with new recipes.

(34) The quarterback that the recruiter watches every week performed well during practice.

(35) The caterer that the housewife recommends to friends brought many expensive foods.

(36) The bricklayer that the contractor assigns to projects arrived late for work.

(37) The surgeon that the nurse refuses to help performed the surgery badly.

(38) The student that the bully teases during lunch fought back very bravely.

(39) The philosopher that the scientist discusses so disrespectfully received a prestigious award.

(40) The translator that the diplomat requests for meetings facilitated the peace talks.

(41) The senator that the voter believes in strongly seemed to be lying.

(42) The criminal that the judge intimidates so easily looked down during sentencing.

(43) The bartender that the patron gossips with quietly washed the beer mugs.

(44) The goalie that the fan cheers for loudly stayed calm under pressure.

(45) The anthropologist that the villager teaches every day learned the local customs.

(46) The heiress that the bachelor pursues so relentlessly left for a long vacation.

(47) The programmer that the manager oversees so meticulously created a new game.

(48) The actress that the designer creates dresses for demanded an eccentric design.

APPENDIX B

Experiment 2: Experimental Items

The following list contains experimental items used in Experiment 2. Each of these items was manipulated for attractor number (singular, plural) and grammaticality (grammatical, ungrammatical) as given in (1).The main-clause subject acted as the attractor, it appeared both as singular, as in (1a) and (1b), and plural, as in (1c) and (1d). The relative clause verb was manipulated for grammaticality; the grammatical sentences are exemplified in (1a) and (1c) and the ungrammatical sentences are exemplified in (1b) and (1d).

(1) a. Singular attractor / grammatical
The musician that the reviewer was praising so highly won the prestigious award.

b. Singular attractor / ungrammatical
*The musician that the reviewer were praising so highly won the prestigious award.

c. Plural attractor / grammatical
The musicians that the reviewer was praising so highly won the prestigious award.

d. Plural attractor / ungrammatical
*The musicians that the reviewer were praising so highly won the prestigious award.

(2) The Marine that the officer was promoting on base saved the stranded platoon.

(3) The patient that the doctor was checking on daily tried an experimental treatment.

(4) The volunteer that the director was relying on completely finished the important project.

(5) The runner that the driver was avoiding that morning waved to say hello.

(6) The player that the coach was describing very favorably arrived to practice early.

(7) The teenager that the farmer was hiring to work picked fruit every morning.

(8) The accountant that the administrator was depending on completely balanced the books on time.

(9) The colleague that the researcher was spending time with created very inventive machines.

(10) The supervisor that the counselor was reporting to weekly provided advice and support.

(11) The customer that the waitress was treating quite badly left a lousy tip.

(12) The dancer that the host was praising so profusely performed in the Broadway musical.

(13) The industrialist that the activist was criticizing all evening profited from creating pollution.

(14) The politician that the publicist was assisting last week expected a check yesterday.

(15) The actor that the producer was considering most seriously performed for a long time.

(16) The firefighter that the ranger was keeping on hand advised about forest fires.

(17) The overseer that the worker was laughing at cruelly fired anyone that mentioned unions.

(18) The lawyer that the candidate was consulting every morning discussed the recent poll.

(19) The landlord that the tenant was paying so reluctantly took trips on weekends.

(20) The comedian that the prisoner was watching so intently saw humor in everything.

(21) The pilot that the smuggler was negotiating with yesterday smoked on the balcony.

(22) The orphan that the nun was tutoring in algebra struggled with the subject.

(23) The columnist that the reader was complaining about frequently criticized others without evidence.

(24) The cheerleader that the choreographer was working out with spent all year training.

(25) The therapist that the survivor was meeting with weekly helped with the recovery.

(26) The sculptor that the donor was supporting so generously held several acclaimed exhibitions.

(27) The author that the librarian was recommending that summer sold well in India.

(28) The news anchor that the viewer was disagreeing with regularly reported the story irresponsibly.

(29) The journalist that the editor was appreciating the most turned stories in promptly.

(30) The skateboarder that the kid was admiring so passionately signed autographs for fans.

