TAMING THE JABBERWOCKY: EXAMINING SENTENCE PROCESSING WITH NOVEL WORDS

by

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ABSTRACT OF THE DISSERTATION

Taming the Jabberwocky: Examining Sentence Processing with Novel Words

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Previous research suggests people are remarkably good at processing sentences that contain novel words. For example, although we do not know what *cratomize* means, we know that the sentence *The man cratomized the boy* is grammatical (unlike *The man cratomize the boy*), and we can answer questions about it (e.g., *who did the man cratomize?*). This dissertation investigates the role of syntactic and morphological information in human sentence processing using relative clause sentences containing nonsense words, such as *The actor who cratomized the critic impressed the director* and *The actor who the cratomer humiliated impressed the director.*

Experiments 1 and 2 reveal that human sentence processing is an automatic reflex which is unaffected by task requirements or presence of novel words. Subsequent experiments further examine processing of such sentences. Experiment 3 reveals that the impact of syntactic context is so great that, for certain syntactic positions, processing novel words bears no additional cost. Experiments 4-6 investigate how syntactic and morphological information interact. These experiments reveal that syntactic information plays a dominant role with morphology playing a very minor role, with incongruence between syntactic and morphological information always being resolved in favor of syntax.

In addition to these behavioral studies, we propose two extensions of existing computational models of sentence processing that enable the models to process sentences with novel words. Our evaluations suggest that the integration of sentence processing models with models of word recognition is a promising future avenue of research. Furthermore, our analyses of English corpora reveal that derivational and inflectional suffixes tend to be infrequently and unreliably used in English, which may (partially) explain why morphological information plays such a minor role in English sentence processing.

In the last section of the dissertation, we conduct cross-linguistic analyses that reveal an inverse relation between morphological and syntactic information. Specifically, languages with freer word-order constraints tend to be morphologically richer than languages with strict syntactic constraints, such as English. This hints at a possibility that morphology might play a greater role during sentence processing in languages that have richer morphology than English.

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This dissertation would not be without the help and support of several people.

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Thank you to my parents and my sister. We have always been close, and they have always been supportive. I could not have done this without their love.

Last, but in no ways the least, a special thank you to my lovely wife, Nikhi. We have struggled, yet we still endure. Her love and support made this, but I am glad this is over, just so we can move on to our next adventure!

Dedication

To my grandfather.

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1. Introduction

"'Begin at the beginning,' the King said, very gravely, 'and go on till you come to the end: then stop.'"
— Lewis Carroll, *Alice's Adventures in Wonderland*

This dissertation attempts to answer the following question: How do we understand words that we have never heard before? Ironically, it is almost a cliché to say that just about any sentence we read or hear is new. Yet, we are able to understand every sentence almost instantaneously. Equally remarkable is our ability to seemingly make sense of novel words, even, sometimes, words that are nonsensical. As an example, consider the following excerpt from Lewis Carroll's (1883) poem, Jabberwocky:

'Twas brillig, and the slithy toves
Did gyre and gimble in the wabe;
All mimsy were the borogoves,
And the mome raths outgrabe.

Despite most of the words having no meaning, we are still somehow able to make some sense of the poem's nonsense. For example, *brillig* likely refers to some property of the day, and *gyre* and *gimble* perhaps refer to the movement of the *slithy toves* in the *wabe*. How do we do this? What is it about the words themselves, and the sentences within which they lie, that allows us to derive meaning where there is none? These are the questions that are addressed in this dissertation.

More specifically, this dissertation asks whether we process sentences containing novel words similarly to regular sentences. Furthermore, what linguistic factors, syntactic or morphological, allow us to process such novel words? Because words that are unknown to one person may be known to another, in our work, we used nonsense words similar to the ones used by Carroll in Jabberwocky. Such nonsense words, more commonly referred to as pseudowords, have similar orthographic and phonological structures as regular words. In other words, pseudowords look and sound like regular words.

In the past, neurolinguistic researchers have used pseudowords to study processing of sentences devoid of semantic content (e.g., Canseco Gonzalez et al., 1997; Canseco-Gonzalez, 2000; Hahne and Jescheniak, 2001; Münte et al., 1997; Rothermich et al., 2009; Silva-Pereyra et al., 2007; Yamada and Neville, 2007). Typically, they have used sentences where all lexical, content words (i.e., nouns, verbs, adjectives, etc.) were replaced with pseudowords, such as in, *The toves that gyred the wabe rathed the outgrabe.* Quite appropriately, such sentences are referred to as Jabberwocky sentences in the literature. Generally speaking, their studies have found that taking away meaning from sentences does not disrupt their syntactic processing (see Section 2.1.1 for a more detailed discussion).

Despite the relative popularity of Jabberwocky sentences in neurolinguistics, such sentences have not as extensively been studied by psycholinguists. However, results of the few studies that have investigated processing of sentences containing such Jabberwocky words also suggest that people process such meaningless sentences as they do regular ones (e.g., Stromswold et al., 1996; Fedorenko et al., 2009).

Traditionally, modeling work in human sentence processing has assumed "clean" input, where words are clearly separated and always known. As such, these models are incapable of handling behavioral data corresponding to the processing of Jabberwocky sentences. Recently, some researchers have begun to develop computational models capable of addressing uncertainty in the perceptual input (e.g., Levy, 2008b, 2011). Such models make the assumption that the input received by the sentence comprehension system may be corrupted by noise, and consider the possibility that some words were incorrectly added, deleted, or substituted. Crucially, early behavioral work has provided results that are consistent with predictions made by such hypotheses (e.g., Levy, 2011; Bergen et al., 2012).

1.1 Contributions

This dissertation makes three primary contributions to the field of psycholinguistics. First, we conduct behavioral studies to better understand how sentences containing unknown words are processed. As mentioned earlier, there is relatively little behavioral work on processing of novel words. Through self-paced reading studies, we show that syntactic context predominantly guides the comprehension of novel words. Moreover, by pitting syntactic information against morphological, we show that syntax outweighs morphology, which suggests that sentence processing is a largely top-down process.

The second major contribution of this dissertation is the evaluation of existing psycholinguistic models of sentence processing, and development of computational models capable of processing novel words. Using our behavioral data, we show that all current psycholinguistic models fall short when dealing with sentences with novel words. Most models assume that the input received by the sentence processing system is clean, with words always separated and known. Here, we suggest ways to extend current sentence processing models to enable handling novel words. We argue that going forward, the next step should be combining work on sentence processing with modeling work on lexical detection and word recognition.

Lastly, the third major contribution of this dissertation is our cross-linguistic work where we examine how syntactic and morphological information interact across languages. We use a large database of languages, where several linguistic features of several languages are identified and marked. Using that database, we perform analyses examining the relation between morphological properties of languages and their word order preferences. Our results show an inverse relation between the two features of languages, with morphologically richer languages being more likely to be syntactically flexible, and vice versa.

1.2 Outline

The remainder of this dissertation is organized as follows.

- **Chapter 2** provides a discussion of relevant background work. First, we discuss previous work on Jabberwocky sentences, as well as recent work on sentence processing models capable of dealing with perceptual uncertainty. Next, we discuss processing of relative clause sentences, and provide an overview of various approaches that have been used to model behavioral data.

- **Chapter 3** presents two behavioral studies on pseudoword detection in sentential contexts. We describe a novel whole-sentence paradigm to evaluate any influence of syntax on word recognition. We conclude the chapter with a discussion of the findings.
- **Chapter 4** presents four behavioral studies on processing of sentences containing pseudowords. Through three self-paced reading experiments, we evaluate the role played by syntax and morphology in deciphering unknown words. We also discuss a word classification study to evaluate whether morphological information on pseudowords can be processed and integrated. We conclude the chapter with a discussion of the general implication of the findings and how they relate to previous work.
- **Chapter 5** discusses new techniques to extend current sentence processing models such that they are capable of processing novel words. We also present corpora analyses to evaluate the reliability of morphological information in English, and the interaction between syntax and morphology across languages.
- **Chapter 6** discusses the relevance of our findings, and proposes directions for future research.

2. Background

"'The time has come,' the walrus said, 'to talk of many things: Of shoes and ships - and sealing wax - of cabbages and kings'"
— Lewis Carroll, *Through the Looking-Glass*

This chapter attempts to condense decades of research on human sentence processing, highlighting previous studies that have informed the work presented in this dissertation.

2.1 Processing Noisy Sentences

The central theme of this dissertation is whether and how sentence processing is affected by the presence of unknown words. An extreme form of unknown words are orthographically and phonologically plausible nonsense words, also known as *pseudowords*, such as *cratomized, thulking, foomer*, etc. In this section, we first discuss previous studies from neurolinguistics that have used sentences containing such meaningless words to study syntactic processing in isolation from semantic processing. Next, we discuss recent work that proposes a rational approach to sentence processing in the presence of uncertain input, called the noisy channel model.

2.1.1 Jabberwocky Sentences

Several neurolinguists have used so-called "Jabberwocky" sentences to investigate how syntax and semantics interact. Jabberwocky sentences are essentially sentences where the syntactic structure is preserved, but all content words are replaced with nonsense words. Effectively, this renders such sentences meaningless, such as in, *All mimsy were the borogoves* and *The mome raths outgrabe.* Typically, Jabberwocky sentences have been used to examine the effects of reduced semantic content on syntactic processing by contrasting syntactic violation effects on such sentences with normal sentences (e.g., Canseco Gonzalez et al., 1997; Canseco-Gonzalez, 2000; Hahne and Jescheniak, 2001; Münte et al., 1997; Rothermich et al., 2009; Silva-Pereyra et al., 2007; Yamada and Neville, 2007)

Most ERP studies have reported that greater left anterior negativities (LANs) and early left anterior negativities (ELANs) are elicited for both normal and Jabberwocky sentences in presence of syntactic violations (Canseco Gonzalez et al., 1997; Canseco-Gonzalez, 2000; Hahne and Jescheniak, 2001; Yamada and Neville, 2007). Typically, LANs and ELANs reflect grammatical anomalies, with ELANs being sensitive to word category (phrase structure) violations and LANs being sensitive to word category as well as morphosyntactic violations (Gunter et al., 2000; Hagoort and Brown, 2000). Thus, these results indicate that the absence of semantic information does not disrupt syntactic processing. Furthermore, this suggests that Jabberwocky sentences can be syntactically processed the same way as normal sentences.

Another ERP measure that is linked to syntactic processing is the P600, which is elicited by both morpho-syntactic violations (e.g. Coulson et al., 1998; Friederici and Kotz, 2003; Hagoort and Brown, 2000; Hahne and Friederici, 1999; Morris and Holcomb, 2005; Osterhout and Mobley, 1995; Osterhout et al., 1997) and word-disambiguation in syntactically ambiguous sentences (e.g. Osterhout and Holcomb, 1992, 1993). Unlike LANs and ELANs, reports of P600 effects on Jabberwocky sentences have been mixed. For example, Hahne and Jescheniak (2001) found that equivalent P600s were elicited for syntactic violations in normal and Jabberwocky sentences. On the other hand, some other researchers have reported an attenuated or absent P600 for syntactic violations in Jabberwocky sentences when compared to syntactic violations in normal sentences (Canseco Gonzalez et al., 1997; Canseco-Gonzalez, 2000; Münte et al., 1997; Yamada and Neville, 2007). It has been argued that such discrepancies may reflect experimental differences, such as the particular language being studied, violation types, and sentential position of syntactic violations (see, Yamada and Neville, 2007). However, the consensus seems to be that P600s may reflect semantically-influenced reanalysis of ungrammatical sentences, and the attenuation or absence of P600s for Jabberwocky sentences likely reflects the absence of semantic content in such sentences.

Taken together, the ERP data indicate that the absence of semantic information does not hinder syntactic processing. In turn, this suggests that the presence of unknown words in sentences might not disrupt syntactic processing. Such neurolinguistic findings are further supported by some psycholinguistic studies. In early work, Stromswold et al. (1996) examined differences in comprehension of two relative-clause constructions: Center-Embedded (CE) sentences, such as *The juice that the child spilled stained the rug*, and Right-Branching (RB) sentences, such as *The child spilled the juice that stained the rug* (see Figure 2.1 for their syntactic structures). Participants were instructed to read whole sentences and decide whether they were acceptable. In one of their three experimental conditions, half of the sentences contained an orthographically and phonologically plausible pseudoword that replaced one of the lexical words (noun/verb) in the sentence. For example, *The child spilled the juice that* <u>*cratomized*</u> *the rug* and *The juice that the* <u>*wanner*</u> *spilled stained the rug*. Their analyses of participants' reading time data revealed a significant effect of syntactic structure of sentences, and participants were slower for CE sentences than RB. Crucially, the effect of syntactic structure persisted even when only sentences containing pseudowords were analyzed. Thus, their results indicate two possibilities: 1) syntactic processing is an automatic reflex which is unaffected by task requirements; and 2) syntactic processing can occur even in presence of pseudowords, and thus unknown words.

In another study, Yamada and Neville (2007) asked participants to judge the grammaticality of a number of sentences falling in one of four categories: 1) grammatical English sentences; 2) ungrammatical English sentences; 3) grammatical Jabberwocky sentences; and 4) ungrammatical Jabberwocky sentences. The Jabberwocky sentences were constructed by replacing all lexical words from the normal sentences with pseudowords. For example, given a normal sentence, *Mommy can cut the meat with that knife*, its Jabberwocky counterpart could be, *Minno can kogg the mibe with that nove*. Their behavioral results indicated that participants were able to judge the grammaticality of Jabberwocky sentences with accuracy almost as high (97%) as for regular sentences (98%). Although their results showed a statistical difference between the two types of sentences, they found that the difference in the number of sentences incorrectly judged was merely one. Again, these results suggest that the presence of unknown, meaningless words does not hamper syntactic processing.

Another study by Fedorenko et al. (2009) more directly examined whether the lack of lexical and referential meaning in Jabberwocky sentences affects their syntactic processing.

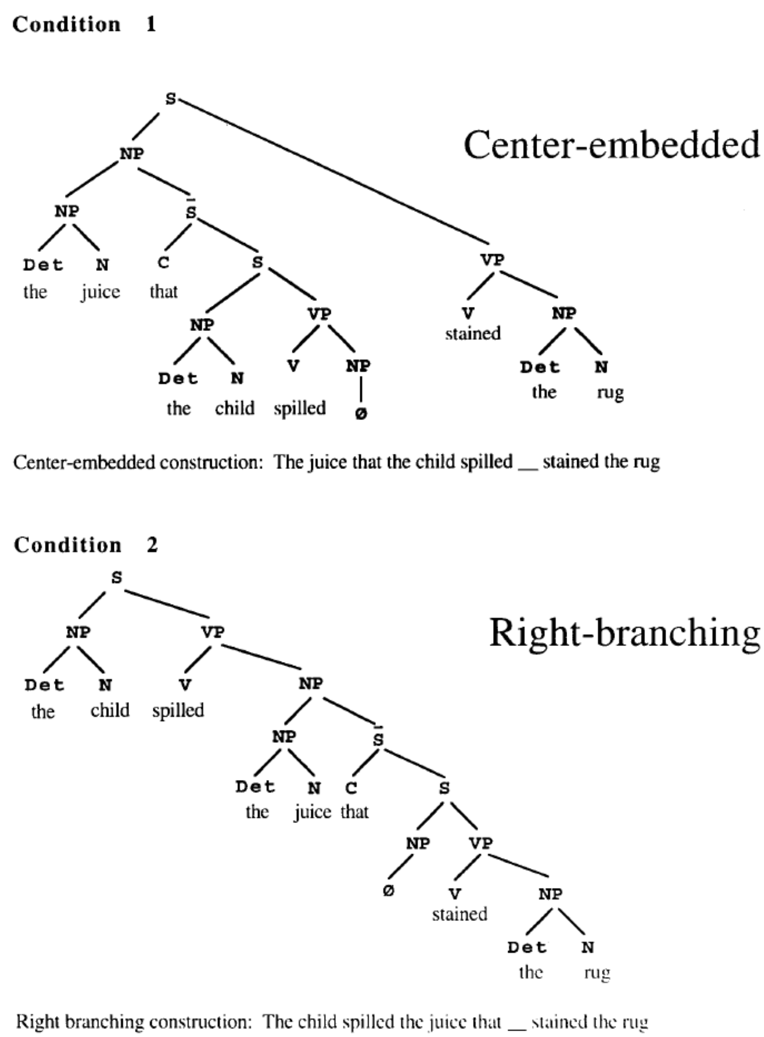


Figure 2.1: Syntactic structures corresponding to the two sentence types used by Stromswold et al. (1996)

In two experiments, they investigated processing of subject- and object-extracted relative clauses, along with main verb/reduced-relative clauses. Their examples are shown below:

(1) Subject-extracted RC: *The rop that strouled the ciff knunted the yeel.*

(2) Object-extracted RC: *The rop that the ciff strouled knunted the yeel.*

(3) Main-verb sentence: *The whamp (had) scrucked the yebb at the cralph.*

(4) Reduced-relative sentence: *The whamp (who was) scrucked by the yebb brotched the cralph.*

Subject-extracted relative clauses (SRCs) and object-extracted relative clauses

(ORCs) have historically been studied in several psycholinguistic studies and clear predictions can be made about processing complexities during their syntactic processing. Presently, researchers unanimously agree that ORCs are harder to process than SRCs, with the two verbs being the points of greatest difficulty (see Section 2.2 for a detailed discussion). Furthermore, main-verb/reduced-relative sentences have also been historically well-studied, and we know that main-verb sentences are easier to process than reduced-relative sentences (e.g., Frazier and Rayner, 1987; Trueswell and Tanenhaus, 1991; MacDonald, 1994; MacDonald et al., 1994; Trueswell and Tanenhaus, 1994; Trueswell et al., 1994; Spivey-Knowlton and Sedivy, 1995). Additionally, the greater difficulty for reduced-relative sentences has been found to be localized at the by-phrase.

In line with this predictions, Fedorenko et al. (2009) found that their participants read ORCs slower than SRCs, especially at the two verbs. Additionally, participants also exhibited greater difficulty responding to comprehension questions following ORCs than SRCs. They also observed a greater processing difficulty for reduced-relatives over main-verb sentences, with the difficulty being most prominent at the by-phrase. Again, participants were less accurate in responding to comprehension questions following reduced-relatives than main-verb sentences. These findings suggest that people can assign thematic roles to nouns, and ambiguously interpret morphologically ambiguous words (e.g., *scrucked* in (3)(4) above). Crucially, these results provide further support for the argument that the presence of novel words and the lack of semantic content in the Jabberwocky sentences does not hinder syntactic processing.

2.1.2 Noisy Channel Models

A fairly recent development in sentence processing research is the noisy channel model (Levy, 2008b, 2011). The noisy channel model is a rational model of sentence comprehension and has its roots in information theory. According to this model, the goal of the comprehender is to derive the speaker-intended true input from a potentially-corrupted perceptual input. This process of inference requires the use of prior linguistic knowledge, which is used to constrain the space of possibilities. Another source of information that guides this process of inference is the comprehender's prior knowledge about the noise-generation process. Essentially, this knowledge allows the comprehender to further rule out unlikely possibilities.

Bergen et al. (2012) formulate the noisy channel model in terms of an optimal Bayesian inference process. The probability that a sentence S was intended given the perceptual input I is equal to:

$$P(S|I) = \frac{P_L(S)P_N(I|S)}{P(I)}$$

Here, P_L is the probability distribution corresponding to prior linguistic information, and P_N is the distribution corresponding to the noise-generation process. Thus, $P_N(I|S)$ is the probability that the input I will be observed when the intended sentence was S. Subsequently, given an input, I, the evidence for a sentence S_1 over S_2 can be estimated using relative posteriors:

$$\frac{P(S_1|I)}{P(S_2|I)} = \frac{P_L(S_1)P_N(I|S_1)}{P_L(S_2)P_N(I|S_2)}$$

Thus, according to this model, only sentence candidates that have a high probability of resulting in the perceptual input (i.e., high value of $P_N(I|S)$) will be plausible candidates for the intended meaning of the speaker. Furthermore, it also highlights the trade-off between linguistic knowledge and the noise process. It is easiest to presume that the perceptual input was the intended target, thus assuming no added noise. However, the presence of noise will be inferred when a candidate sentence exists that is sufficiently similar to the input, and has a much greater probability according to the language model P_L (see Bergen et al., 2012, for more details).

Support for the noisy channel model comes through a self-paced reading study by Levy (2011), in which participants read sentences of the following form:

(5) *As the soldiers marched, toward the tank lurched an injured enemy combatant.*

(6) *As the soldiers marched into the bunker, toward the tank lurched an injured enemy combatant.*

(7) *As the soldiers marched, the tank lurched toward an injured enemy combatant.*

(8) *As the soldiers marched into the bunker, the tank lurched toward an injured enemy combatant.*

For sentences such as (5), they found heightened reading time at the main verb position (e.g., *lurched*). This reading time slowdown was not observed for any other type of sentence. Levy interpreted their results as indicating that participants disregard orthographic information (commas in this case) on the basis of prior linguistic information that biases them towards a certain reading (e.g., *As the soldiers marched toward the tank...*). This bias takes them towards a syntactic "garden-path," which later results in a syntactic reanalysis causing heightened processing costs.