(31) The rancher that the cowboy was stealing money from filed a criminal complaint.

(32) The receptionist that the boss was giving small projects failed to perform well.

(33) The chef that the gourmet was visiting every week came up with new recipes.

(34) The quarterback that the recruiter was watching every weekend received large contract offers.

(35) The caterer that the hostess was recommending to friends brought many expensive foods.

(36) The bricklayer that the contractor was assigning to projects arrived late for work.

(37) The surgeon that the nurse was refusing to help performed the surgery badly.

(38) The student that the bully was teasing during lunch fought back very bravely.

(39) The philosopher that the scientist was discussing so disrespectfully wrote in complicated language.

(40) The translator that the diplomat was asking for help facilitated the peace talks.

(41) The senator that the voter was listening to patiently seemed like a liar.

(42) The criminal that the judge was intimidating the most looked down during sentencing.

(43) The bartender that the patron was gossiping with quietly hated the bar.

(44) The goalie that the fan was cheering for loudly stayed calm under pressure.

(45) The anthropologist that the villager was teaching every day learned the local customs.

(46) The heiress that the bachelor was pursuing so relentlessly married richer men.

(47) The programmer that the manager was overseeing so meticulously created software for gaming.

(48) The actress that the designer was creating dresses for demanded very eccentric designs.

APPENDIX C

Experiments 3 & 4: Experimental Items

The following list contains experimental items used in Experiments 3 and 4. Each of these items was manipulated for attractor number (singular, plural) and grammaticality (grammatical, ungrammatical) as given in (1).The main-clause subject acted as the attractor, it appeared both as singular, as in (1a) and (1b), and plural, as in (1c) and (1d). The relative clause subject was manipulated for grammaticality; the grammatical sentences are exemplified in (1a) and (1c) and the ungrammatical sentences are exemplified in (1b) and (1d).

(1) a. Singular attractor / grammatical
The musician that the reviewers were praising so highly won the prestigious award.

b. Singular attractor / ungrammatical
*The musician that the reviewer were praising so highly won the prestigious award.

c. Plural attractor / grammatical
The musicians that the reviewers were praising so highly won the prestigious award.

d. Plural attractor / ungrammatical
*The musicians that the reviewer were praising so highly won the prestigious award.

(2) The Marine that the officers were promoting on base saved the stranded platoon.

(3) The patient that the doctors were checking on daily tried an experimental treatment.

(4) The volunteer that the directors were relying on completely finished the important project.

(5) The runner that the drivers were avoiding that morning waved to say hello.

(6) The player that the coaches were describing very favorably arrived to practice early.

(7) The teenager that the farmers were hiring to work picked fruit every morning.

(8) The accountant that the administrators were depending on completely balanced the books on time.

(9) The colleague that the researchers were spending time with created very inventive machines.

(10) The supervisor that the counselors were reporting to weekly provided advice and support.

(11) The customer that the waitresses were treating quite badly left a lousy tip.

(12) The dancer that the hosts were praising so profusely performed in the Broadway musical.

(13) The industrialist that the activists were criticizing all evening profited from creating pollution.

(14) The politician that the publicists were assisting last week expected a check yesterday.

(15) The actor that the producers were considering most seriously performed for a long time.

(16) The firefighter that the rangers were keeping on hand advised about forest fires.

(17) The overseer that the workers were laughing at cruelly fired anyone that mentioned unions.

(18) The lawyer that the candidates were consulting every morning discussed the recent poll.

(19) The landlord that the tenants were paying so reluctantly took trips on weekends.

(20) The comedian that the prisoners were watching so intently saw humor in everything.

(21) The pilot that the smugglers were negotiating with yesterday smoked on the balcony.

(22) The orphan that the nuns were tutoring in algebra struggled with the subject.

(23) The columnist that the readers were complaining about frequently criticized others without evidence.

(24) The cheerleader that the choreographers were working out with spent all year training.

(25) The therapist that the survivors were meeting with weekly helped with the recovery.

(26) The sculptor that the donors were supporting so generously held several acclaimed exhibitions.

(27) The author that the librarians were recommending that summer sold well in India.

(28) The news anchor that the viewers were disagreeing with regularly reported the story irresponsibly.

(29) The journalist that the editors were appreciating the most turned stories in promptly.

(30) The skateboarder that the kids were admiring so passionately signed autographs for fans.

(31) The rancher that the cowboys were stealing money from filed a criminal complaint.

(32) The receptionist that the bosses were giving small projects failed to perform well.

(33) The chef that the gourmets were visiting every week came up with new recipes.

(34) The quarterback that the recruiters were watching every weekend received large contract offers.

(35) The caterer that the hostesses were recommending to friends brought many expensive foods.

(36) The bricklayer that the contractors were assigning to projects arrived late for work.

(37) The surgeon that the nurses were refusing to help performed the surgery badly.

(38) The student that the bullies were teasing during lunch fought back very bravely.

(39) The philosopher that the scientists were discussing so disrespectfully wrote in complicated language.

(40) The translator that the diplomats were asking for help facilitated the peace talks.

(41) The senator that the voters were listening to patiently seemed like a liar.

(42) The criminal that the judges were intimidating the most looked down during sentencing.

(43) The bartender that the patrons were gossiping with quietly hated the bar.

(44) The goalie that the fans were cheering for loudly stayed calm under pressure.

(45) The anthropologist that the villagers were teaching every day learned the local customs.

(46) The heiress that the bachelors were pursuing so relentlessly married richer men.

(47) The programmer that the managers were overseeing so meticulously created software for gaming.

(48) The actress that the designers were creating dresses for demanded very eccentric designs.

APPENDIX D

Experiment 5: Experimental Items

The following list contains experimental items used in Experiment 5. Each of these items was manipulated for attractor number (singular, plural), grammaticality (grammatical, ungrammatical), and RC type (subject-extracted, object-extracted) as given in (1). The noun inside the RC acted as the attractor, it appeared both as singular, as in (1a)-(1b) and (1e)-(1f), and plural, as in (1c)-(1d) and (1g)-(1h). The main clause subject was manipulated for grammaticality; the grammatical sentences are exemplified in (1a), (1c), (1e) and (1g), and the ungrammatical sentences are exemplified in (1b), (1d), (1f) and (1h). The subject-extracted RCs (SRC) are shown in (1a)-(1d) and the objected-extracted RCs (ORC) are shown in (1e)-(1h).

(1) a. SRC / Singular attractor / grammatical
The Marines that saved the officer last week were promoting the military very forcefully.

b. SRC / Singular attractor / ungrammatical
*The Marine that saved the officer last week were promoting the military very forcefully.

c. SRC / Plural attractor / grammatical
The Marines that saved the officers last week were promoting the military very forcefully.

d. SRC / Plural attractor / ungrammatical
*The Marine that saved the officers last week were promoting the military very forcefully.

e. ORC / Singular attractor / grammatical
The Marines that the officer saved last week were promoting the military very forcefully.

f. ORC / Singular attractor / ungrammatical
*The Marine that the officer saved last week were promoting the military very forcefully.

g. ORC / Plural attractor / grammatical
The Marines that the officers saved last week were promoting the military very forcefully.

h. ORC / Plural attractor / ungrammatical
*The Marine that the officers saved last week were promoting the military very forcefully.

(2) The patients that the doctor saw every day were buying some drugs at the pharmacy.

(3) The volunteers that the director trusted so completely were finishing the project on time.

(4) The players that the coach described very kindly were practicing the plays during warmup.

(5) The runners that the driver passed every morning were waving to people at the playground.

(6) The teenagers that the farmer liked so well were picking fresh fruit every morning.

(7) The accountants that the administrator hired last year were working all weekend last week.

(8) The colleagues that the researcher viewed so highly were creating video games for children.

(9) The counselors that the supervisor reported last week were providing good advice for women.

(10) The customers that the waitress greeted so fondly were sitting very comfortably at the bar.

(11) The dancers that the host found so amusing were performing on Sunday in a musical.