In another study, Bergen et al. (2012) evaluated the noisy channel model's prediction that comprehenders should infer that a perceived input contains an error if there exists a similar sentence with a higher prior probability of occurrence. They had participants read the following four types of sentences:

(9) Dense-NN: *The intern chauffeur for the governor hoped for more interesting work.*

(10) Dense-NV: *The intern chauffeured for the governor hoped for more interesting work.*

(11) Sparse-NN: *The inexperienced chauffeur for the governor hoped for more interesting work.*

(12) Sparse-NV: *Some interns chauffeured for the governor hoped for more interesting work.*

The sentences all differed at the first three word positions, which the authors refer to as the preamble. In the example sentences, "NN" indicates noun-noun preambles, whereas "NV" indicates noun-verb ones. "Dense" conditions contained preambles which had other grammatical phrases in their morphological neighborhood, whereas "Sparse" conditions were not in the morphological neighborhood of other syntactic constructions.

Bergen et al. predicted that in the Dense-NN condition, participants might infer that the word *chauffeured* was intended instead of *chauffeur*. Consequently, they predicted this would result in a syntactic garden-path which would need to be resolved at the main verb, *hoped*, causing greater processing difficulty. In line with these predictions, their results showed that participants read the main verb significantly slowly in the Dense-NN case than the other three cases.

The noisy channel model also seems to be consistent with the Jabberwocky findings discussed in the previous section. Although Jabberwocky sentences lack any lexical or referential content, people are still able to syntactically process them. It is plausible that on encountering novel, meaningless words, people interpret them as noise, and try to infer the intended input. If so, it is possible that sentence processing proceeds by finding orthographically or phonologically similar words and substituting them in place of the Jabberwocky words. Such an account would predict greater overall processing difficulty for Jabberwocky sentences, but otherwise no difference in the end-product of the syntactic analyses. This is consistent with the results of Yamada and Neville (2007) who found that people are just as good at judging grammaticality of Jabberwocky sentences as they are for regular sentences.

2.2 Processing Relative Clauses

The second, but not secondary, theme of this dissertation is the processing of relative clause sentences. Historically, relative clause sentences have proved to be a valuable test-bed for psycholinguistic research on sentence processing. In this section, we first describe relative clause sentences, then present important empirical findings, and lastly discuss various approaches that have been employed to explain those findings.

2.2.1 Relative Clauses

Essentially, relative clause sentences are sentences that contain a subordinate clause which modifies a noun or a sentential phrase, by either making it more specific or providing supplementary information. For example, consider the sentence, *The man who killed the girl feared the detective.* Here, *who killed the girl* is a relative clause that specifies which man it was who feared the detective. Put simply, relative clauses have a missing argument that is shared with the main clause element on which they are grammatically dependent.

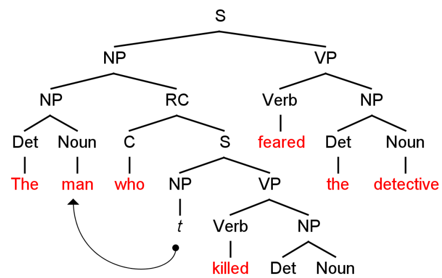
In our example, *kill* is a verb that requires two arguments: the killer and the one who was killed. The killer in *who killed the girl* is missing from the clause, but we know it to be *the man* from the main clause. Thus, this is a case where the grammatical subject of the relative clause is missing, or better put, extracted. (As an aside, the noun phrase present in the relative clause is usually referred to as an "embedded NP.") These cases are also referred to as Subject-Extracted Relative Clauses.

It is also possible for the grammatical object of the relative clause to be extracted, which gives us Object-Extracted Relative Clauses, for example, *The man who the girl killed feared the detective.* Moreover, the relative clause can be attached to either the subject of the main clause, as in our examples so far, or the object of the main clause. For example, we can have cases such as, *The girl feared the man who killed the detective* and *The girl feared the man who the detective killed.*

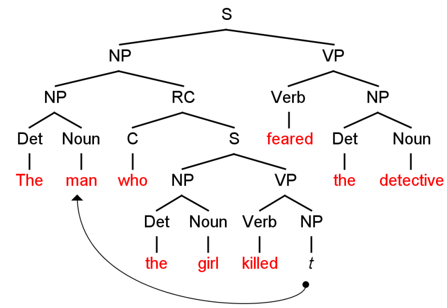
According to standard linguistic theories, the extracted argument leaves a trace behind in the relative clause which is co-indexed with the shared noun in the main clause. Figure 2.2 depicts the four types of relative clause sentences that we have discussed so far along with the trace linking to the shared noun. Correct interpretation of these sentences essentially involves identifying these traces and linking them to the appropriate constituent. The general appeal of relative clauses is in the ability to re-arrange the same set of words to create four different types of sentences, as in the four examples we have seen so far. Crucially, as the next section will show, the four types of relative clause sentences differ in terms of their overall processing complexity.

2.2.2 Behavioral Findings

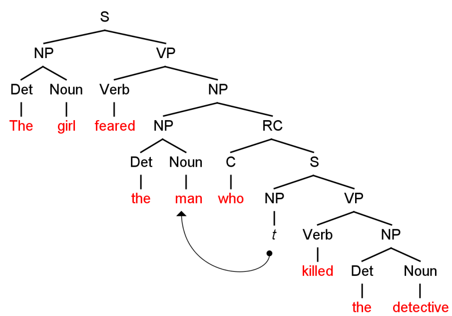
In the late '60s, Chomsky and colleagues argued that center-embedded structures, such as cases where the relative clause modifies the subject of the main clause, should be more difficult to understand than their right-branching counterparts, such as cases where the relative clause modifies the object of the main clause (Chomsky, 1957, 1965; Chomsky and Miller, 1963). They hypothesized that center-embedding necessitates existence of additional memory structures to facilitate processing. Subsequent behavioral work verified their



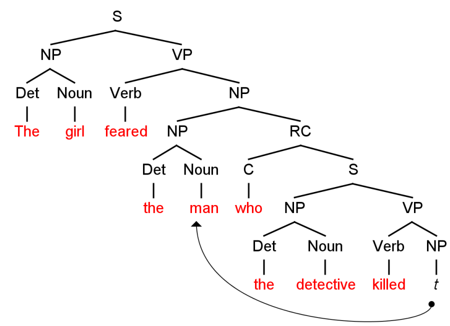
(a) Center-embedded, subject-extracted relative clause



(b) Center-embedded, object-extracted relative clause



(c) Right branching, subject-extracted relative clause



(d) Right branching, object-extracted relative clause

Figure 2.2: Syntactic structures corresponding to four different relative clause sentences.

predictions, and observed a greater processing difficulty when relative clauses are center-embedded (Miller and Isard, 1964; Waters et al., 1991; Caplan et al., 1994; Stromswold et al., 1996). Presently, there is little debate on processing difficulties for center-embedded relative clauses vis à vis their right-branching counterparts.

On the other hand, there continues to be active work on processing differences between Subject-extracted Relative Clauses (SRCs) and Object-extracted Relative Clauses (ORCs). Recall that SRCs are relative clause sentences where the subject of the relative clause is missing, whereas ORCs have relative clauses with missing objects. Unlike center-embedded and right-branching relative clauses, there is overall much less structural variability between SRCs and ORCs (compare Figures 2.2a and 2.2c with Figures 2.2b and 2.2d, respectively). However, as it turns out, there is quite a significant processing complexity difference between the two sentence types.

One of the earliest works that investigated the difference between SRCs and ORCs was by King and Just (1991), who examined the two sentence types with special emphasis on working memory capacity. They collected word-by-word reading times for relative-clause sentences, such as:

(13) ORC: *The reporter that the senator attacked admitted the error.*

(14) SRC: *The reporter that attacked the senator admitted the error.*

Furthermore, they manipulated participants' effective working memory capacity by either imposing an extraneous memory load or supplying pragmatic information that aided comprehension. Overall, their results indicated that ORCs were harder to process than SRCs, with the two verbs positions (e.g., *attacked* and *admitted*) being the points of major processing difficulty. Moreover, they found that readers with less working memory capacity tended to have greater difficulty dealing with ORCs, thus indicating an influence of working memory on relative clause comprehension.

Their findings have since been replicated by a number of studies that used similar self-paced reading paradigms (e.g., Gordon et al., 2001; Warren and Gibson, 2002; Gibson et al., 2005; Grodner and Gibson, 2005). Furthermore, eye-tracking studies examining differences between ORCs and SRCs have also observed similar patterns of processing difficulties (Traxler et al., 2002; Staub, 2010). At this point, there is general consensus that ORCs are harder than SRCs. Furthermore, the actual positions where processing difficulties occur are also uncontroversially agreed upon. Current research aims to explain exactly what cognitive and linguistic factors cause these processing differences between the two sentence types. Whereas working memory has been shown to play a role in the processing of relative clause sentences, there are other factors that could also have an influence. The next section presents the various approaches that have been used to explain these empirical findings.

2.2.3 Models of RC Processing

In this section, we will borrow Gordon and Lowder's (2012) broad classification of the various psycholinguistic models that have been used to explain relative clause processing differences. Largely, the various models can be classified into the following three categories: 1) working-memory based models; 2) frequency-based models; and 3) models based on semantic and pragmatic interpretation.

Memory-based Models

One of the earliest explanations for SRC-ORC differences comes from Miller and Chomsky (1963). They hypothesized that the difference between the two structures stems from the fact that in SRCs, the extracted element (the missing subject) can be immediately integrated with the relative clause verb. On the other hand, in ORCs, the extracted element (the missing object) must be held in memory across several intervening words until it can be integrated with the relative clause. This argument received empirical support from behavioral studies that observed an effect of working-memory on the ability to process ORCs (e.g., King and Just, 1991).

A similar argument is made by the *dependency locality theory* (DLT; Gibson, 1998, 2000). The argument remains that ORCs are harder than SRCs because the extracted element needs to be kept in memory before it can be integrated with the relative clause verb. Additionally, the theory posits that processing difficulty is proportional to the amount of working memory resources used for comprehension. Specifically, DLT splits processing costs into two parts: 1) integration cost; and 2) storage cost. Integration cost is a measure of the cost associated with integrating new input into already built structures. It is defined to be proportional to the number of intervening discourse referents between the extracted element and the relative clause verb. On the other hand, storage cost reflects the storage of parts of the input that are later used in completing syntactic structures. Unlike integration costs, there is no definite specification of how to measure these storage costs. Further, Gibson (1998) claimed that integration costs can alone be used to obtain first approximations of processing costs, and thus storage costs are almost always ignored.

The DLT also draws on the *givenness hierarchy* (Gundel et al., 1993) to explain the contribution of the intervening relative clause noun towards the processing costs. New discourse referents (e.g., indefinite NPs) are assumed to be less readily accessible and are taken to cause greater processing difficulties than established referents, such as pronouns. This claim received support from Warren and Gibson (2002) who found that the amount of processing difficulty in ORCs is inversely proportional to the givenness of the intervening referent.

Contrasting the givenness account of DLT is the similarity-based account that focuses on semantic similarity between the extracted and the intervening nouns. The claim is that both nouns are encoded in the memory and retrieved when the relative clause verb is being integrated. The greater the similarity between the two nouns, the greater will be the resulting confusion in assigning the correct thematic roles (agent, patient, etc.). Support for this argument comes from several behavioral studies (e.g., Gordon et al., 2001, 2004, 2006; Van Dyke and Lewis, 2003; Van Dyke and McElree, 2006). For example, Gordon et al. (2001) investigated the effect of the types of NPs (descriptions, indexical pronouns, and names) in ORC sentence processing. They found that cases where the extracted and the intervening NPs were of the same type were harder to process than cases where two NPs differed.

Another memory-based account of relative clause processing uses the ACT-R cognitive architecture (Lewis and Vasishth, 2005; Lewis et al., 2006). This model explains ORC processing costs through memory encoding, storage, and retrieval effects. By this account, higher processing difficulty for ORC sentences is a result of lower activation of words, due to some decay, that need to be retrieved for integration with the relative clause verb. The greater the number of intervening words, the higher is the decay, and thus, the greater is the processing difficulty at the verb.

Criticism against memory-based approaches have come indirectly due to the contentious nature of the initial experimental evidence. The initial work used a dual-task method to show that processing complexities of the two sentence types are influenced by effective working memory capacity (King and Just, 1991; Just and Carpenter, 1992). However, the validity and consistency of these initial claims have been questioned by some researchers (Waters and Caplan, 1996; Caplan and Waters, 1999). For example, Caplan and Waters (1999) noted that not all statistical analyses were reported, and that the reported results did not support original hypothesis. Further, they claimed that their attempts at replicating the results proved unfruitful. The argument is far from settled and there continues to be an ongoing debate on the topic (see, Fedorenko et al., 2006; Evans et al., 2011).

Frequency-based Models

The second category of models highlight the role of experience in explaining processing differences between ORCs and SRCs. Broadly, the idea is that structures that are encountered more frequently are easier to process than structures that are less frequent. Support for this argument comes from corpus studies that have found that SRCs occur more frequently than ORCs (Gordon and Hendrick, 2005; Roland et al., 2007).

Further support comes from a behavioral study by Reali and Christiansen (2007). Through a corpus study, they observed that pronominal ORCs are more frequent than pronominal SRCs when the noun in the relative clause is personal (e.g., *I, you, we*) than when it is impersonal (*it*). They conducted a series of self-paced reading studies to evaluate the frequency-based prediction that ORC processing would be easier when the embedded pronoun is personal. Their results were consistent with the frequency-based predictions, and suggest that statistical information plays a role in relative clause processing.

Another behavioral study that highlighted the importance of statistical information in relative clause processing was by Wells et al. (2009). They manipulated reading experiences of participants over several weeks, and found that participants who were exposed to relative clauses showed less processing difficulties for ORCs than the control group. These results again support frequency-based claims, and indicate that individual variances due to differences in structural experience could also influence sentence processing.

Currently, the most prominent frequency-based model is the *surprisal theory* (Hale, 2001; Levy, 2008a). It estimates word-level processing complexity as the negative log-probability of a word given the preceding context (usually, preceding syntactic context). That is:

$$\text{Complexity}(w_i) \propto -\log P(w_i|w_{1\ldots i-1}, \texttt{CONTEXT})$$

Essentially, surprisal theory measures processing complexity at a word as a function of how unexpected the word is in its context. Surprisal is minimized (i.e. approaches zero) when a word *must* appear in a given context (i.e., when $P(w_i|w_{1\ldots i-1}, \texttt{CONTEXT}) = 1$), and approaches infinity as a word becomes less and less likely. Given the fact that SRCs occur more frequently than ORCs, the model predicts that overall surprisal of SRCs should be less than overall surprisal of ORCs (see Hale, 2001).

Another frequency-based approach used *simple recurrent networks* (Elman, 1991) to show that the processing of SRCs is facilitated by the presence of the canonical noun-verb-noun structure in English (MacDonald and Christiansen, 2002). The argument is that greater frequency of noun-verb-noun sequences in English greatly facilitates the processing of the noun-verb-noun-verb sequence in SRCs than the noun-noun-verb-verb sequence in ORCs. Furthermore, MacDonald and Christiansen (2002) observed that this facilitation remains even when the relative frequency of SRCs and ORCs is equated in the training corpus.

There have been two major criticisms of frequency-based models. In a corpus study, Gordon and Hendrick (2005) observed that while SRCs are more frequent than ORCs, a large portion of SRCs contained an intransitive relative clause verb (e.g., *the toaster that broke...*). However, ORCs necessarily have to have a transitive embedded verb. Moreover, they observed that if the intransitive cases are removed, the frequency difference between SRCs and ORCs is significantly reduced. Given that most behavioral studies contrast ORCs with SRCs that contain transitive verbs, these findings question the general validity of frequency-based approaches.

Another issue has been the localization of processing difficulty. As we have seen so far, behavioral findings have almost unanimously shown that the embedded verb and the main verb are the points of major difficulty (cf. Staub, 2010). In contrast, the surprisal model predicts that the cost of low expectation for ORCs should be paid at the embedded NP rather than the embedded verb (Levy, 2008a). To see why, consider the ORC sentence, *The reporter who the senator attacked admitted the error* and the SRC sentence, *The reporter who attacked the senator admitted the error.* After the relative pronoun, *who*, there is uncertainty about the rest of the relative clause. Because the first word following the relative pronoun, *who*, determines the structure of the relative clause, surprisal predicts that processing costs should be higher at the embedded NPs in the ORC case, and the embedded verb in the SRC case.

Meaning-based Models

The third class of models of relative clause processing utilize semantic and pragmatic factors to explain processing differences between SRCs and ORCs. Put simply, the idea is that SRCs are easier to process because their meaning can be derived relatively easily as compared to ORC sentences. This idea stems from the work of King and Just (1991) who found that having a semantic relationship between the various entities (NPs and the verbs) in relative clause sentences facilitated the processing of those sentences. In turn, this facilitation reduced the overall processing difference between SRCs and ORCs. For example, they found that sentences like, *The robber that the fireman rescued stole the jewelry*, were easier to process than sentences like, *The robber that the fireman detested watched the program.* They justified such differences by claiming that *robber, fireman,* and *rescued* are more semantically related than *robber, fireman*, and *detested*, which facilitates processing.

One justification for the meaning-based account focuses on pragmatic and discourse factors. According to this argument, in ORCs, the purpose of the relative clause is to use a more familiar NP in the relative clause to ground the less familiar extracted NP in discourse. However, in SRCs, the embedded NP does not serve such a grounding function. Thus, the more functional nature of the embedded NP in ORCs results in overall greater processing complexity in those sentences. Support for this argument comes from corpora analyses that have found that ORCs tend to have more familiar or “given” NPs within the relative clause than SRCs (Gordon and Hendrick, 2005).

Another justification focuses on sentence-internal relationships. The argument is that ORCs contain a perspective shift, whereas SRCs do not, which contributes to processing differences between the two sentence types (MacWhinney, 1977; MacWhinney and Pleh, 1988). To see this, consider again the ORC sentence, *The reporter who the senator attacked admitted the error*, and the SRC sentence, *The reporter who attacked the senator admitted the error*. In the ORC sentence, we first have to take the perspective of the *reporter*, then the *senator*, and then finally, the *reporter* again. On the other hand, in the SRC sentence, we only take the perspective of the *reporter*.

The animacy of the NPs has also been proposed to have an effect on processing differences between the two relative clause sentences (e.g., Gennari and MacDonald, 2008, 2009; Mak et al., 2002, 2006; Traxler et al., 2002, 2005). Consider the following four sentences:

(15) ORC/inanimate embedded NP: *The director that the movie pleased received a prize.*

(16) ORC/inanimate extracted NP: *The movie that the director watched received a prize.*

(17) SRC/inanimate embedded NP: *The director that watched the movie received a prize.*

(18) SRC/inanimate extracted NP: *The movie that pleased the director received a prize.*

Behavioral studies have revealed that the animacy of the extracted and embedded NPs has an overall effect on the processing of ORCs. For example, the first ORC sentence (15) contains an animate extracted NP and an inanimate embedded NP. Such cases have been found to be harder to process than both the SRC cases (17)(18). Crucially, the second ORC sentence (16), which contains an inanimate extracted NP and an animate embedded NP, is not harder to process than the SRC cases (Traxler et al., 2002, 2005).

One explanation for the animacy effect comes from Traxler et al. (2002, 2005). They proposed an *active filler strategy* (Clifton and Frazier, 1989; Frazier and Clifton, 1989) during relative clause processing. According to them, during sentence processing encountering the relative pronoun, *that*, predicts and generates an SRC structure. If the rest of the sentence conforms with that structure, parsing proceeds further. However, if the rest of the sentence does not conform with the SRC structure (i.e., the sentence is an ORC sentence), the syntactic structure needs to be reanalyzed. Their argument is that reanalysis is more difficult when the extracted NP is animate than when it is inanimate, because it is easier to construct a scenario where an inanimate NP is an object of the relative clause verb.

In recent work, Lowder and Gordon (2012) showed that not only are ORC sentences like (15) harder than SRC sentences, but they are also harder than other ORC sentences where the embedded NP is also animate. For example, their comparison between sentences like, *The director that the movie pleased received a prize* and *The director that the actor pleased received a prize*, suggested that having an inanimate embedded NP makes processing more complex. They interpreted their results as indicating a local difficulty associated with integrating inanimate NPs with verbs. Moreover, they found that the difficulty associated with integrating inanimate NPs with verbs is reduced when the two entities appear in separate clauses (e.g., *The movie that pleased the director...* is easier than *The movie pleased the director*).

The main challenge facing such meaning-based accounts comes from a number of studies that have found processing differences between ORCs and SRCs even when the semantic content of the test stimuli is arbitrary. Furthermore, controlling for thematic roles across the RC types, as well as balancing the semantic relationships between the NPs and the verbs, does not change the overall pattern of results (King and Just, 1991; Johnson et al., 2011). These findings suggest that while semantic and pragmatic factors may play some role in relative clause processing, they do not sufficiently explain the overall difficulty of processing ORCs over SRCs.

3. Novel Word Detection

"'No, no! The adventures first,' said the Gryphon in an impatient tone: 'explanations take such a dreadful time.'"
— Lewis Carroll, *Alice's Adventures in Wonderland*

3.1 Overview

This chapter presents two experiments where participants read whole sentences and determined whether they contained a pseudoword. Previous work by Stromswold et al. (1996) found that participants' performance in such tasks is influenced by sentences' syntactic structures. Their findings suggest an automatic nature of syntactic processing, and highlight the robustness of the syntactic parser in presence of pseudowords, and, hence, unknown words. The goal of the studies presented here is two-fold. Firstly, we wish to verify the findings of Stromswold et al. (1996). Additionally, by using a greater variety of sentence structures, we wish to evaluate the generalizability of their findings. Secondly, and more importantly, we wish to evaluate whether syntactic information influences the detectability of pseudowords.

3.1.1 Predictions

To reiterate, in the two experiments presented here, participants were shown sentences and were asked to determine whether they contained a pseudoword. Task performance was measured using reading times and judgment accuracy. Depending on what sources of information influence performance in the task, we made the following predictions:

1. **No syntactic processing**: The task can be effectively performed by a linear scan of the words till a pseudoword is detected. In this case, syntactic parsing would not be needed, and, thus, might not influence performance on the task. Moreover, a left-to-right scan would predict that a pseudoword towards the front of the sentence would be detected faster than one towards the end. Thus, such a strategy predicts a monotonically increasing relation between reading time and pseudoword position.

2. **Syntactic processing**: Another possibility is during the left-to-right scan to detect a pseudoword, syntactic parsing is involuntarily performed. In this case, we expect to find structural effects on task performance. Such structural effects could either be side effects, based solely on processing differences between the various structures, or might indicate a direct influence of syntactic context on pseudoword detection. We can distinguish between the two possibilities by testing for an interaction between sentences' syntactic structures and the syntactic position of pseudowords within those sentences. A significant interaction between syntactic structure and pseudoword position would reflect an influence of syntactic context on pseudoword detection. On the other hand, the lack of a significant interaction would indicate that the structural effect is merely a side effect.

3. **Pseudonouns vs. pseudoverbs**: Independent of the effect of syntactic structure is the influence of morphological information on pseudoword detection. Such an effect may be analyzed by evaluating performance differences between pseudonouns and pseudoverbs. One issue is the possible risk of confounding morphological effects with syntactic effects. For example, a pseudoverb will not only have morphological information which identifies its syntactic category (such as, an *-ed* ending), but will also be in a syntactic position which corresponds to its category. Thus, any difference between pseudonouns and pseudoverbs could be due to either morphological or syntactic effects. If we find differences between pseudonouns and pseudoverbs, as well as structural effects on task performance, further tests will need to tease apart morphological and syntactic influences.

3.2 Experiment 1

In this experiment, we attempted to replicate the findings of Stromswold et al. (1996) using similar stimuli and design.

3.2.1 Methods

Participants

Twenty-five native and monolingual English-speaking college students participated in the study. All had normal or corrected-to-normal vision, and none had a history of a language or learning disorder.

Stimuli

In this experiment, we used two types of relative-clause sentences as our target sentences. Half of them were object-extracted center-embedded sentences, such as, *The juice that the child spilled stained the rug.* The other half were right-branching sentences, in which subject-extracted relative clauses were attached to the objects of the sentences, for example, *The child spilled the juice that stained the rug.* Phrase-structure trees corresponding to the two sentence types are shown in Figure 2.1.

Moreover, we constructed orthographically and phonologically plausible pseudowords that were embedded in half of all sentences. Each pseudoword was structured such that it was morphologically consistent with the lexical word (i.e., noun or verb) that it replaced. All pseudoverbs ended with an *-ed* suffix, whereas pseudonouns were morphologically bare (i.e., had no recognizable suffix). Appendix A.1 details how the pseudowords were generated for this and all subsequent experiments. Examples of sentences containing pseudowords are shown below:

- No pseudoword: *The juice*$_1$ *that the child*$_2$ *spilled*$_3$ *stained*$_4$ *the rug*$_5$.
- Pseudoword Pos. 2: *The juice that the* <u>*tremode*</u> *spilled stained the rug.*
- Pseudoword Pos. 3: *The juice that the child* <u>*renalled*</u> *stained the rug.*
- Pseudoword Pos. 4: *The juice that the child spilled* <u>*taised*</u> *the rug.*
- Pseudoword Pos. 5: *The juice that the child spilled stained the* <u>*slibe*</u>.

Design

Each participant saw a total of 144 sentences, half of which were center-embedded relative-clauses, and half were right-branching. In half of the target sentences, a single lexical word (noun or verb) at position 2, 3, 4, or 5 was replaced with a pseudoword. Each position was replaced equally often, and thus there were 18 sentences per pseudoword position. The lexical positions are indicated with subscripts in the two examples below:

- *The juice*$_1$ *that the child*$_2$ *spilled*$_3$ *stained*$_4$ *the rug*$_5$.
- *The child*$_1$ *spilled*$_2$ *the juice*$_3$ *that stained*$_4$ *the rug*$_5$.

The complete list of target stimuli is presented in Appendix A.2.

The list of 144 sentences was pseudo-randomized such that no more than 4 consecutive trials contained the same value for any of the parameters (structure and position). Half of the participants received the sentences in this order, and half received the sentences in the reverse order.

Procedure

The experiment was presented using PyGame (`http://www.pygame.org`) on a 21-inch flat-screen LCD monitor with 1920×1080 pixels resolution. Participants were told they would be reading English sentences and would have to judge whether they contained a nonsense word. Before the experimental sentences, they read 8 practice sentences that were all of the form, *The* NOUN VERB*ed the* NOUN. Half of the practice sentences contained a pseudoword that replaced one of lexical words.

Following the practice trials, the actual experimental session began. Each trial was preceded by a crosshair appearing at the center of the screen for 1 second. Participants were instructed to fixate on the crosshair and wait for the sentence to appear. After the crosshair, participants viewed the whole sentence which was centered on the screen and displayed with a 30-pt font. Participants were instructed to press the LEFT SHIFT key if the sentence was "good" (did not contain a nonsense word) or the RIGHT SHIFT key if the sentence was "bad" (did contain a nonsense word). Response times were recorded from the moment the sentence was presented until a response key was pressed. They were instructed to respond as quickly as possible without sacrificing accuracy.

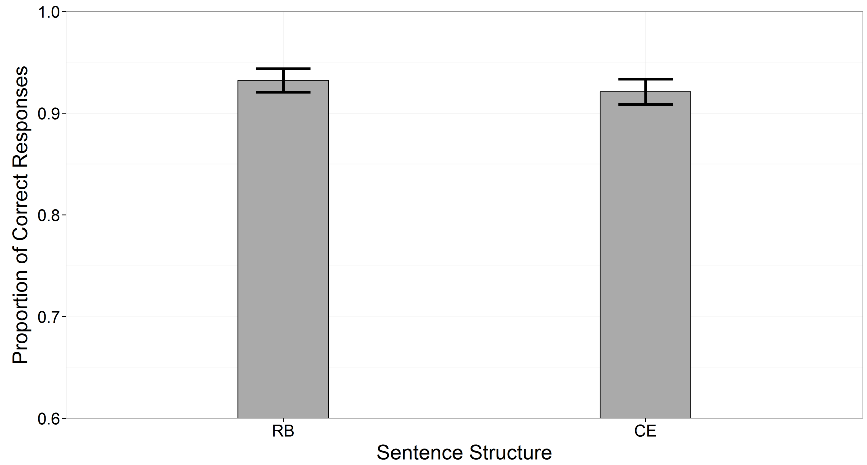
3.2.2 Results

Accuracy

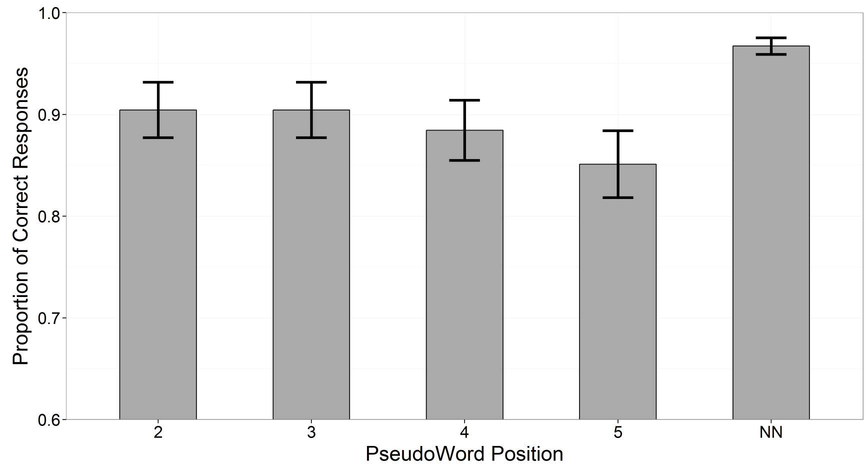
Overall, participants correctly responded to 93% of the trials (3336 out of 3600). We performed a 2 (sentence structure) × 5 (pseudoword position) ANOVA with Subject as a random variable to analyze the effect of sentence structure and pseudoword position on accuracy. Results indicated a main effect of sentence structure with participants being more accurate on right-branching sentences than center-embedded sentences (RB: 93.22%; CE: 92.11%; $F(1, 24) = 4.74, p < .05$). Furthermore, there was a main effect of pseudoword position with participants' accuracy decreasing as the pseudoword moved further away from the front of the sentence ($F(4, 96) = 10.62, p < .001$; see Figure 3.1b). Lastly, we also found a significant interaction between sentence structure and pseudoword position which is depicted in Figure 3.1c ($F(4, 96) = 2.50, p < .05$).

We repeated the analyses using only sentences that contained a pseudoword. The results of the ANOVA again revealed main effects of sentence structure ($F(1, 24) = 5.33, p < .05$) and pseudoword position ($F(3, 72) = 4.65, p < .05$). However, the interaction between sentence structure and pseudoword position was no longer significant ($F(3, 72) = 2.18, p = .10$). This indicates that the previously significant interaction was likely due to the presence of regular sentences.

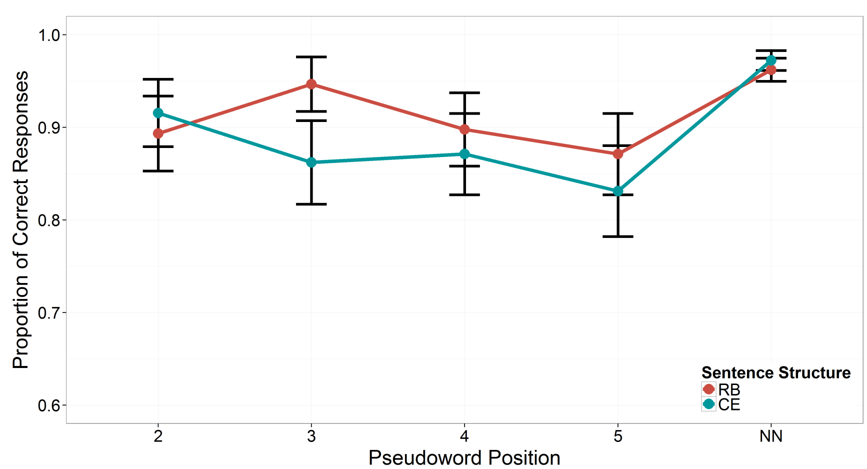
To evaluate the influence of pseudoword category (i.e., pseudonouns vs. pseudoverbs), we also conducted a 2 (sentence structure)× 2 (pseudoword category) ANOVA with Subject as a random variable using only sentences that contained pseudowords. The results revealed a main effect of sentence structure, with participants again performing better for right-branching sentences than center-embedded ($F(1, 24) = 5.33, p < .05$). Neither the main effect of pseudoword category nor the interaction between it and sentence structure



(a) Main effect of Sentence Structure



(b) Main effect of Pseudoword Position



(c) Interaction

Figure 3.1: Effects of Sentence Structure and Pseudoword Position on accuracy in Experiment 1. NN = No nonsense word. Error bars represent confidence intervals.

was found to be statistically significant (both F's < 1).

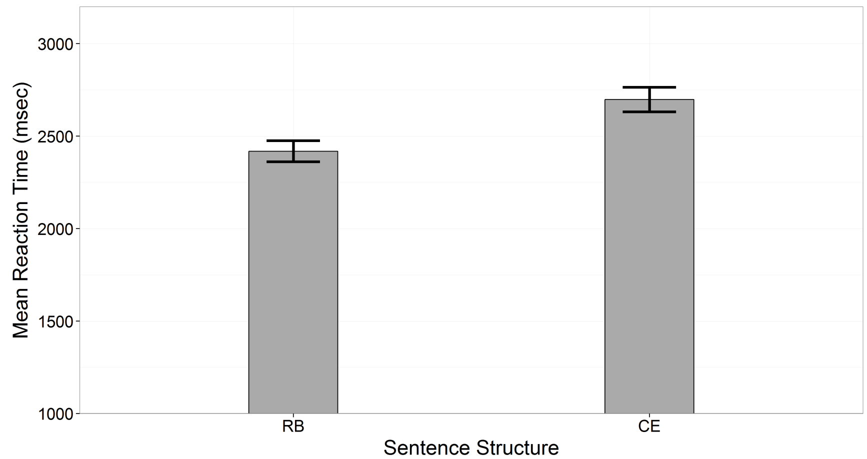
Reaction Time

The reaction time results reported here correspond to only those trials to which participants correctly responded. However, the pattern of the results does not change on including trials in which participants were incorrect.

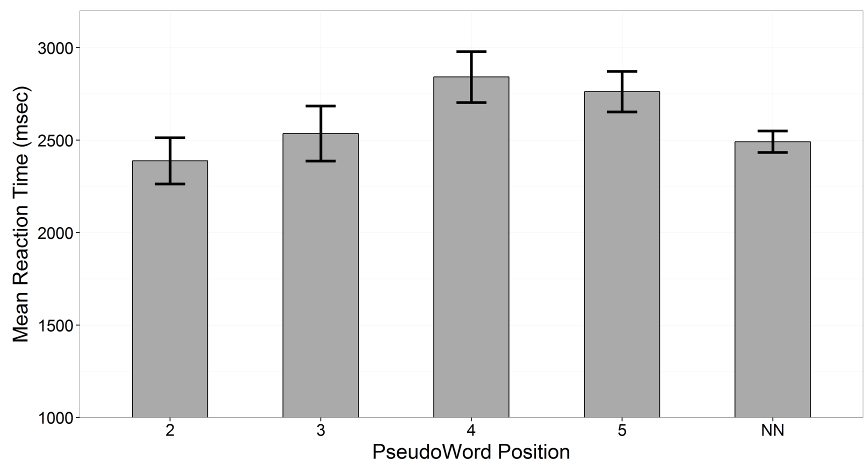
We evaluated the effects of sentence structure and pseudoword position on reaction time using a 2 (sentence structure) $\times$ 5 (pseudoword position) ANOVA with Subject as a random variable. The ANOVA revealed a main effect of sentence structure on reaction time, with participants responding 280 ms slower when sentences were center-embedded than when sentences were right-branching (CE: 2698 ms; RB: 2418 ms; $F(1, 24) = 43.29, p < .001$). We also found a main effect of pseudoword position ($F(4, 96) = 7.38, p < .001$). As the Figure 3.2b shows, participants responded faster when pseudowords were in earlier positions (positions 2 and 3) than when pseudowords were towards the end of the sentences (positions 4 and 5). The interaction between syntactic structure and pseudoword position was also statistically significant ($F(4, 96) = 5.92, p < .001$). As depicted in Figure 3.2c, this interaction possibly resulted because there was a reading time difference between the two sentence types only when there was a pseudoword in position 3 or when it was absent.

As with our accuracy analyses, we repeated the analysis using only sentences containing a pseudoword. Once again, the 2 $\times$ 4 ANOVA revealed a similar pattern of results. We found main effects of sentence structure ($F(1, 24) = 26.71, p < .001$), pseudoword position ($F(3, 72) = 10.12, p < .001$), and a significant interaction ($F(3, 72) = 5.83, p < .001$).

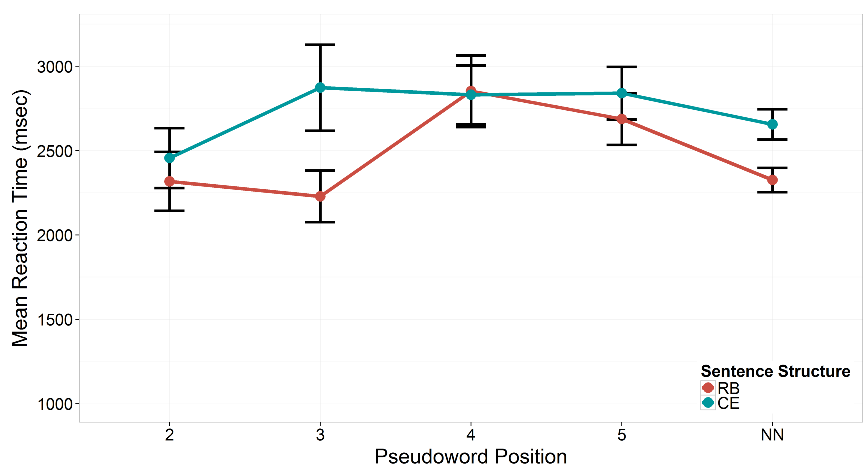
Lastly, we conducted a 2 (sentence structure)$\times$2 (pseudoword category) ANOVA with Subject as a random variable using only sentences containing pseudowords. The analysis revealed a main effect of sentence structure in the expected direction, with participants being more than 200 ms slower on center-embedded sentences ($F(1, 24) = 27.35, p < .001$). We also found a main effect of pseudoword category on reaction time, with participants being roughly 200 ms slower for pseudoverbs than for pseudonouns ($F(1, 24) = 8.80, p < .05$; see Figure 3.3. The interaction between the two factors was not statistically significant.



(a) Main effect of Sentence Structure



(b) Main effect of Pseudoword Position.



(c) Interaction

Figure 3.2: Effects of Sentence Structure and Pseudoword Position on reaction time in Experiment 1. NN = No nonsense word. Error bars represent confidence intervals.

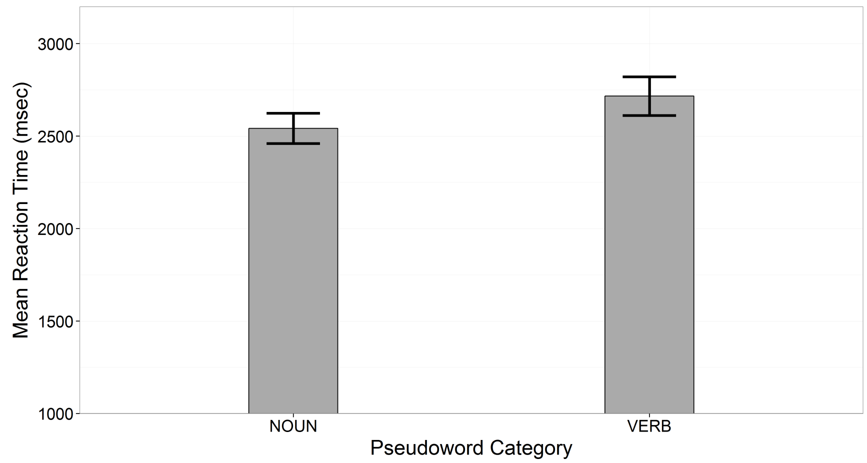


Figure 3.3: Main effect of Pseudoword Category on reaction time in Experiment 1. Error bars represent confidence intervals.

3.2.3 Discussion

Overall, our findings are consistent with those reported by Stromswold et al. (1996). In a task which can be performed by a simple linear scan to find a nonsense word, we found that participants' performance is influenced by the syntactic structure of the sentences. We also found that performance degrades monotonically as a function of the distance of the pseudoword from the front of the sentence. Critically, we found an interaction between sentences' syntactic structure and the position of the pseudowords. Taken together, these findings are consistent with a model that predicts an influence of syntactic context on pseudoword detection.

We also found evidence indicating an effect of morphological information on pseudoword detection. We found that participants were slower in identifying pseudoverbs over pseudonouns, however there was no difference in accuracy of their judgments. This suggests that the reading time effect was not due to a speed-accuracy tradeoff. All of our pseudoverbs contained an *-ed* suffix, whereas all pseudonouns were morphologically bare. Thus, it is likely that these findings reflect the use of available morphological information to determine whether a word is known. Perhaps, for pseudoverbs, participants involuntarily attempted to strip the verbal suffix and examine the remaining stem, and subsequently, failing to identify the word, performed another search with the whole word intact. However, as pseudonouns were morphologically bare, only one search might have been performed. Such a strategy would be consistent with our reading time results.

One limitation of this study is the use of only two syntactic structures as target stimuli. The lack of any "filler" sentences might have allowed participants to develop task-specific strategies to specifically deal with the two sentence types. If so, any generalization should be made cautiously. In the following experiment, we set to address this shortcoming by using a greater variety of sentences.

3.3 Experiment 2

3.3.1 Methods

Participants

Twenty-six native and monolingual English-speaking college students participated in the study. All had normal or corrected-to-normal vision, and none had a history of a language or learning disorder.

Stimuli

In this study, we used four types of relative-clause sentences as target sentences. In half of the sentences the relative clause was attached to the subject of the sentence, and in the other half, the relative clause was attached to the object of the sentence. Moreover, in half of the sentences, the relative clause was subject-extracted (i.e., the subject was missing), whereas in the other half, the relative clause was object-extracted. We constructed the sentences in quadruplets by first identifying a triplet of nouns and a pair of verbs, and arranging them suitably. An example quadruplet is given below:

(1)a. SS: *The actor who impressed the critic humiliated the director.*
   b. SO: *The actor who the critic impressed humiliated the director.*
   c. OS: *The director humiliated the actor who impressed the critic.*
   d. OO: *The director humiliated the actor who the critic impressed.*

The code describing the sentences can be interpreted as follows: the first letter corresponds to whether the relative-clause was subject-attached (S) or object-attached (O), and the second letter corresponds to whether the relative-clause was subject-extracted (S) or object-extracted (O).