(12) The industrialists that the activist hated so much were profiting from deals with the mafia.

(13) The lobbyists that the publicist helped last week were expecting the check last month.

(14) The actors that the producer favored so strongly were performing on Broadway last summer.

(15) The firefighters that the ranger kept on hand were advising the campers about forest fires.

(16) The managers that the worker teased so mercilessly were reacting very poorly to down-sizing.

(17) The lawyers that the candidate called every morning were discussing the judge on the case.

(18) The landlords that the tenant assisted so reluctantly were taking short trips on week-ends.

(19) The comedians that the writer knew so well were performing on television in a special.

(20) The pilots that the smuggler tricked last month were smoking Cuban cigars on the balcony.

(21) The orphans that the nun annoyed so badly were struggling at school with algebra.

(22) The columnists that the anchor admired so much were arguing about politics on the set.

(23) The cheerleaders that the choreographer loved so much were resting all year after the finals.

(24) The therapists that the detective asked for help were treating crash victims for trauma.

(25) The sculptors that the donor approached so quickly were showing popular pieces to buyers.

(26) The musicians that the reviewer respected so greatly were winning many awards at the show.

(27) The authors that the librarian met on sabbatical were selling signed books in India.

(28) The reporters that the pundit criticized so often were bribing police officers for leads.

(29) The journalists that the editor abused the most were vacationing with family in Europe.

(30) The snowboarders that the skier admired so passionately were passing out soup at the shelter.

(31) The ranchers that the cowboy attacked last week were filing a complaint at the station.

(32) The receptionists that the boss complimented so kindly were failing to finish the paperwork.

(33) The chefs that the gourmet consulted every week were creating new recipes from scratch.

(34) The quarterbacks that the recruiter ignored at tryouts were getting contract offers all week.

(35) The caterers that the hostess enjoyed so much were bringing expensive food for dinner.

(36) The bricklayers that the contractor knew for years were completing the patio very quickly.

(37) The surgeons that the nurse teased for fun were performing the procedure very badly.

(38) The students that the bully confronted at lunch were yelling very loudly for the teachers.

(39) The philosophers that the scientist rejected so sharply were writing new articles each week.

(40) The translators that the diplomat asked for help were facilitating peace talks at the UN.

(41) The senators that the official trusted so much were listening to speakers at the meeting.

(42) The criminals that the judge intimidated the most were looking down sadly during the trial.

(43) The bartenders that the server assisted so often were serving weak drinks all evening.

(44) The goalies that the defender respected so much were staying in position during penalties.

(45) The anthropologists that the villager taught every day were learning the customs very slowly.

(46) The heiresses that the bachelor pursued so tirelessly were moving to England last year.

(47) The programmers that the manager mocked so harshly were creating new software for gaming.

(48) The actresses that the designer treated so rudely were recommending edgy designs for the show.

(49) The receivers that the referee ignored last night were getting first downs every play.

(50) The models that the photographer met so often were working with celebrities last week.

(51) The bankers that the teller hated so strongly were stealing from accounts in Switzerland.

(52) The brokers that the investor consulted last week were making stock trades on gut feelings.

(53) The motorcyclists that the mechanic trusted so much were selling illicit drugs for the gang.

(54) The butchers that the dietitian supported so strongly were selling fresh meat at low prices.

(55) The bakers that the nutritionist found in town were creating new breads from organic wheat.

(56) The carpenters that the painter helped without delay were building wooden chairs by hand.

(57) The instructors that the sailor approached last week were flirting with everyone in the bar.

(58) The trainers that the client saw every week were lifting 400 pounds on the leg press.

(59) The plumbers that the homeowner contacted last month were draining the sewage from the yard.

(60) The roofers that the exterminator irritated at work were installing the roof all evening long.

(61) The gamers that the technician beat in Halo were living at home without paying rent.

(62) The guards that the warden approached during work were keeping most prisoners in order.

(63) The rappers that the singer imitated without consent were creating new singles in the studio.

(64) The poets that the novelist cited so often were writing several sonnets for the collection.