As in the previous study, we also constructed orthographically and phonologically plausible pseudowords that were embedded within the sentences. Once again, the pseudoverbs always ended with an *-ed* inflectional suffix (e.g., *boped, clummed, garfed*). Unlike the previous study, some of the pseudonouns contained a nominal derivational suffix (e.g., *pilobist, autoner, enlator*), whereas some were morphologically bare (e.g., *burse, mafe, smoob*). However, none of the nouns had an inflectional ending (e.g., plural *-s*).

Design

We used a total of 60 target relative-clause quadruplets (see (1) above for an example quadruplet), and each participant saw only one sentence from each quadruplet. In 48 of the relative-clause sentences, a single lexical word (noun or verb) was replaced with an orthographically and phonologically plausible pseudoword. As in the previous study, we identified 4 lexical word positions (2, 3, 4, and 5), and each position was replaced equally often. The syntactic category of the pseudoword reflected the syntactic category of the word that it replaced, and thus verbs were replaced by pseudoverbs and nouns by pseudonouns. Example SS sentences containing pseudowords are shown below:

- No pseudoword: *The* $actor_1$ *who* $impressed_2$ *the* $critic_3$ $humiliated_4$ *the* $director_5$.
- Pseudoword Pos. 2: *The actor who amberated the critic humiliated the director.*
- Pseudoword Pos. 3: *The actor who impressed the cushar humiliated the director.*
- Pseudoword Pos. 4: *The actor who impressed the critic amberated the director.*
- Pseudoword Pos. 5: *The actor who impressed the critic humiliated the cushar.*

In addition to the 60 target sentences, participants also read 180 filler sentences. The filler sentences were constructed with the aim of adding greater syntactic variability, and a total of 10 different syntactic structures were used to generate fillers. Half of the filler sentences contained a pseudoword that replaced one of the lexical words. Thus, overall, 57.5% of the sentences contained pseudowords. Appendix A.3 lists the complete set of target and filler sentences, along with the pseudowords used in the study.

We constructed 20 lists of target stimuli using a Latin-square design to ensure that relative clause type and pseudoword position was balanced across participants. We selected one list for each participant, which was then combined with the set of fillers. The combined set of 60 target stimuli and 180 filler stimuli was pseudo-randomized to ensure that there were no more than 2 consecutive trials had the same structure and no more than 3 consecutive trials had the same pseudoword position.

Procedure

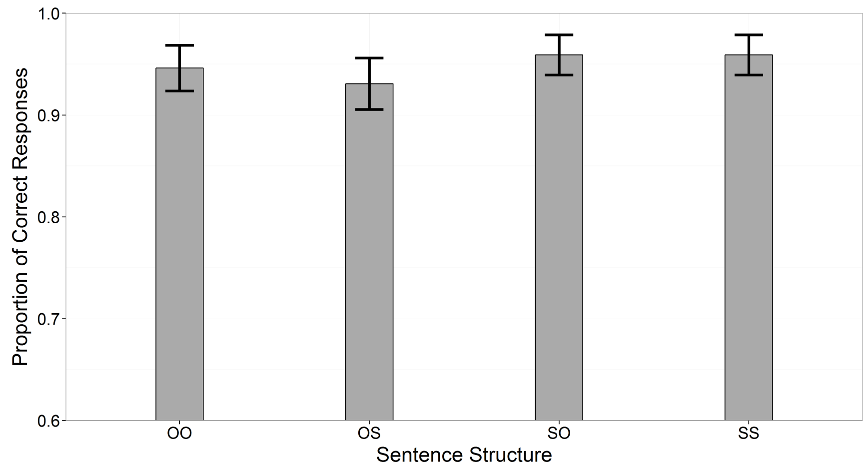
The experimental procedure was the same as the previous experiment.

3.3.2 Results

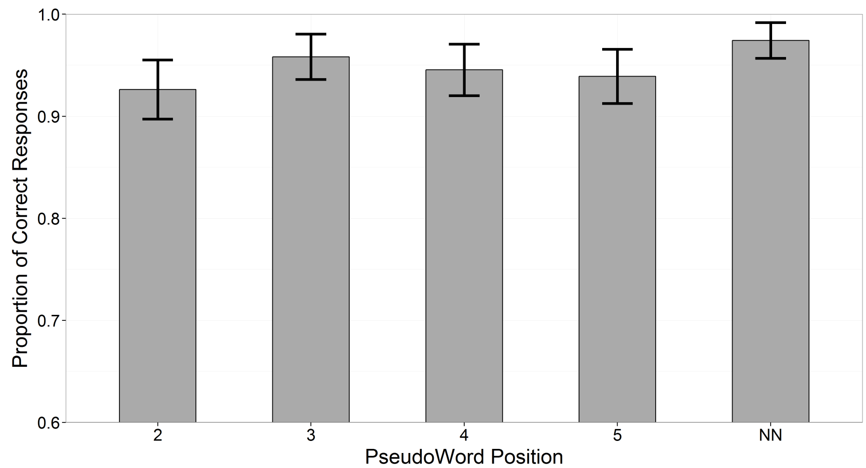
Accuracy

Overall, participants correctly responded to 95% of all sentences (5922 out of 6240), and an equal proportion of target sentences (1480 out of 1560). We conducted a 4 (sentence structure) × 5 (pseudoword position) ANOVA using Subject as a random variable to analyze the effect of sentence structure and pseudoword position on accuracy on the target sentences. Results suggested that neither sentence structure ($F(3, 75) = 1.51, p = .2$) nor pseudoword position ($F(4, 100) = 1.84, p = .1$) had a significant effect on participants' accuracy in the task. The interaction between the two factors was also not significant ($F(12, 300) < 1$). We repeated the analyses with only those sentences that contained a pseudoword and found similar results with neither main effects nor the interaction being statistically significant (all p's $> .3$). Figure 3.4 depicts the results graphically.

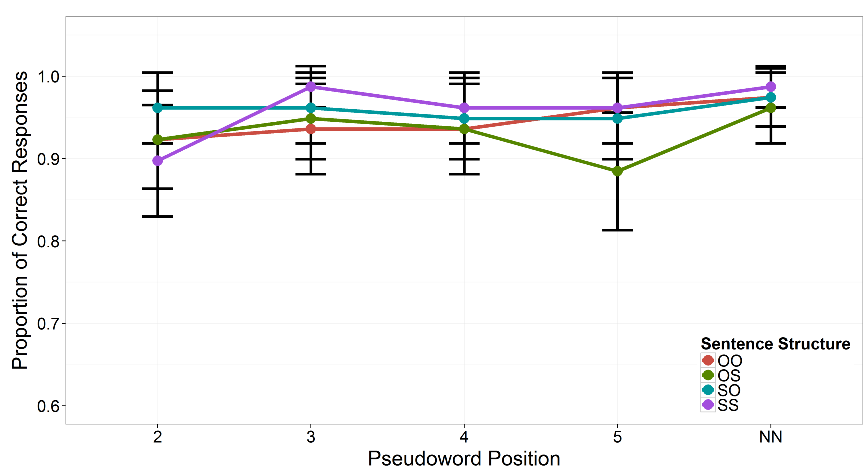
To compare the results of this experiment with the previous one, we also performed a 2 (sentence structure) × 5 (pseudoword position) ANOVA with Subject as a random



(a) Sentence Structure



(b) Pseudoword Position



(c) Interaction

Figure 3.4: Non-significant effects of Sentence Structure and Pseudoword Position on accuracy in Experiment 2. NN = No nonsense word. Error bars represent confidence intervals.

variable using only those sentences which were structurally similar to the sentences used in Experiment 1 (i.e., SO: *The actor who the critic impressed humiliated the director* and OS: *The director humiliated the actor who impressed the critic*). Contrary to the results of the first experiment, we did not find significant main effects of either variable, nor was the interaction significant (all p's $> .1$).

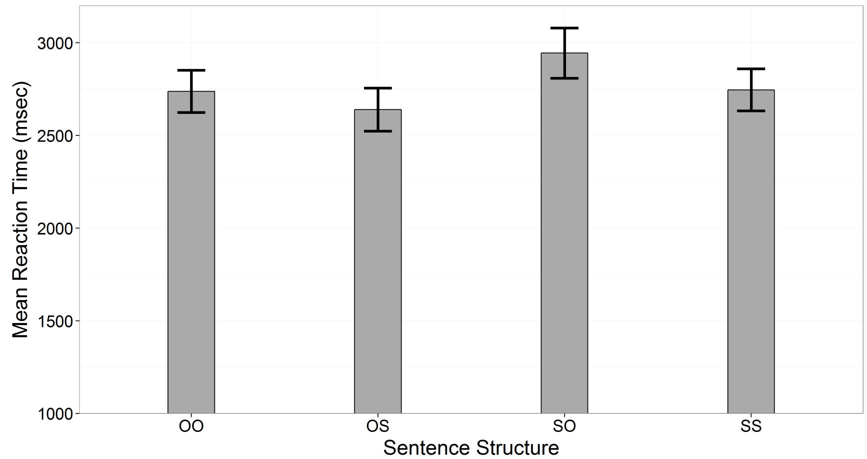
As earlier, we evaluated the influence of pseudoword category (pseudonouns vs. pseudoverbs) on task performance. We selected only those sentences that contained a pseudoword and performed a 4 (sentence structure) $\times$ 2 (pseudoword category) ANOVA with Subject as a random variable. Again, no main effects were found to be significant, and neither was the interaction between the two variables.

Reaction Time

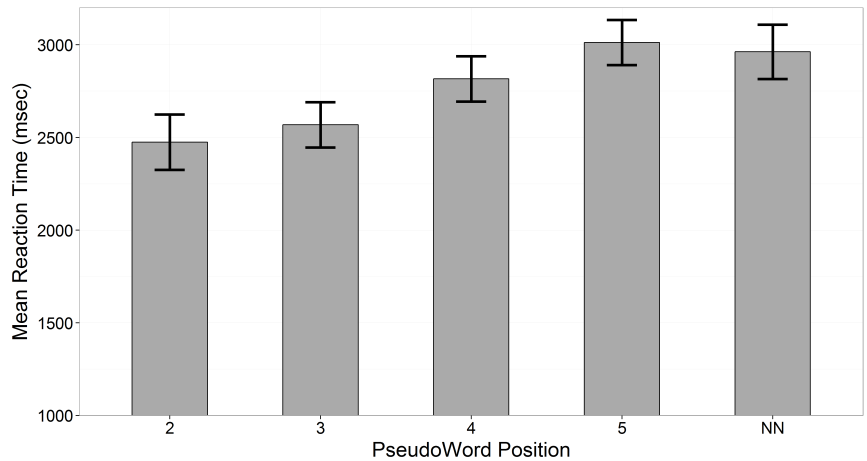
The results reported here correspond to only those trials to which participants correctly responded. However, the pattern of results does not change on including all trials.

To evaluate the effects of sentence structure and pseudoword position on reaction time, we conducted a 4 (sentence structure) $\times$ 5 (pseudoword position) ANOVA with Subject as a random variable. The results of the ANOVA revealed a main effect of sentence structure ($F(3, 75) = 5.24, p < .05$). As depicted in Figure 3.5a, participants were fastest for OS sentences (e.g., *The director humiliated the actor who impressed the critic*) and slowest for SO sentences (e.g., *The actor who the critic impressed humiliated the director*). The ANOVA also revealed a main effect of pseudoword position ($F(4, 100) = 8.34, p < .001$). As shown in Figure 3.5b, participants were slower overall for the early positions (2 and 3) than the later ones (4 and 5) and the no-pseudoword cases. The interaction between sentence structure and pseudoword position was not found to be significant ($F(12, 300) = 1.22, p = .3$), and is depicted in Figure 3.5c. We repeated the analyses using only those sentences that contained a pseudoword, and the pattern of results remained unchanged.

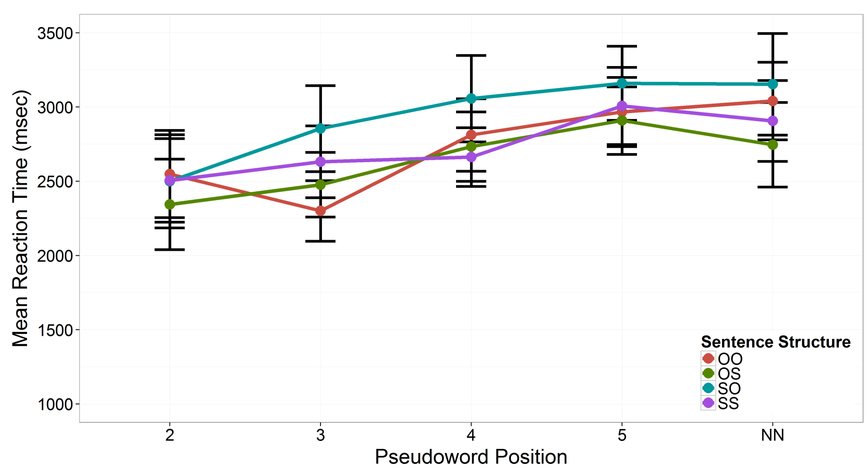
Once again, to facilitate a comparison between the results of this experiment and the previous one, we performed an analysis using only SO and OS sentences. The results of



(a) Main effect of Sentence Structure



(b) Main effect of Pseudoword Position



(c) Non-significant interaction

Figure 3.5: Effects of Sentence Structure and Pseudoword Position on reaction time in Experiment 2. Error bars represent confidence intervals.

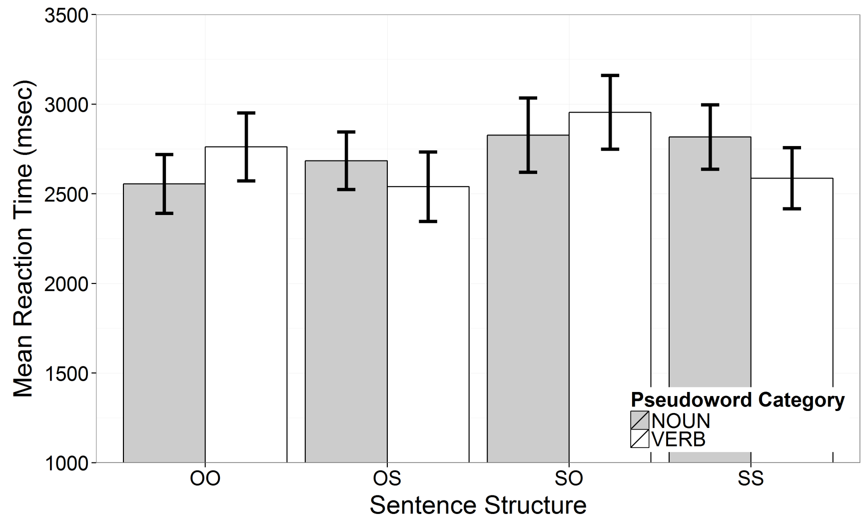


Figure 3.6: Significant interaction between Sentence Structure and Pseudoword Category on reaction time in Experiment 2. Error bars represent confidence intervals.

the 2 × 5 ANOVA indicated main effects of both sentence structure ($F(1, 25) = 14.78, p < .001$) and pseudoword position ($F(4, 100) = 5.61, p < .001$). However, unlike the previous experiment, the interaction was not significant ($F(4, 100) < 1$).

Lastly, we conducted a 2 (sentence structure)×2 (pseudoword category) ANOVA with Subject as a random variable to evaluate the influence of the lexical category of the pseudowords. The results indicated a main effect of sentence structure ($F(3, 75) = 3.82, p < .05$), but no main effect of pseudoword category ($F(1, 25) < 1$). Additionally, the interaction between syntactic structure and pseudoword category was found to be significant ($F(3, 75) = 3.15, p < .05$), and is depicted in Figure 3.6.

3.3.3 Discussion

Overall, there appear to be some striking differences between the results of this experiment and the previous one. Unlike the previous experiment, none of our experimental variables had any significant effect on participants' accuracy. Furthermore, while we did observe main effects of both sentence structure and pseudoword position on participants' reaction time data, we did not find any significant interaction between the two variables. Recall our initial discussion where we had argued that such an interaction would be indicative of a direct influence of syntactic context on pseudoword detection, as opposed to being merely a side effect.

The results from this experiment are consistent with a model that iteratively constructs the syntactic structure of a sentence while actively trying to detect a pseudoword. In such a model, every word is first evaluated to determine whether it is known. If the word is known, it can be syntactically integrated with previously constructed structures. However, if the word is unknown, the model can stop. Such a model predicts both a structural effect and a monotonically increasing positional effect, but not an interaction between the two.

To further evaluate the predictions of such a model, we conducted a post-hoc analysis by grouping together "early" positions (2 and 3) with "late" positions (4 and 5). Using only those sentences which contained a pseudoword, we performed a 4 (sentence structure) $\times$ 2 (position type) ANOVA with Subject as a random variable. As expected, the results indicated a significant main effect of syntactic structure ($F(3, 75) = 3.59, p < .05$). We also observed a main effect of position type with participants being slower by about 400 ms for late positions as opposed to early positions ($F(1, 25) = 47.38, p < .001$). Moreover, when we repeated the analyses with regular sentences being included in the "late" category, we observed the same pattern of results. These results point to a monotonically increasing effect of pseudoword position, and support the iterative syntactic model. Furthermore, these results indicate that the structural effect might not have had a direct influence on pseudoword detection.

Another difference between the results of this experiment and the previous one is the lack of an effect of the syntactic category of pseudowords. Unlike in the previous experiment, where participants took longer time for pseudoverbs than pseudonouns, we observed no such effect in this experiment. It is possible that the inclusion of nominal suffixes on half of the pseudonouns may have influenced the results. This is consistent with our initial argument that greater time for pseudoverbs may have been a consequence of a two-step lexical search: first, using the stripped stem with the suffix removed; and second, using the word as a whole.

Also unlike in the previous experiment, we found an interaction between the syntactic category of the pseudowords and the syntactic structure of the sentences. Looking at Figure 3.6, it is not apparent what might have caused the interaction. The pattern of the data indicates a tendency for pseudoverbs to cause greater reading time than pseudonouns for object-extracted cases (OO and SO), and an opposite trend for subject-extracted cases (OS and SS). However, the overlap between the error bars suggests no significant differences for any sentence type. We verified this by conducting one-way ANOVAs with pseudoword category as fixed factors for all four sentence types. As expected, no differences were statistically significant (all p's $> .05$). Crucially, the graph in Figure 3.6 indicates that the sentence structure effect was observed only when the pseudowords were verbs. We conducted two one-way ANOVAs with sentence structure as fixed factors for the two pseudoword categories. For pseudonouns, we failed to obtain a main effect of sentence structure ($F(3, 75) = 1.95, p = .13$). On the other hand, we did find a main effect of sentence structure when pseudowords were verbs ($F(3, 75) = 5.37, p < .005$).

Why were pseudoverbs treated differently than pseudonouns? Many researchers in the past have observed a greater processing complexity at the verb position in object-extracted relative clause sentences (e.g., King and Just, 1991; Gordon et al., 2001; Traxler et al., 2002; Grodner and Gibson, 2005; Staub, 2010). For example, consider the following two sentences:

(1) *The actor who impressed the critic humiliated the director*

(2) *The actor who the critic impressed humiliated the director.*

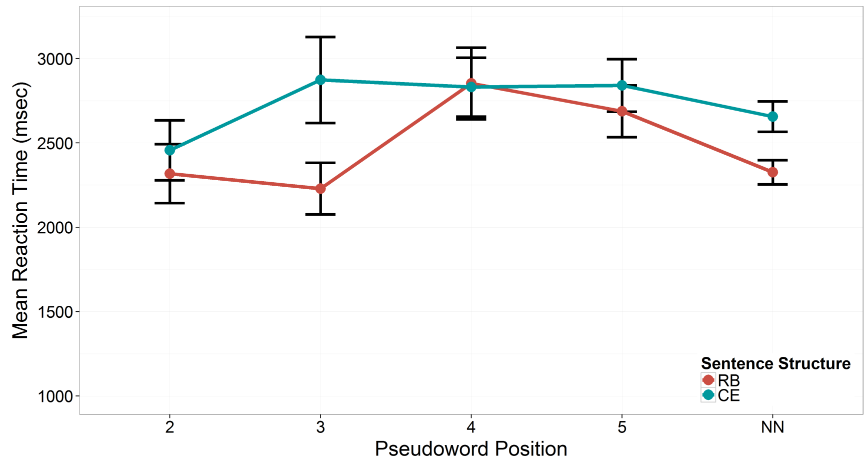
Researchers have observed greater processing difficulty while reading the word, *impressed*, in the object-extracted case (2) than the subject-extracted case (1) (Grodner and Gibson, 2005; Staub, 2010). Thus, it is likely that the syntactic processing effect at these verb positions may have inflated the reading times in the object-extracted cases. This would be consistent with the pattern of results that we observed in our study (see Figure 3.6).

3.4 General Discussion

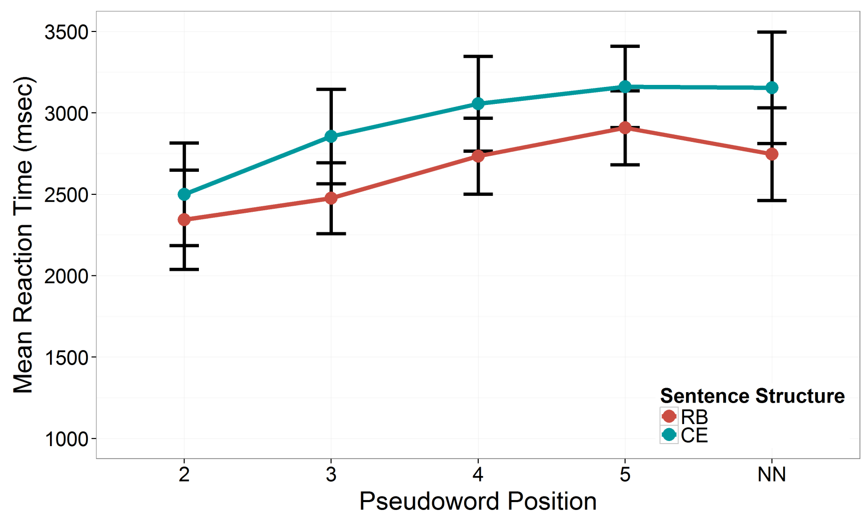
In this chapter, we were encouraged by early findings of Stromswold et al. (1996) to investigate whether syntactic information can influence word detection and identification. Our first experiment confirmed their original findings, and suggested that both syntactic and morphological information may play a role in word identification. However, our attempt to generalize those findings provided us with mixed results. On one hand, consistent with the results of Stromswold et al. (1996), we did observe an effect of syntactic structure on task performance. As we argued earlier, this indicates an automatic nature of syntactic processing, and echoes claims by Fodor (1983) that parsing is obligatory when a sentence-like stimulus is presented. Although interesting, this finding is perhaps not unexpected. In everyday life, there is hardly any scenario where we observe letters or words that we do not have to parse. Words are always used to convey ideas, and words together always form sentences, the meanings of which can only be interpreted by syntactically parsing the individual words.

On the other hand, we were unable to observe effects which would be consistent with a syntactic influence on pseudoword detection. Moreover, we found no evidence for an effect of morphological information on the task either. Figure 3.7 compares reaction time results for similar sentences across the two experiments. As we can see, there are clear differences in the way the two structures were dealt with across the two experiments. This points towards a difference in the strategies employed in the two studies, but the data at hand do not allow us to conclusively determine what the difference might be.

We speculate two possibilities as to why we may have observed differences between the two experiments. Firstly, it could be that the effects that we observed in the first experiment were merely a by-product of task-specific strategies used by participants to handle the two constructions. The primary purpose of filler sentences is essentially preventing such special strategies. It is possible that the absence of filler sentences in the first experiment confounded those results, and contributed to the differences between the two studies.



(a) Experiment 1



(b) Experiment 2

Figure 3.7: Comparison between reaction time results from Experiment 1 and Experiment 2.

Secondly, the stimuli across the two experiments also differed in terms of the animacy. Whereas in the first experiment, nouns were animate or inanimate, in the second experiment, nouns always referred to animate entities. In the past, a number of researchers have argued for an influence of animacy in sentence processing (e.g., Caplan et al., 1994; Mak et al., 2002, 2006; Lamers and de Hoop, 2005; Traxler et al., 2005; Gennari and MacDonald, 2008, 2009). As discussed earlier (see Section 2.2.3), having an inanimate extracted NP makes the processing of ORCs harder than having an animate NP (e.g., Traxler et al., 2002, 2005). It could be that this difference in the stimuli contributed to the difference in the overall pattern of results between the two experiments.

For better or worse, there are limitations to the whole-sentence pseudoword detection paradigm that we used in this chapter. The whole-sentence reading time measures are too coarse for a proper evaluation of the time-frame and localization of syntactic processing in presence of pseudowords. It could be that participants were in fact reading till the end of every sentence, and not merely stopping when they encountered a pseudoword (as predicted by the iterative syntactic model described earlier). Unfortunately, whole-sentence reading times do not allow us to directly evaluate this possibility.

In terms of the bigger picture, the pseudoword detection paradigm can only allow us to evaluate whether syntactic and morphological information influence word identification. However, a richer question is whether sentences that contain pseudowords, and, hence, novel words, can be just as effectively comprehended as regular sentences. Moreover, another important question is what type of linguistic information allows us to process sentences containing novel words. Once again, whole-sentence reading time measures do not allow us to address such deeper questions.

4. Novel Word Processing

"Curiouser and curiouser."
— Lewis Carroll, *Alice's Adventures in Wonderland*

4.1 Overview

As we saw earlier (Section 2.1), the lack of semantic content in sentences does not seem to affect syntactic processing. For example, a sentence like, *The boy was cratomized by the girl*, can seemingly be parsed just as well as the sentence, *The boy was liked by the girl.* Evidence supporting this hypothesis has come from several neurolinguistic (e.g., Canseco Gonzalez et al., 1997; Canseco-Gonzalez, 2000; Hahne and Jescheniak, 2001; Münte et al., 1997; Rothermich et al., 2009; Silva-Pereyra et al., 2007; Yamada and Neville, 2007) as well as psycholinguistic studies (e.g., Stromswold et al., 1996; Fedorenko et al., 2009).

Taken together, findings from these studies suggest that syntactic processing is not disrupted by the presence of novel, meaningless words. However, to date, no one has investigated what linguistic factors—such as, syntactic, morphological, or discourse/pragmatic—guide processing of such sentences. In this chapter, we examine whether and how syntactic and morphological information guide processing of such sentences. Furthermore, by contrasting processing costs throughout such sentences with regular sentences, we evaluate the overall impact of having novel words in sentence processing.

4.2 Experiment 3

This section presents the first study where we examine how people process sentences containing pseudowords using a self-paced reading paradigm. Here, we only investigate the effects of syntactic context on pseudoword processing by controlling for morphological variance. The primary goal is to further evaluate findings from our earlier pseudoword detection studies which indicated a role of syntactic context on novel word identification, and thus, potentially, novel word processing.

4.2.1 Methods

Participants

Thirty-six native and monolingual English-speaking college students participated in the study. All had normal or corrected-to-normal vision, and none had a history of a language or learning disorder.

Stimuli

The target sentences consisted of center-embedded relative clauses. Half of the target sentences were subject-extracted relative clauses (SRCs), and the other half were object-extracted relative clauses (ORCs). All sentences were constructed in pairs such that each pair consisted of the same set of words. Moreover, all nouns in the sentences referred to animate entities. One such pair is shown below:

- SRC: *The actor*$_1$ *who impressed*$_2$ *the critic*$_3$ *humiliated*$_4$ *the director*$_5$.
- ORC: *The actor*$_1$ *who the critic*$_2$ *impressed*$_3$ *humiliated*$_4$ *the director*$_5$.

In half of the sentences, a word in one of three lexical word positions (2, 3, or 4, see subscripts above) was replaced with an orthographically and phonologically plausible pseudoword (e.g., *threak*, *scoaned*). All pseudoverbs were constructed such that they ended with an *-ed* suffix, whereas all pseudonouns were morphologically bare (i.e., had no recognizable suffix). Moreover, the pseudowords always reflected the syntactic category of the replaced word. In other words, pseudonouns were used to replace nouns, and pseudoverbs replaced verbs. Examples of sentences containing pseudowords are shown below:

- SRC/NN: *The actor*$_1$ *who impressed*$_2$ *the critic*$_3$ *humiliated*$_4$ *the director*$_5$.
- SRC/2: *The actor who <u>scoaned</u> the critic humiliated the director.*
- SRC/3: *The actor who impressed the <u>threak</u> humiliated the director.*
- SRC/4: *The actor who impressed the critic <u>scoaned</u> the director.*

- ORC/NN: *The actor*$_1$ *who the critic*$_2$ *impressed*$_3$ *humiliated*$_4$ *the director*$_5$*.*
- ORC/2: *The actor who the threak impressed humiliated the director.*
- ORC/3: *The actor who the critic scoaned humiliated the director.*
- ORC/4: *The actor who the critic impressed scoaned the director.*

Design

We constructed 60 target sentence pairs for the study. Participants read only one sentence from each pair, and a total of 30 SRC sentences and 30 ORC sentences. As mentioned earlier, half of the target sentences contained a pseudoword in one of three lexical word positions (2, 3, or 4). Each position was replaced equally often across the two sentence types, and thus there were 5 sentences per condition (sentence structure × pseudoword × position).

In addition to the target sentences, participants read 120 filler sentences that varied syntactically. A total of 12 syntactic structures were used to create the fillers, with 10 sentences per structure. As with the target sentences, half of the filler sentences contained a pseudoword in one of the lexical word positions. See Appendix A.4 for a complete list of experimental items.

We generated 12 lists of target stimuli using a Latin-square design to ensure that sentence type and pseudoword position was balanced across participants. For each participant, one list was selected, which was combined with the set of fillers. The combined set of 60 target and 120 filler stimuli was pseudo-randomized to ensure that no more than 2 consecutive trials had the same structure and no more than 3 consecutive trials had the same pseudoword position.

Procedure

In this experiment, we used a non-cumulative word-by-word self-paced reading paradigm (Just et al., 1982). Participants read sentences one word at a time, and following each sentence, answered a yes/no comprehension question. Each question was of the form: *Did the* NOUN VERB *the* NOUN*?* Participants responded by pressing either F to answer Yes or J to answer No.

The experiment was presented using PyGame (`http://www.pygame.org`) on a 21-inch flat-screen LCD display with 1920×1080 pixels resolution. Participants were told they would be reading English sentences and would have to answer comprehension questions after each sentence. Each trial was preceded by a crosshair appearing at the center of the screen for 1 second. Participants were instructed to fixate on the crosshair and wait for the sentence to appear. After the crosshair, participants saw a series of dashes on the screen, where each dash corresponded to a letter in a word. The inter-word spaces between words were preserved in the dashed representation. Participants were instructed to press the SPACEBAR to see the first word, and repeatedly press the same button to move forward. After the first word, every time they pressed the SPACEBAR, the current word was replaced with dashes and the next word appeared. We collected reading times starting from the moment a word appeared till the key was pressed.

After the last word, participants were presented with the comprehension question which was displayed whole and was centered on the screen. Underneath the question, participants viewed the two answer options (Yes or No) and the keys corresponding to them. A feedback message was provided after each response. If participants correctly responded to the question, the word CORRECT flashed briefly on the screen. If they were incorrect, the word INCORRECT flashed instead. They were instructed to respond as quickly as possible without sacrificing accuracy.

Before the experimental sentences, participants were given 8 practice items and questions to familiarize them with the task. All practice sentences were of the form, *The* NOUN VERB*ed the* NOUN. Moreover, half of the practice sentences contained a pseudoword that replaced one of lexical words.

4.2.2 Results

Comprehension Question Accuracy

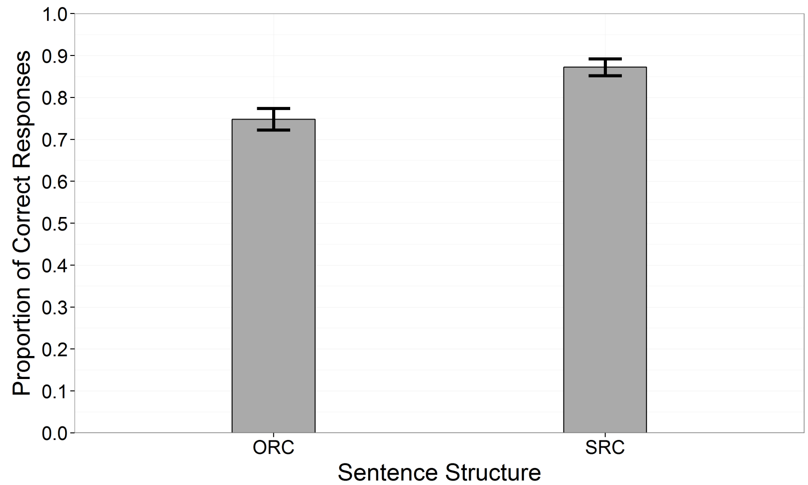
Overall, participants correctly answered 87% (5660 out of 6480) of the comprehension questions. Moreover, they correctly answered 81% (1750 out of 2160) of the comprehension questions following target sentences. To analyze the effect of sentence structure and pseudoword position on accuracy for the target sentences, we conducted a 2 (sentence structure) $\times$ 4 (pseudoword position) ANOVA with Subject as a random factor.

Results indicated a main effect of sentence structure, with participants being more accurate on questions following SRC sentences than for questions following ORC sentences (ORC: 75%; SRC: 87%; $F(1, 35) = 71.85, p < .001$). We also found a main effect of pseudoword position ($F(3, 105) = 11.07, p < .001$). As Figure 4.1b shows, participants were most accurate when the pseudoword was in the 4th lexical word position (e.g., *The actor who impressed the critic scoaned the director*), than for any other position—including the no pseudoword cases.

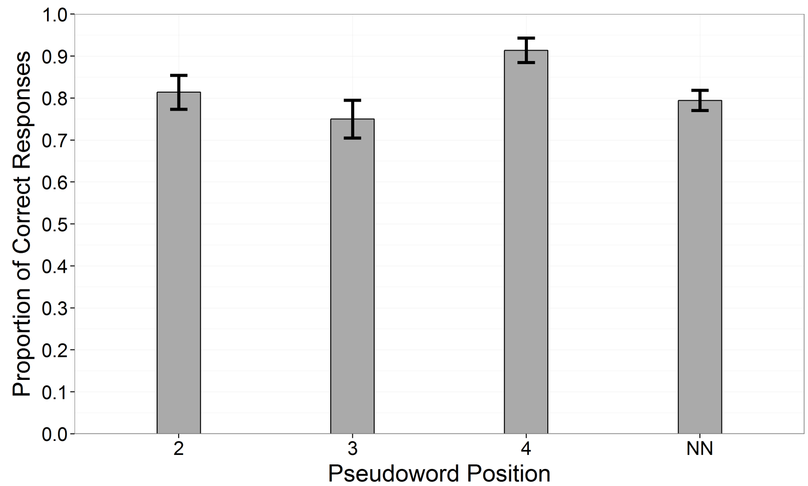
Lastly, the interaction between sentence structure and pseudoword position was also significant ($F(3, 105) = 5.72, p < .05$). As depicted in Figure 4.1c, the interaction likely reflects the difference in the magnitude of the structural effect for the 4 pseudoword positions. For all 4 position conditions, we see that accuracy for ORC sentences was worse than for SRC sentences. However, for pseudoword position 4 and the no pseudoword case (the NN sentence), the effect appears to be weaker.

Reading Time

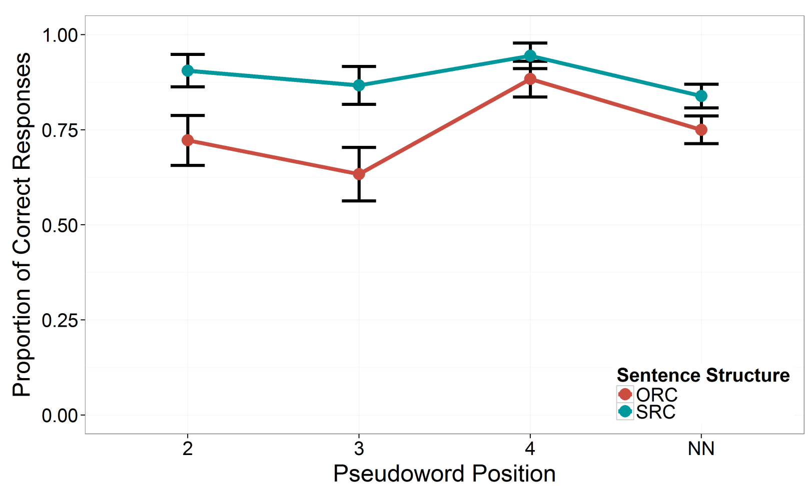
Typically, to analyze reading time data from a self-paced reading study, we need to account for word length differences as well as overall differences in participants' reading rates (see, Ferreira and Clifton, 1986; Trueswell et al., 1994). Thus, we derived a regression equation that predicted reading times from word length using data from all target and filler sentences. Subsequently, at each word position, the reading time predicted by the regression equation was subtracted from the actual measured reading time to obtain a residual reading time.



(a) Sentence Structure



(b) Pseudoword Position



(c) Interaction

Figure 4.1: Effects of Sentence Structure and Pseudoword Position on accuracy in Experiment 3. Error bars represent confidence intervals.

Residual reading times were computed separately for every participant, and data from all trials (including fillers) were used to derive them.

Crucially, before generating residual reading times, we removed outlier items in the following way. We first computed average reading times at all word positions. Next, we flagged sentences where for at least one word, the reading time was greater than the mean plus 6 times standard deviation for its specific syntactic position. Subsequently, all such flagged sentences were removed. Overall, we discarded 3% of the all items (151 out of 6480).

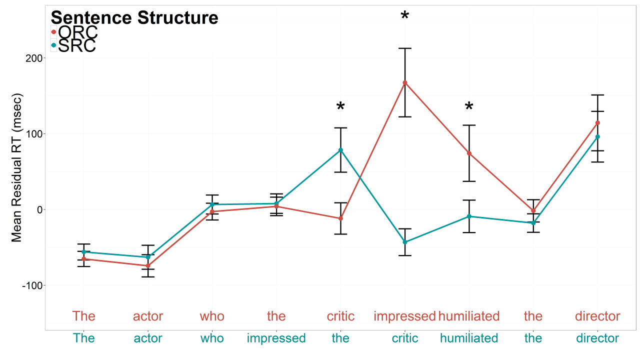
We evaluated the differences in reading time measures between the two relative-clause sentences using "aligned" comparisons. Using ORC sentences as the baseline, we compared the two sentence types by matching like words. For example, consider the following two sentences:

- ORC: *The actor who the critic impressed humiliated the director.*
- SRC: *The actor who impressed the critic humiliated the director.*

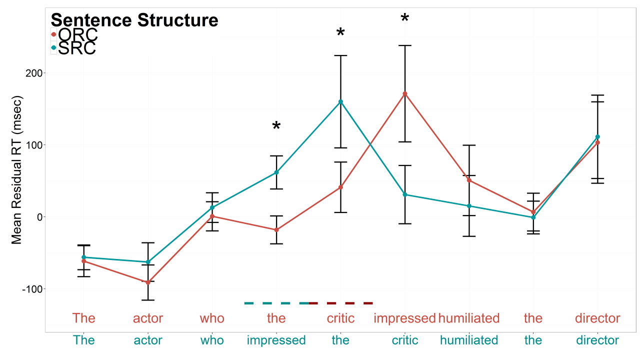
For the aligned comparisons, we compared the words in the ORC sentence with their counterparts in the SRC sentence. Thus, *critic* in ORC was compared with *critic* in SRC, allowing us to get a measure of relative differences across the two sentence types.

To perform the aligned comparisons, we fitted linear mixed-effects regression models (Baayen, 2008; Baayen et al., 2008) at each word position. The models included residual reading times as the dependent variable, and sentence structure as the fixed factor. Moreover, all models included random intercepts for Subject and Item. We separately performed the aligned comparisons for all 4 pseudoword position conditions. Graphs depicting the data and the results are shown together in Figure 4.2. The critical case is the no pseudoword condition, which allows us to compare our reading time data with what is known from the literature (see Section 2.2.2). As expected, we observed greater difficulty at both verb positions with participants being slower for ORCs than SRCs (RC verb: $t = -9.36, p < .001$; Main verb: $t = -3.74, p < .001$).[1] In addition, we observed a greater reading time at the

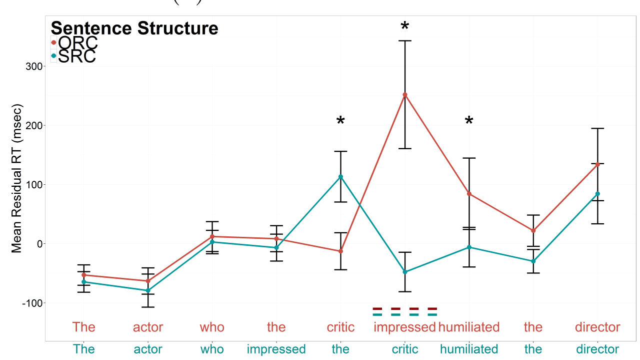
[1]The analyses treat the ORC condition as the baseline, thus negative t-values indicate faster reading time for SRCs.



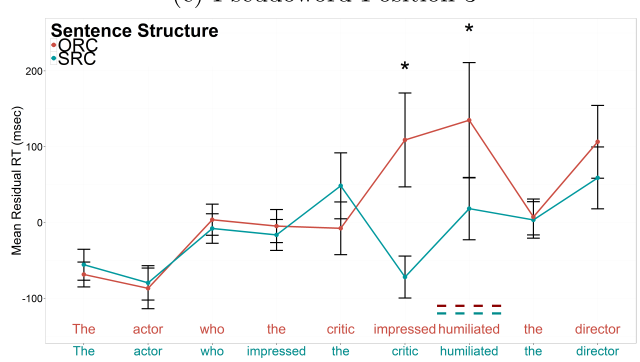
(a) No Pseudoword



(b) Pseudoword Position 2



(c) Pseudoword Position 3



(d) Pseudoword Position 4

Figure 4.2: Line graphs depicting aligned comparisons between ORCs and SRCs for the four pseudoword position conditions in Experiment 3. Error bars represent confidence intervals. Asterisks indicate significant differences.

embedded noun (e.g., *critic*; $t = 4.98, p < .001$), however in the opposite direction.

For the pseudoword conditions, we observed a similar pattern of results. For pseudowords in all 3 positions, we consistently found greatest reading time difficulty at the embedded verb for ORCs over SRCs. Moreover, similar processing differences were also observed at the main verb position when there was a pseudoword in position 3 or 4, but not when there was a pseudoword in position 2.

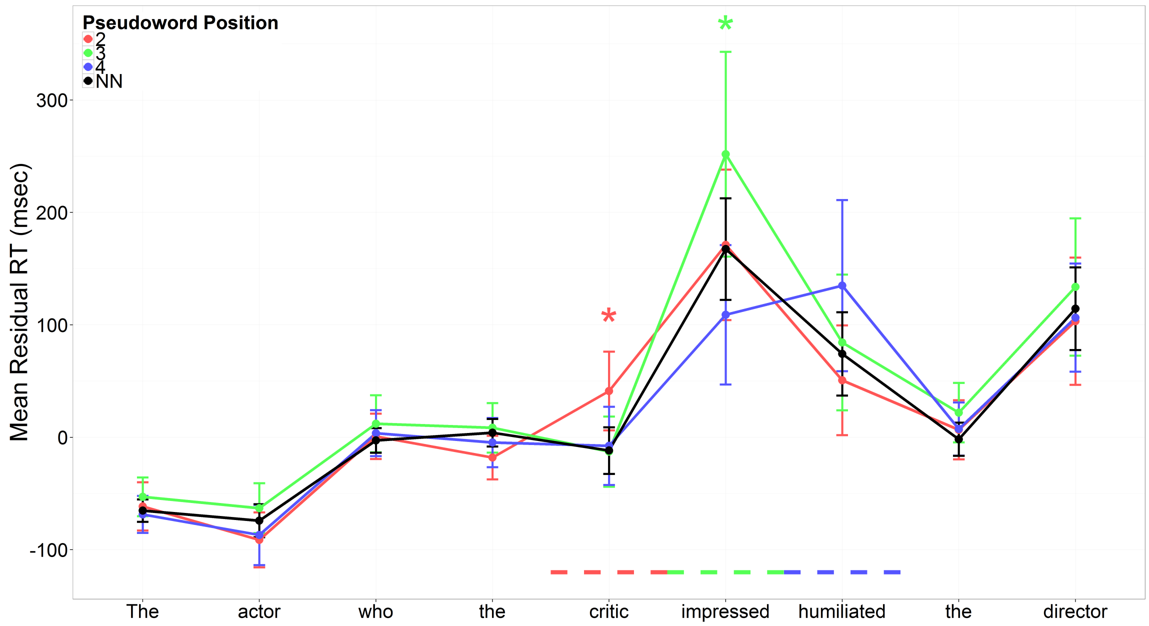
We used a similar set of analyses to investigate the effects of having a pseudoword at various syntactic positions. For each of the two sentence structures, we fitted linear mixed-effects regression models at all word positions. The regular, no-pseudoword, case was treated as the baseline, and the other three position conditions were compared against it. Again, all models included random intercepts for Subject and Item. Figure 4.3 depicts the data and the results.

For the ORC sentences, pseudowords at positions 2 and 3 caused a significant reading time slowdown at the corresponding positions (2: $t = 2.81, p < .01$; 3: $t = 2.19, p < .05$). For the SRC sentences, only pseudowords at positions 2 caused a significant reading time effect at the corresponding position ($t = 4.16, p < .001$). Moreover, this significant reading time slowdown persisted till the end of the relative clause (both p's $< .01$).

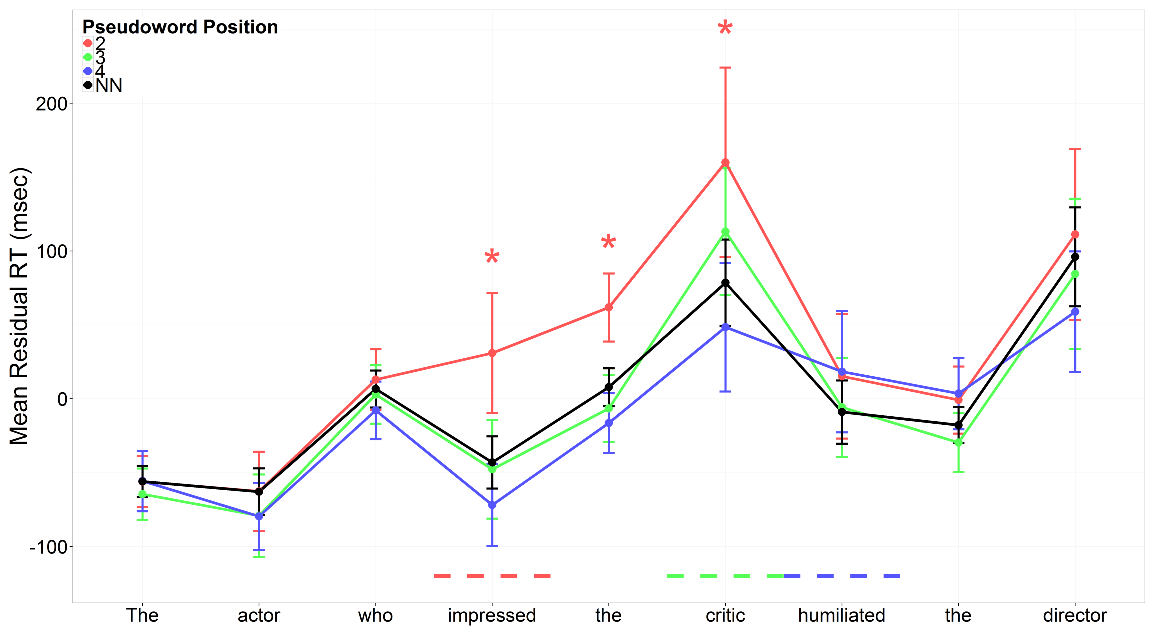
4.2.3 Discussion

On the whole, the results of this experiment make a strong case for an influence of syntactic information in processing sentences containing unknown words. Particularly interesting are the results of participants' performance on comprehension questions. As expected, we found that answering questions based on ORC sentences was harder than answering questions based on SRC sentences. This indicates an overall difficulty in processing and comprehending ORC sentences, which is consistent with previous work (a detailed discussion is provided in Section 2.2).

Interestingly, we find that for some cases, participants were better at answering questions when the corresponding sentence contained a pseudoword. Especially interesting is the fact that participants were more accurate when there was a pseudoword at the main



(a) Object-extracted relative clauses



(b) Subject-extracted relative clauses

Figure 4.3: Line graphs depicting residual reading times corresponding to the four pseudoword position conditions for the two sentence structures in Experiment 3. NN = No nonsense word. Error bars represent confidence intervals. Colored asterisks indicate significant differences between the corresponding position conditions and the no-pseudoword condition.

verb position than when there was no pseudoword at all. Typically, the objective behind including comprehension questions in self-paced reading studies is to ensure that participants actually read the sentences, instead of merely pressing keys to reach the end. One artifact of our comprehension questions was that in cases where sentences contained a pseudoword, the corresponding question always included that pseudoword. Thus, for sentences like, *The actor who scoaned the critic humiliated the director* and *The actor who the critic impressed scoaned the director*, corresponding questions could be: *Did the actor scoan the critic?* or *Did the director scoan the actor?*

It may be that pseudowords are highlighted in memory, or somehow attract attention, which may make answering questions based on them easier. However, an attention-based argument suggests participants should be more accurate for all pseudoword cases than for regular sentences. Another possibility is that the main verb position is somehow easier to integrate than either of the embedded positions. Perhaps, by the point the sentence processor reaches the main verb position, most of the structure of the sentence is already determined so the word can be ignored or integrated with less effort. A third possibility is that comprehension questions which do not involve the relative clause are harder to answer than those which do. For example, consider a sentence, *The actor who impressed the critic humiliated the director*. It might be that answering questions involving *actor, humiliated,* and *director* is easier than answering questions involving *actor, impressed*, and *critic*.

Regardless, the fact that participants were just as accurate when there were pseudowords than when there were none indicates that they were able to syntactically process these sentences. This further suggests that the presence of unknown words does not hinder syntactic processing. Additional support for this comes from the aligned comparisons (shown in Figure 4.2). From a high-level comparison between Figure 4.2a and Figures 4.2b, 4.2c, & 4.2d, we can see that the overall pattern of results is similar for the pseudoword and the no-pseudoword cases. Taken together, these data highlight the fact that even in presence of unknown words, sentence processing can function as usual.

In the previous chapter, we discussed a possible influence of syntactic information on novel word identification. We hypothesized that it is likely that syntactic information might further be used to guide syntactic integration of unknown words. Our data indicates that this might indeed be the case. As Figure 4.3 highlights, certain syntactic positions aid unknown word processing to such an extent that there is practically no processing difference between unknown words and regular words (specifically, position 4 in both ORCs and SRCs). On the other hand, for particular syntactic positions, processing costs associated with unknown words can be so severe that it carries over to the following set of words (e.g., position 2 in SRCs). On the whole, these data make a strong case for an influence of syntactic context on unknown word processing.

In the next section, we examine whether morphological information can also aid processing of sentences containing unknown words. Furthermore, we examine the relative importance of the two sources of information by investigating what happens when they conflict with each other.

4.3 Experiment 4

4.3.1 Methods

Participants

Thirty-two participants took part in this experiment. They were all native and monolingual English-speaking college students, and had normal or corrected-to-normal vision. None had a history of any language or learning disorder.

Stimuli

The experimental stimuli was similar to those used in Experiment 3, with the following two exceptions. First, we only substituted pseudowords at positions 2 and 3. This decision was primarily practical: we wanted to reduce the total number of unique experimental conditions, and the results of the previous experiment showed that having a pseudoword in position 4 did not affect reading time.

The other difference was the inclusion of morphological information on the pseudowords. All pseudowords included a derivational suffix (e.g., *-or, -ify, ician, -ize*) and an inflectional suffix (e.g., *-s, -ed*). Moreover, the morphological information could either be consistent with the syntactic category of the replaced word (the "Congruent" condition), or inconsistent (the "Incongruent" condition). Congruent pseudonouns had a nominal derivational suffix (*-or, -er, -ist,* or *-ician*) and a plural suffix (*-s*). Likewise, congruent pseudoverbs had a verbal derivational suffix (*-ify, -ize,* or *-ate*) and a past-tense inflectional ending (*-ed*). For the incongruent condition, the verbal and nominal suffixes were interchanged, and thus incongruent pseudonouns had verbal suffixes and incongruent pseudoverbs nominal. Some example sentences are shown below.

- SRC/NN: *The* $actor_1$ *who* $impressed_2$ *the* $critic_3$ $humiliated_4$ *the* $director_5$.
- SRC/congruent verb: *The actor who <u>strubdified</u> the critic humiliated the director.*
- SRC/incongruent verb: *The actor who <u>moldicians</u> *the critic humiliated the director.*
- SRC/congruent noun: *The actor who impressed the <u>guendors</u> humiliated the director.*
- SRC/incongruent noun: *The actor who impressed the <u>forigated</u> humiliated the director.*

- ORC/NN: *The* $actor_1$ *who the* $critic_2$ $impressed_3$ $humiliated_4$ *the* $director_5$.
- ORC/congruent verb: *The actor who the critic <u>strubdified</u> humiliated the director.*
- ORC/incongruent verb: *The actor who the critic <u>moldicians</u> humiliated the director.*
- ORC/congruent noun: *The actor who the <u>guendors</u> impressed humiliated the director.*
- ORC/incongruent noun: *The actor who the <u>forigated</u> impressed humiliated the director.*

Design

We used 64 pairs of object- and subject-extracted relative clause sentences, where sentences in each pair consisted of the same set of words. Participants read only one sentence from each pair, for a total of 32 ORC and 32 SRC sentences. Half of the sentences contained a pseudoword replacing a word in one of two lexical word positions (2 or 3). Furthermore, half of the pseudoword cases contained a congruent pseudoword that was consistent with the syntactic category of the word it replaced (i.e., pseudonoun for noun and pseudoverb for verb), and the other half contained an incongruent pseudoword (i.e., pseudonoun for verb and pseudoverb for noun). Each condition was balanced within participants, and there were a total of 4 sentences per experimental condition (sentence structure × pseudoword × position × congruency).

In addition to the target sentences, participants read 120 filler sentences. We used the same set of fillers as in the previous experiment, which varied syntactically and comprised of 12 different syntactic constructions. Again, half the filler sentences contained a pseudoword all of which were morphologically congruent. All target and filler sentences, as well as the pseudowords that were used in this study, are listed in Appendix A.5.

We generated 16 lists of target items using a Latin-square design to ensure that across participants all target sentences featured equally often with all the experimental manipulations. For each participant, we selected one list and combined it with the filler items. The combined set of 184 items was then pseudo-randomized to ensure that no more than 2 consecutive trials had the same sentence structure and no more than 3 consecutive trials had the same pseudoword position.

Procedure

The experimental procedure was the same as in Experiment 3.

4.3.2 Results

Comprehension Question Accuracy

Taking all items into account, participants correctly answered 87% (5097 out of 5888) of the comprehension questions. If we look at only the target sentences, participants' accuracy was slightly less at 80% (1623 out of 2048), which is understandable given that the target sentences were syntactically complex. We analyzed the effect of sentence structure and pseudoword position on accuracy using a 2×3 ANOVA with Subject as a random variable.

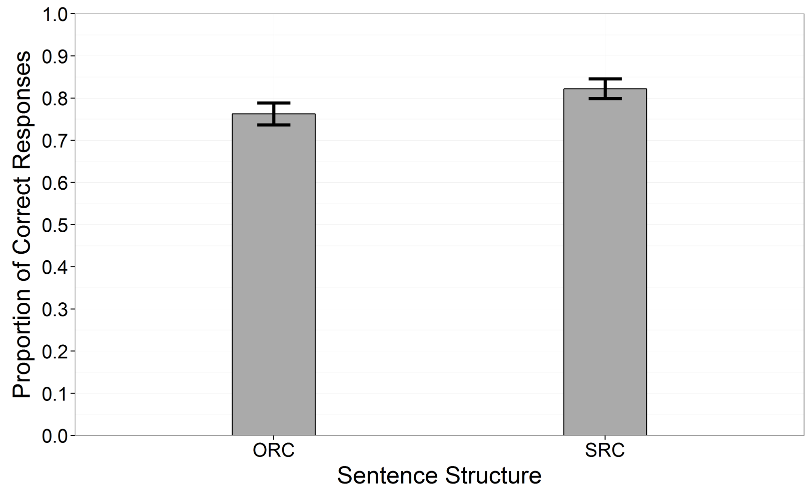
As in Experiment 1, we found a main effect of sentence structure with performance being worse on questions following ORCs than SRCs (ORC: 77%; SRC: 82%; $F(1,31) = 10.23, p < .01$). Moreover, we also observed a main effect of pseudoword position ($F(2,62) = 30.91, p < .001$). As Figure 4.4b shows, participants performed best for questions following regular sentences (85% accuracy) than for sentences containing pseudowords. Also, performance was worse when the pseudoword was in position 3 (69%) than when it was in position 2 (78%).

Lastly, the interaction between sentence structure and pseudoword position was also found to be significant ($F(2,62) = 4.13, p < .05$). The interaction is depicted in Figure 4.4c, and is likely due to the fact that the structure effect was most prominent when pseudowords were in position 2 and was non-existent when pseudowords were in position 3. The pattern of results remained intact when we ran the same analyses using only those sentences that contained pseudowords.

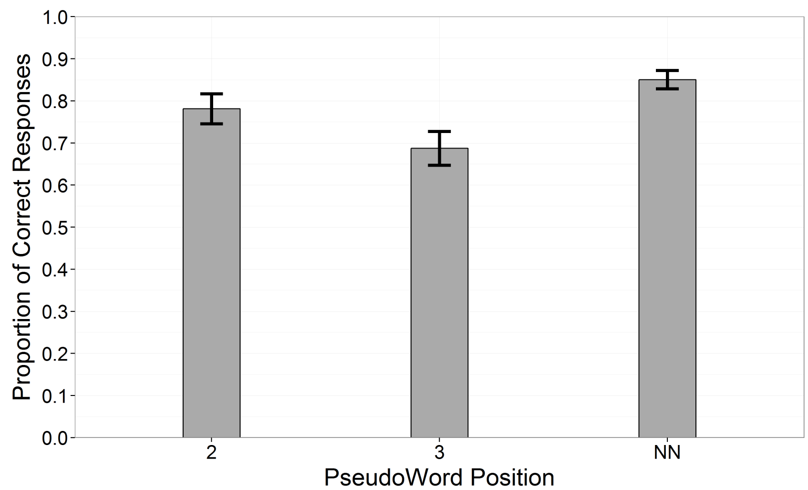
To evaluate the effect of morphological congruency, we conducted another 2×2 ANOVA with sentence structure and morphological congruency as fixed factors and Subject as a random factor. Because regular sentences did not vary in terms of morphological congruency, we did not include them in the analysis. Again, we observed a main effect of sentence structure ($F(1,31) = 5.90, p < .05$). However, neither the main effect of morphological congruency ($F(1,31) = 1.07, p = .31$) nor the interaction was found to be statistically significant ($F(1,31) < 1$).

Reading Time

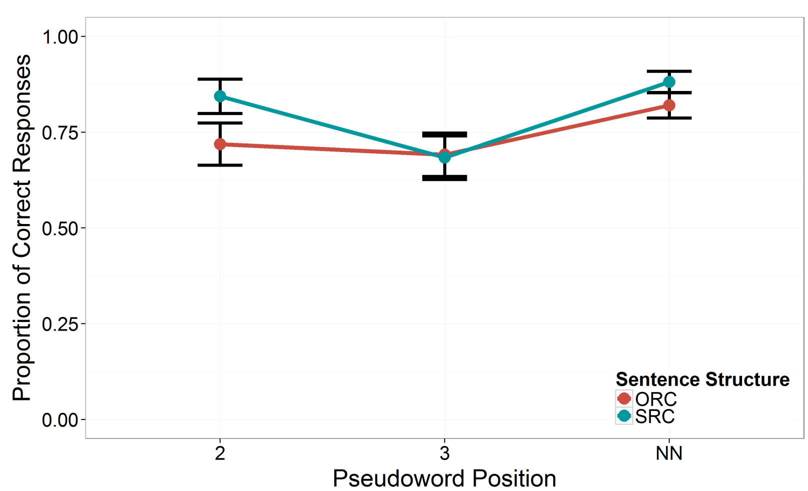
The reading time analyses were similar to those done in Experiment 3. Like earlier, we removed outliers by identifying items where reading time at any word exceeded mean plus 6 times the standard deviation at the word's specific syntactic position. Overall, 3% (185 out of 5888) of the data had to be discarded. Subsequently, we computed a regression equation to predict reading time from word length using all remaining data. The regression equation



(a) Sentence Structure



(b) Pseudoword Position



(c) Interaction

Figure 4.4: Effects of Sentence Structure and Pseudoword Position on accuracy in Experiment 4. Error bars represent confidence intervals.

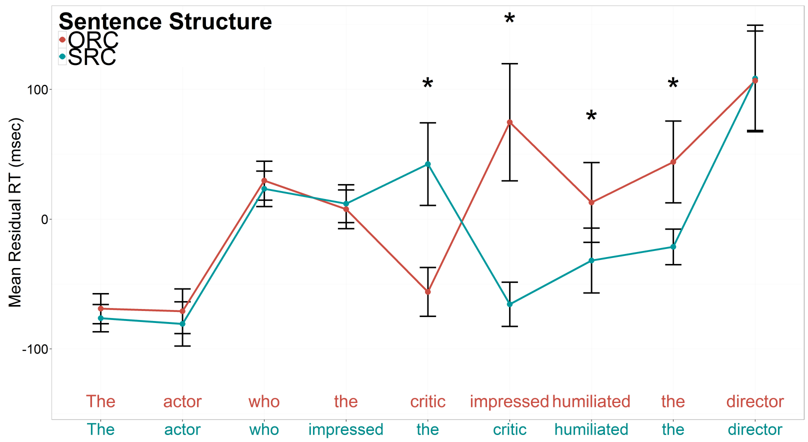
was then used to compute residual reading times by subtracting from actual reading times the predicted measures.

We first performed aligned comparisons where similar words across the two relative clause sentences were compared with each other. To perform the aligned comparisons, we fitted linear mixed-effects regression models at each word position where residual reading times were predicted using sentence structure as the fixed factor. All regression models included random intercepts for Subject and Item. Figure 4.5 depicts the results of our analyses. Looking at only the regular sentences (see Figure 4.5a), we observed a similar pattern of results as in the previous experiment. Participants read ORCs slower than SRCs, with the two verb positions being the areas of greatest difficulty (RC verb: $t = -6.17, p < .001$; main verb: $t = -2.39, p < .05$). The difficulty at the two verb positions also carried over to the following word position (*the*: $t = -3.92, p < .001$). As in Experiment 3, we also found that participants were slower at the embedded noun in SRCs than ORCs ($t = 5.45, p < .001$).

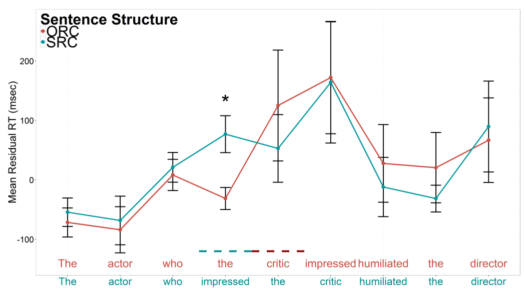
Also shown in Figure 4.5 are the data for the pseudoword cases. Despite the local effects of pseudowords, we can see that the overall pattern of data remains largely similar to regular sentences. Interestingly, a visual comparison of morphologically congruent and the incongruent cases (Figures 4.5b & 4.5d vs. Figures 4.5c & 4.5e) does not reveal any striking differences between the two cases.

To investigate the effects of having pseudowords at various syntactic positions, we again fitted mixed-effects regression models at all word positions for the two relative clause sentences. The models predicted residual reading times at individual positions using a fixed factor that crossed pseudoword position and morphological congruency, as well as random intercepts for Subject and Item. As before, the baseline was the regular, no pseudoword case. Additionally, for the pseudoword cases, we performed further analyses to compare the two Congruency cases using another set of regression models where the fixed factor was morphological congruency. The data and the results are depicted in Figure 4.6.

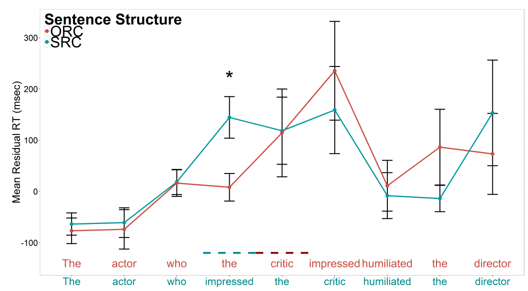
For the ORC sentences, pseudowords caused a localized reading time slowdown at their respective positions ($2_{congruent}$: $t = 5.71, p < .001$; $2_{incongruent}$: $t = 6.04, p < .001$;



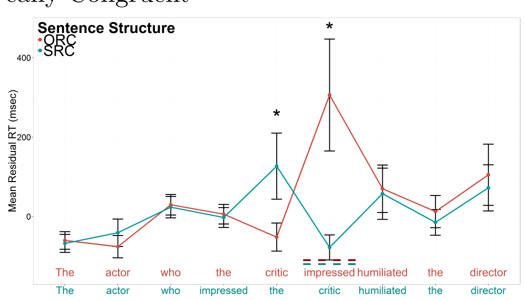
(a) No Pseudoword



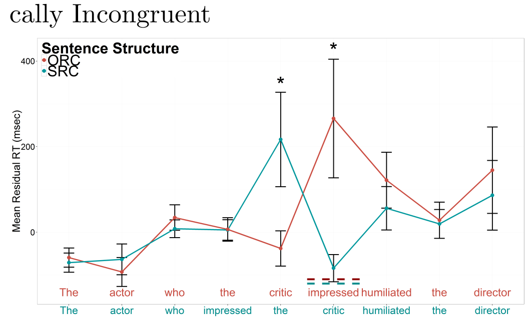
(b) Pseudoword Position 2 and Morphologically Congruent



(c) Pseudoword Position 2 and Morphologically Incongruent

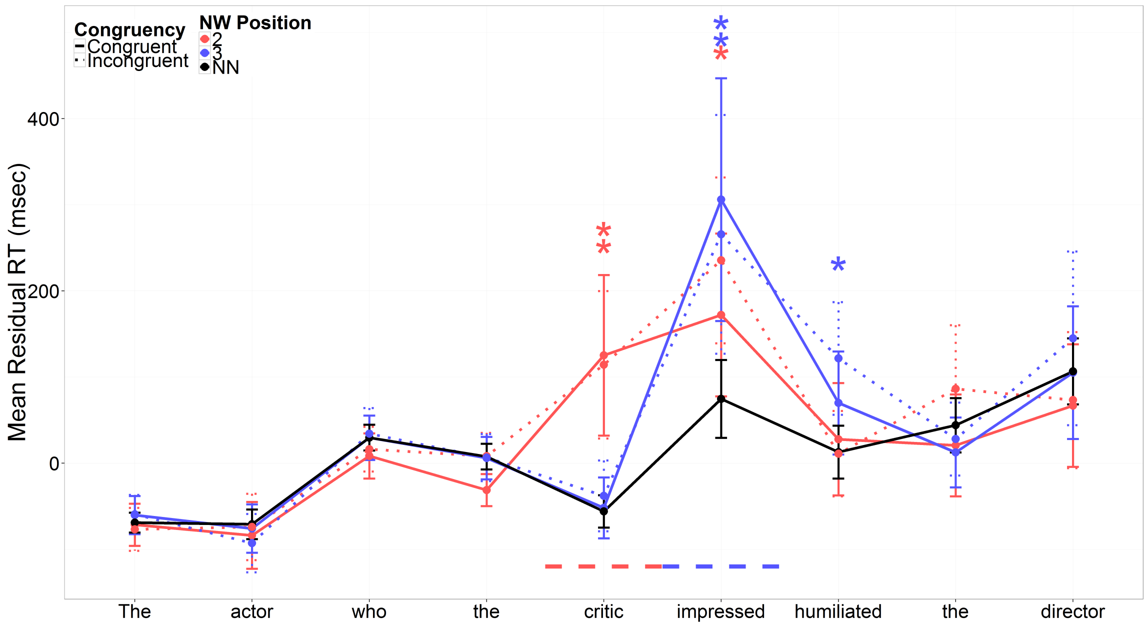


(d) Pseudoword Position 3 and Morphologically Congruent

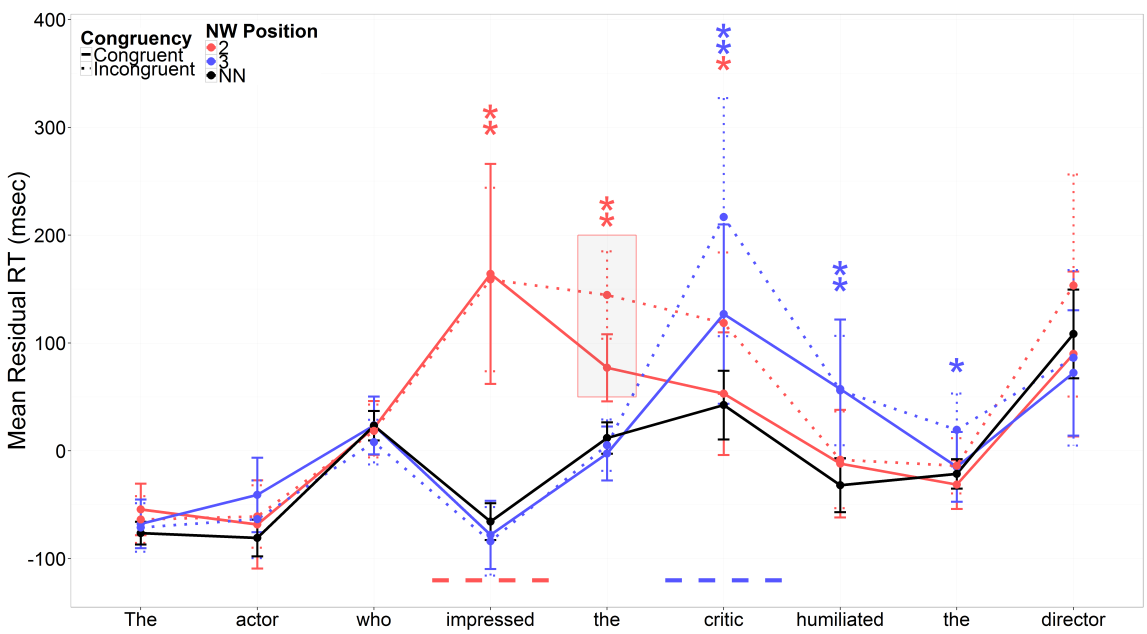


(e) Pseudoword Position 3 and Morphologically Incongruent

Figure 4.5: Line graphs depicting the various aligned comparisons between ORCs and SRCs in Experiment 4. Error bars represent confidence intervals. Asterisks indicate significant differences.



(a) Object-extracted relative clauses



(b) Subject-extracted relative clauses

Figure 4.6: Line graphs depicting residual reading times for the four pseudoword conditions along with the regular sentences for the two sentence structures in Experiment 4. NN = no nonsense word. Error bars represent confidence intervals. Colored asterisks indicate significant differences between the corresponding position conditions and the no-pseudoword condition.

$3_{congruent}$: $t = 3.54, p < .001$; $3_{incongruent}$: $t = 4.33, p < .001$). Moreover, only for the incongruent cases, we observed a "spillover" at the following word. When there was an incongruent pseudoword at position 2, there was a significant reading time slowdown at the following RC verb position ($t = 2.78, p < .01$). Also, when there was an incongruent pseudoword at position 3, there was a significant reading time slowdown at the main verb position ($t = 3.08, p < .01$). Direct comparisons between the congruent and the incongruent cases revealed no significant reading time differences at any word.

For the SRC sentences, all pseudowords again caused a reading time slowdown at their corresponding positions ($2_{congruent}$: $t = 5.91, p < .001$; $2_{incongruent}$: $t = 5.96, p < .001$; $3_{congruent}$: $t = 4.76, p < .001$; $3_{incongruent}$: $t = 2.40, p < .05$). Both the congruent and incongruent cases caused a reading time spillover that carried over to the following words. However, the length of the spillover varied across the congruency conditions. For pseudowords in position 2, morphologically congruent cases caused a spillover only at the next word (*the*; $t = 3.81, p < .001$). On the other hand, morphologically incongruent cases caused a spillover effect at the following two word positions (*the*: $t = 7.58, p < .001$; embedded noun: $t = 2.21, p < .05$). Likewise, for pseudowords in position 3, morphologically congruent cases caused spillover only at the following word position (main verb; $t = 3.16, p < .01$). However, morphologically incongruent cases caused a spillover effect at the next two word positions (main verb: $t = 3.04, p < .01$; *the*: $t = 2.80, p < .01$). Direct comparisons between the congruent and the incongruent cases revealed a significant difference only when the pseudowords were in position 2. Furthermore, the difference was only significant at the word right after the pseudoword (*the*; $t = -2.46, p < .05$; see shaded region in Figure 4.6b).

4.3.3 Discussion

The main question that this experiment addressed was whether morphological information influences processing of sentences containing unknown words. The overall pattern of results fails to provide any conclusive evidence supporting any influence of morphological information. If we consider the performance of participants on comprehension questions, their accuracy on the task was not affected by morphological congruency in any way. Crucially, the data did suggest that the presence of pseudowords had an adverse effect on performance. Together, this indicates that while unknown words may cause some issues with assimilating syntactic information, any inconsistency between syntactic and morphological information does not.

Similarly, the reading time data was also inconclusive. As discussed earlier, direct comparisons between reading times for ORCs and SRCs revealed similar overall patterns even when the pseudowords contained suffixes that were not consistent with their syntactic category (see Figure 4.5). In addition, we failed to consistently find any significant reading time penalty associated with incongruent morphological information.

However, we did observe a significant reading time difference between morphologically congruent and incongruent conditions after a pseudoword in lexical position 2 in SRC sentences. This position also happens to be the only syntactically ambiguous position across the two sentence types. For example, consider the following sentence fragment, *The actors who moldicians ...* This fragment may be interpreted as the start of an ORC sentence, such as *The actors who moldicians admire humiliated the director.* Critically, the pseudoword can be judged as being morphologically incongruent only after the next word has been read, as in *The actors who moldicians the ...* Thus, any processing difficulty should be observed only at the next word position, which is consistent with what we found in our data.

Furthermore, we also found a difference in lengths of the spillover effects caused by the two types of pseudowords. This difference suggests that while reading and integrating an incongruent pseudoword may not be locally difficult, it may cause processing difficulties later on during sentence processing. In turn, this could be indicative of a potential impact of morphological information on pseudoword processing.

Why do we not see any consistent differences between morphologically congruent and incongruent cases? There are two possible explanations. First, it could be that sentence processing is predictive, and syntactic context heavily outweighs any morphological information. Consider the morphologically incongruent cases that we used in this experiment:

(1) *The actors who* *moldicians* *the critic humiliated the director.*

(2) *The actors who impressed the* *forigated* *humiliated the director.*

(3) *The actors who the* *forigated* *impressed humiliated the director.*

(4) *The actors who the critic* *moldicians* *humiliated the director.*

Of the four possibilities, incongruent pseudonouns, e.g., (2)(3), do not seem as out of place as incongruent pseudoverbs, e.g., (1)(4). The presence of the preceding *the* strongly guides the interpretation of the incongruent pseudoverb as a pseudonoun. For example, it is not difficult to treat the incongruent pseudonouns as being adjectival nouns (e.g., "the ostracized," "the damned," "the justified," etc.)

Likewise, because of the ambiguous nature of the *-s* suffix, the incongruent pseudoverb cases, e.g., (1)(4), only stand out if there is a subject-verb disagreement (as in (1)). On the other hand, if the subject-verb agreement condition is not violated (as in (4)), even these do not seem too odd. Possibly, this is because the *-s* suffix also indicates the third-person singular present tense (e.g., *the actor likes the director*).

Taking all this into account, it is possible that participants never really treated the morphologically incongruent cases as being any different. Perhaps, when processing unknown words, sentence processing chooses to favor syntactic information over morphological, overruling the latter in case of any disagreement. This would also explain why we observed a difference between congruent and incongruent conditions only when syntactic information was ambiguous, and hence, inadequate.

Another possibility is that morphological information may not have been captured at all. It might be that suffixes on pseudowords are not parsed, and the pseudowords are always treated as a whole. In other words, if a word looks like a nonsense word, perhaps morphological processing does not take place. On the other hand, it could be that even if morphological information is extracted and recognized, it is only utilized if the semantic content of the whole word can be generated. In other words, even if the sentence processor can identify suffixes on a pseudoword, it may choose to disregard that information if the word as a whole is meaningless.

In the next two experiments, we separately evaluate both these arguments. The next section (Section 4.4) describes an online study that evaluates the latter argument by asking participants to judge whether a pseudoword is a noun or a verb using only morphological information. The following section (Section 4.5) discusses an experiment where we examine whether the lack of adequate syntactic information causes the sentence processor to favor morphological information instead.

4.4 Experiment 5

Experiment 5 is an online lexical discrimination study in which participants judged whether pseudowords presented in isolation were more noun-like or verb-like. The goal is to evaluate whether people can identify and utilize morphological information on pseudowords to determine their syntactic category.

4.4.1 Methods

Participants

Thirteen native and monolingual English-speaking college students participated in the study. All had normal or corrected-to-normal vision, and none had a history of a language or learning disorder.

Stimuli and Design

We created orthographically and phonologically plausible pseudowords that varied morphologically. Specifically, we created 8 different kinds of pseudowords by manipulating the number and type of suffixes on nonsense stems. We used nominal derivational suffixes (-*cian, -er, -or, -ist*), verbal derivational suffixes (*-ify, -ate, -ize*), a nominal inflectional suffix (the plural *-s*), and a verbal inflectional suffix (the past-tense *-ed*) to generate the items. We also had two conditions where the nominal and verbal suffixes were crossed. One class of pseudowords contained a nominal derivational suffix and a verbal inflectional ending, and another contained a verbal derivational suffix and the nominal plural ending. The 8 categories and some examples are shown below.

- NDE: Nominal derivational — *crotician, bullawer, bolitist*, etc.
- NIN: Nominal inflectional — *nusts, bullifs, sergs*, etc.
- NDENIN: Nominal derivational and nominal inflectional — e.g., *elusists, buestors, cheldors*, etc.
- VDE: Verbal derivational — *peagify, forigate, conturize*, etc.
- VIN: Verbal inflectional — *tissed, offalded, tirasted*, etc.
- VDEVIN: Verbal derivational and verbal inflectional — *visified, calikated, thafassized*, etc.
- NDEVIN: Nominal derivational and verbal inflectional — *bottisted, lawticianed, justatored*, etc.
- VDENIN: Verbal derivational and nominal inflectional — *phonorizes, prutifies, ballicizes*, etc.

In total, we created 16 pseudowords for each category, giving us a complete list of 128 items (see Appendix A.6). Each participant viewed all 128 items, and a different randomized list was created for each participant, ensuring that the order of presentation did not play any role.

Procedure

This was an online study developed using PHP, where participants saw one word at a time, and rated it on the following 5-point scale: GOOD NOUN, OK NOUN, NOUN OR VERB, OK VERB, GOOD VERB. They were told that they would be reading nonsense words that looked like English words, and were instructed to use their best judgment in determining whether they looked like nouns or verbs. Each word was presented at the center of the webpage, and underneath the word were 5 radio buttons with the corresponding labels. On clicking any of the radio button, the next word appeared and the response was recorded. This was not a timed study, and participants were told to take as long as they needed to respond.

4.4.2 Results

In our analyses, we converted the 5-point scale into a numerical one using the following mapping:

- Good Noun = -2
- OK Noun = -1
- Noun or Verb = 0
- OK Verb = 1
- Good Verb = 2

Subsequently, we computed the mean scores for all categories. Essentially, a highly positive mean score indicates that an particular category of pseudowords is strongly verbal, whereas a highly negative mean score indicates that it is strongly nominal.

Moreover, the absolute value of the mean score corresponds to how strongly does the morphological information biases towards a certain syntactic category. In other words, if the morphological information present on one class of pseudowords strongly biases the words towards a specific syntactic category (noun or verb), we expect the absolute value of the mean score for that class of pseudowords to be closer to 2. Conversely, if the morphological information does not bias the interpretation towards any specific syntactic category, we expect the absolute mean value to be closer to 0.

The data from our study is graphically depicted in Figure 4.7. We performed three sets of planned comparisons to evaluate this data. For our first analysis, we excluded data where the morphological information was crossed between nominal and verbal suffixes (i.e., the NdeVin and VdeNin cases were excluded). Using the remaining data, we conducted a 2 $\times$ 2 ANOVA using number of suffixes and syntactic category of the suffixes as fixed

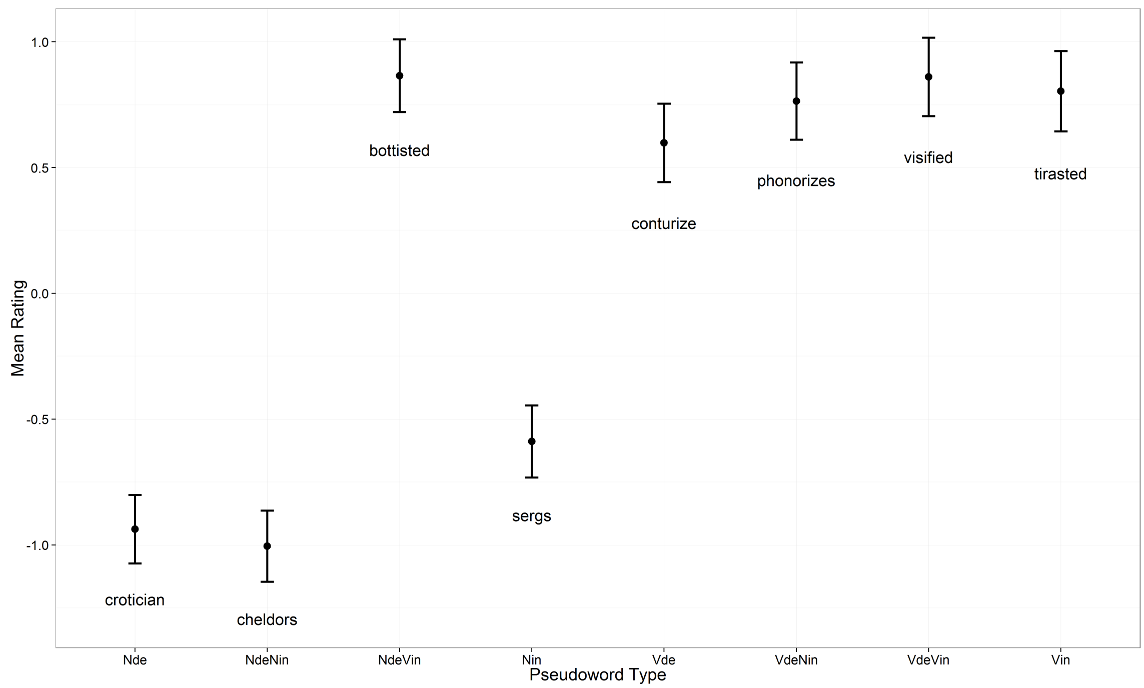


Figure 4.7: Graph depicting mean ratings for the 8 pseudoword categories used in Experiment 5. The error bars correspond to confidence intervals.

factors and Subject as a random factor. The dependent measure was absolute value of ratings, and essentially the analysis examined whether the number and syntactic category of suffixes influenced the determination of the syntactic category of a pseudoword. The motivation for using absolute rating over raw scores was our interest in measuring how strongly different types of morphological information guide lexical discrimination. From Figure 4.7, it is clear that nouns are different from verbs. However, we are interested in measuring whether nominal suffixes are more, less, or equally informative as verbal suffixes, which we can evaluate only using absolute scores.

The results of the ANOVA indicated a main effect of the number of suffixes, with two suffixes influencing participants to a greater extent than having only one suffix (mean absolute rating with two suffixes: 1.29; with one suffix: 1.15; $F(1, 12) = 10.20, p < .01$). We did not observe any main effect of syntactic category ($F(1, 12) < 1$), nor any interaction between the two factors ($F(1, 12) = 1.72, p = .2$). This indicates that nominal and verbal suffixes do not differentially influence the task.

For our second set of analyses, we evaluated whether inflectional and derivational suffixes are treated differently when determining the syntactic category of words. We used only those data where pseudowords contained only one suffix (i.e., NDE, NIN, VDE, and VIN). The analysis was performed using a 2 × 2 ANOVA with type of suffix and syntactic category as the two fixed factors and Subject as a random factor. Again, the dependent measure was absolute rating. We found no significant main effect of type of suffix ($F(1, 12) < 1$) or syntactic category ($F(1, 12) = 3.32, p = .09$).

However, the interaction between the two factors was significant ($F(1, 12) = 18.55$, $p < .01$). For nominal suffixes, derivational suffixes had a stronger influence than inflectional suffixes (mean absolute rating for derivational: 1.21; for inflectional: 1.00). On the other hand, for verbal suffixes, it was the inflectional suffixes that had a greater influence over derivational (mean absolute rating for derivational: 1.09; inflectional: 1.29). This effect can also be seen in Figure 4.7, where we see that between NDE and NIN, it is the inflectional case that is closer to 0, indicating a weaker influence on lexical discrimination. However, between VDE and VIN, it is the derivational case that seems to have a weaker influence. It is possible that the ambiguous nature of the nominal inflectional ending, *-s*, played a role in this interaction. Unfortunately, we were limited in our study because of English only having one nominal inflectional suffix, and thus had to use *-s*.

For our final set of analyses, we wanted to evaluate whether crossed suffixes differentially influenced determination of a word's syntactic category. However, as the data clearly shows, the ambiguous nature of the nominal inflectional marker (*-s*) did in fact prove to be an issue. For the nominal cases, we see that if the inflectional ending was consistent with the derivational suffix, participants were strongly biased towards a nominal judgment. However, when the inflectional ending was verbal, their decision was reversed. On the other hand, for verbal suffixes, we see that both cases correctly resulted in participants' being biased towards a verbal judgment.

4.4.3 Discussion

The goal of this experiment was to investigate whether people can recognize and utilize morphological information on pseudowords to determine their syntactic categories. Our data strongly suggests that people can indeed use derivational and inflectional morphological information. Moreover, our findings indicate that both the quantity and the reliability of morphological information affects lexical discrimination.

One concern is that the only nominal inflectional suffix, the plural *-s*, also doubles as a verbal inflectional suffix, the third person singular present tense marker, e.g., *likes, rises*. Thus, it is possible to interpret the crossed pseudoverb case (VdeNin) as having a verbal inflectional suffix rather than a nominal inflectional. Potentially, this could act as a confound in any comparison between crossed pseudonouns (NdeVin) and crossed pseudoverbs. As the data shows, when the information was ambiguous (e.g., the *-s* ending), participants' judgments were influenced by more reliable information (e.g., the VdeNin case). Furthermore, when two suffixes contradicted, the decision was biased towards one interpretation over another (such as in the NdeVin case), possibly on the basis of some reliability estimate.

In Section 4.3.3, we argued that the reason why we may not have found a difference between morphologically congruent and incongruent pseudowords could be that participants either could not recognize morphological information on those words or chose to disregard it. The results of this experiment speak against the former argument. The pseudonouns and pseudoverbs used in Experiment 4 correspond to the NdeNin and VdeVin cases used here. As our results indicate, for both types of pseudowords, participants could correctly determine their corresponding syntactic category.

4.5 Experiment 6

In this section, we examine whether the reason why we found little-to-no effect of morphological incongruency in Experiment 4 is because syntactic information outweighs morphological information. We do so by asking what happens in cases when syntactic information is ambiguous. If morphological information can potentially influence sentence processing, we expect cases of morphological inconsistency to lead to syntactic garden-paths.

For example, consider the following sentence: *The actor who moldicians like/critics impressed the director*. At the word, *moldicians*, there is not enough syntactic information to reliably predict the rest of the sentence. It is possible for the fragment to be the start of either a subject-extracted relative clause (SRC), as in *The actor who likes critics impressed the director*, or an object-extracted relative clause (ORC), as in *The actor who critics like impressed the director*. Thus, if morphological information is used to make a decision, we expect the two nominal suffixes (*-cian* and *-s*) to bias sentence processing towards an ORC interpretation. Subsequently, if the next word is inconsistent with that interpretation (e.g., *The actor who moldicians critics impressed the director*), it might lead to a syntactic "garden-path," thus causing greater processing difficulty at that word (and possibly following words).

4.5.1 Methods

Participants

Thirty-two native and monolingual English-speaking college students participated in the study. All had normal or corrected-to-normal vision, and none had a history of a language or learning disorder.

Stimuli

The target items were object-extracted (ORCs) and subject-extracted relative clauses (SRCs). The relative clause sentences used in this experiment differed from the target items of Experiments 3 and 4 in two ways. Firstly, all embedded nouns were plurals and were never preceded by the article, *the*. Secondly, all verbs were in the third-person present tense, but could be either singular or plural depending on the subject-verb agreement constraints. Examples of the modified relative clause sentences are shown below:

- SRC: *The actor who admires critics humiliated the director.*

- ORC: *The actor who critics admire humiliated the director.*

The relative clauses were so modified to ensure that the word after the relative pronoun, *who*, always ended with an *-s* suffix. The goal was to ensure that participants treated any pseudoword ending with an *-s* in that position as being equally likely to be either a verb or a noun.

Because of the specific nature of the question that this study addressed, our pseudowords were also slightly different from the ones used in the previous experiment. All pseudowords ended with an *-s* suffix. Moreover, they always contained either a nominal or a verbal derivational suffix that preceded the *-s* ending. Thus, pseudonouns (e.g., *duppists, noachers, protters*) could be distinguished from pseudoverbs (e.g., *duppifies, noachates, prottizes*) only by stripping away the *-s* ending and identifying the remaining derivational morpheme. Furthermore, we constructed these pseudowords in pairs, such that each pair of pseudonoun and pseudoverb shared the same stem. For example, using a stem, *dupp*, a pseudonoun could be *duppists* and a pseudoverb could be *duppifies.* This was to ensure that only morphological information from the derivational suffixes played a role, and to control for any influence of specific pseudo-stems.

Also unlike the previous experiments, pseudowords were only inserted in the 2nd lexical word position (word after *who*). In the morphologically congruent condition, the pseudowords reflected the syntactic category of the word they replaced. Thus, in SRCs, the pseudowords were always pseudoverbs, and in ORCs, they were pseudonouns. On the other hand, in the morphologically incongruent condition, the syntactic category of the pseudowords was reversed. Thus, SRCs had pseudonouns and ORCs had pseudoverbs.

Design

We used 40 pairs of object- and subject-extracted relative clause sentences, such that both sentences in a pair contained a similar set of words. However, due to subject-verb agreement concerns, some pairs contained RC verbs that differed in terms of tense marking (see *admire* and *admires* in the example above). Participants only read one sentence from each pair, and a total of 20 ORC and 20 SRC sentences. Half of the sentences contained a pseudoword that replaced the word after *who*. Furthermore, half of the pseudoword cases contained morphologically congruent pseudowords, whereas the other half contained morphologically incongruent pseudowords. In total, there were 5 sentences per experimental condition (sentence structure × pseudoword × congruency).

In addition to the 40 target items, participants also read 80 filler sentences which varied syntactically. Ten different syntactic structures were used to construct the filler items, with 8 sentences per structure. Half of the filler sentences contained a pseudoword that replaced one of its lexical words. Moreover, half of the pseudoword cases contained a morphologically congruent pseudoword, whereas the other half contained a morphologically incongruent pseudoword. Because only one position in target items was replaced with pseudowords, we took care to ensure that in fillers pseudowords were inserted in varied locations. Overall, 30 items had a pseudoword at the second lexical word position, 19 in the third position, and 11 in the fourth. All target sentences, filler sentences, and pseudowords used in this study are listed in Appendix A.7.

A Latin-square design was used to present the stimuli such that, across participants, all target sentences occurred equally often with all experimental manipulations. Furthermore, the combined set of 120 target and filler items was randomized before every session. This ensured that the order of presentation did not influence performance.

Procedure

The experimental procedure was similar to the one used in Experiments 3 and 4, with a few changes. As was the case for Experiment 5, this was an online study. We used the Ibex toolkit developed by Alex Drummond, which is currently being hosted at: `http://spellout.net/ibexfarm`. Ibex is essentially an online resource that can be used to conduct web-based self-paced reading studies.

However, the format of presentation remained the same as in Experiments 3 and 4. Participants were told they would be reading English sentences, and had to answer comprehension questions following each sentence. Initially, every sentence was presented with all words being replaced by dashes. Participants navigated through the sentence by pressing the SPACEBAR to see the next word. They could only view one word at a time, and pressing the SPACEBAR simultaneously replaced the current word with dashes again. The time from the onset of a word till the time the key was pressed was recorded as the corresponding reading time at that word.

After completing every sentence, participants were presented with the comprehension question which was always of the form: *Did the* NOUN VERB *the* NOUN*?*. They answered Yes or No by pressing one of two keys that corresponded to the options. They were then presented with a feedback message (CORRECT or INCORRECT) that flashed on the screen for half a second.

Before the experimental items, participants were presented with 6 practice items that familiarized them with the task and the setup. The practice items were comprised of simple active sentences followed by comprehension questions. To familiarize them with pseudowords, half of the practice items included a pseudoword that replaced one of the lexical words.

4.5.2 Results

Comprehension Question Accuracy

Overall, participants in this study were much less accurate than in our previous two self-paced reading experiments. Considering all data, participants correctly answered 76% (2908 out of 3840) comprehension questions. Moreover, their accuracy on questions following target items was 71% (911 out of 1280). Contrast this with Experiment 4 where participants responded with 87% accuracy on all trials and 80% accuracy on target items. It is likely that this decrease in overall performance is due to the web-based nature of this study. Looking at individual performance, we found a considerable number of participants with low accuracy. For example, there were 10 participants who had had less than 70% accuracy in all trials, or less than 60% accuracy with target items.

We analyzed the effect of sentence structure and the presence of pseudowords on accuracy by conducting a 2×2 ANOVA with Subject as a random factor. As expected, we found a main effect of sentence structure with participants being much more accurate on questions following SRC sentences than for questions following ORC sentences (ORC: 65%; SRC: 77%; $F(1, 31) = 18.91, p < .001$). Moreover, the difference between items that did not contain a pseudoword and items that did was found to be marginally significant, with participants being less accurate when pseudowords were present (68%) than when they were absent (75%; $F(1, 31) = 4.12, p = .05$). However, the interaction between the two factors was not significant ($F(1, 31) = 3.17, p = .08$).

We further evaluated any effect of morphological congruency by analyzing data from only those items that contained a pseudoword. We conducted a 2×2 ANOVA with sentence structure and morphological congruency as fixed factors and Subject as a random factor. Again, we found a main effect of sentence structure (ORC: 59%; SRC: 77%; $F(1, 31) = 16.33, p < .001$). However, we found no main effect of morphological congruency ($F(1, 31) < 1$). In addition, the interaction between the two factors was found to be significant ($F(1, 31) = 4.34, p < .05$). As shown in Figure 4.8, the likely cause of the interaction is the greater performance difference between SRCs and ORCs when pseudowords were morphologically incongruent. We tested this by conducting two one-way ANOVAs with sentence structure as the fixed factor for the two morphological congruency conditions. When pseudowords were morphologically congruent, we found no effect of sentence structure on accuracy ($F(1, 31) = 3.41, p = .07$). On the other hand, when they were morphologically incongruent, we found a significant main effect ($F(1, 31) = 15.59, p < .001$).

Reading Time

The reading time analyses were similar to the ones we used in Experiments 3 and 4. Given the web-based nature of the experiment, we decided to use a stricter criterion to identify outliers. Unlike the previous experiments, here we chose to discard reading times 5 standard deviations away from the mean instead of 6. Overall, 4% of the data (152 out of 3840) had to be discarded. Like earlier, we used the remaining data to compute a regression equation that predicted reading time from word length for every subject. Subsequently, we computed

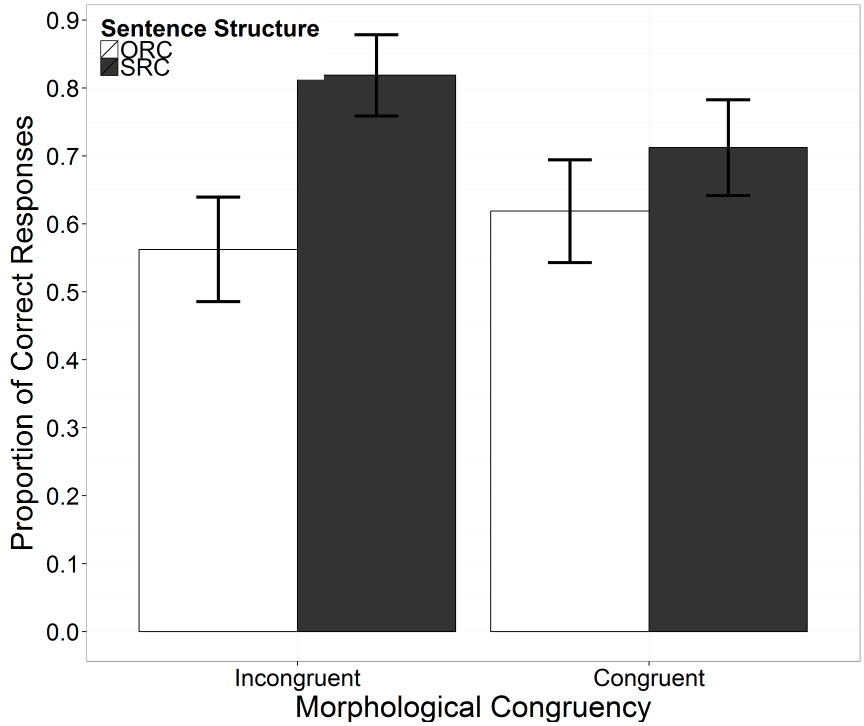


Figure 4.8: Significant interaction between Sentence Structure and Morphological Congruency on accuracy in Experiment 6.

residual reading times by subtracting from actual reading times the predicted measures from the regression equation.

First, we performed aligned comparisons where similar words in the two sentences were compared with each other. To perform the comparisons, we fitted linear mixed-effects regression models at each word position using the ORC sentence structure as the baseline. The models predicted residual reading times using sentence structure as a fixed factor and random intercepts for Subject and Item. The data is depicted in Figure 4.9. For regular sentences that did not contain pseudowords, we found significant reading time differences between ORC and SRC sentences at the two verb positions, with participants being slower for the ORC sentences (RC verb: $t = -2.56, p < .05$; main verb: $t = -3.40, p < .01$). We also found a significant reading time difference between the two sentences at the word following the main verb (*the*: $t = -2.66, p < .01$), presumably indicating a spillover from the main verb position. A similar pattern of results was found for both the morphologically congruent and incongruent pseudoword conditions, with participants being overall slower for ORC sentences than SRCs, and the main verb position in particular being the point of consistent difficulty.

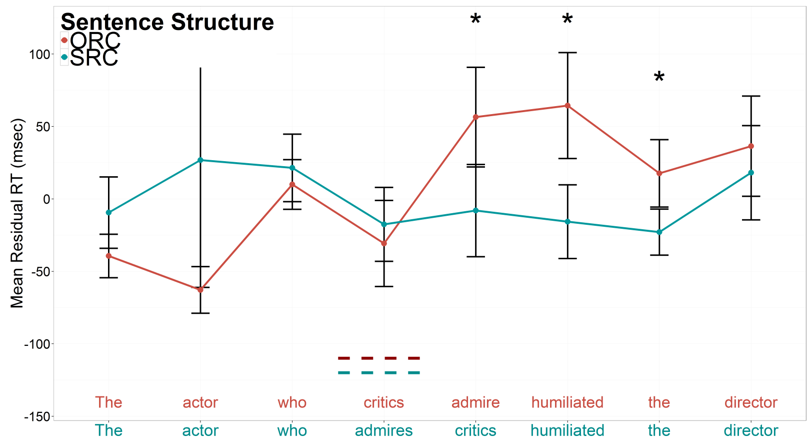
To investigate the effect of the two pseudoword conditions on residual reading times, we again used linear mixed-effects models. For the two target sentences, we fitted models that predicted residual reading times at each word position using a 3-level condition factor (congruent pseudoword, incongruent pseudoword, no pseudoword) and random intercepts for Subject and Item. These models compared the two pseudoword conditions against the no pseudoword cases. Moreover, we fitted additional models at all word positions to directly compare the congruent and incongruent cases using only data corresponding to pseudoword cases. The data and the results are depicted in Figure 4.10.

For the ORC sentences, both pseudoword conditions caused a reading time slowdown at both embedded positions: embedded noun (congruent: $t = 2.66, p < .01$; incongruent: $t = 4.08, p < .001$), and RC verb (congruent: $t = 2.09, p < .05$; incongruent: $t = 2.13, p < .05$). In addition, when the pseudoword was incongruent, there was a significant reading time penalty at the main verb position ($t = 2.90, p < .01$), possibly indicative of a greater processing cost associated with incongruent morphology. However, direct comparisons between the two pseudoword conditions revealed no significant differences at any point in the sentence.

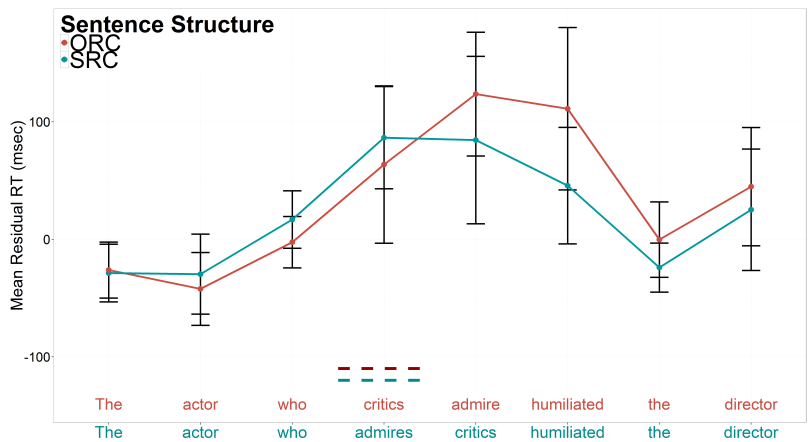
For the SRC sentences, both pseudoword conditions caused a reading time slowdown at both the embedded positions as well as the main verb: embedded noun (congruent: $t = 2.20, p < .05$; incongruent: $t = 2.54, p < .05$), RC verb (congruent: $t = 3.90, p < .001$; incongruent: $t = 5.11, p < .001$), and main verb (congruent: $t = 2.12, p < .05$; incongruent: $t = 2.52, p < .05$). Once more, direct comparisons between the two pseudoword conditions revealed no significant differences at any point.

4.5.3 Discussion

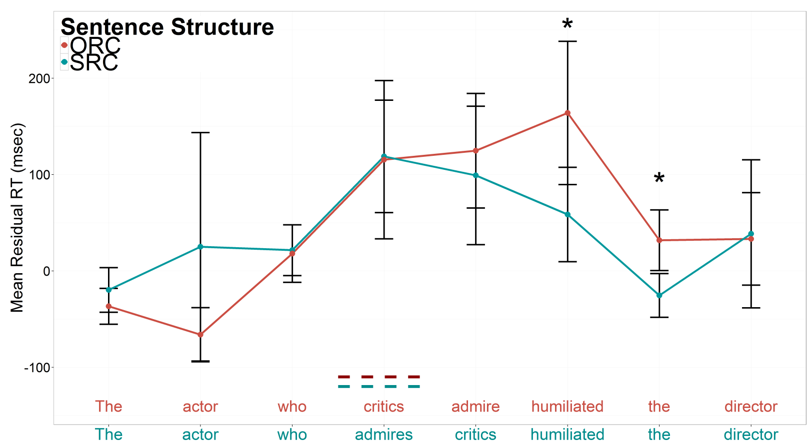
This study was designed to answer one specific question: if syntactic information is missing or ambiguous, is morphological information used to guide sentence processing? As we argued



(a) No Pseudoword

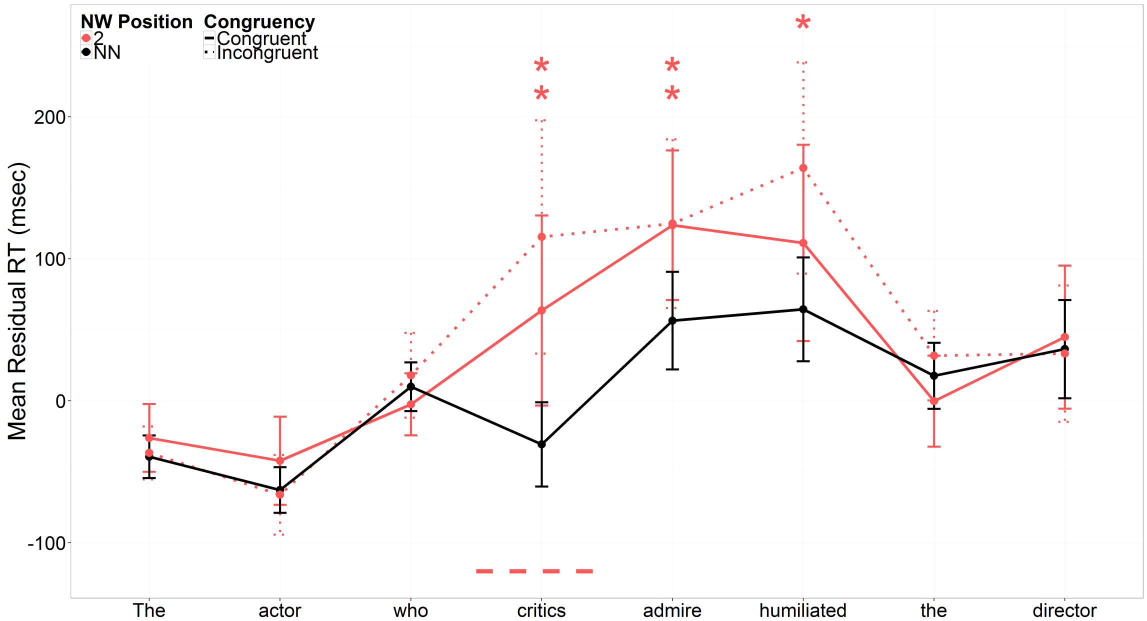


(b) Morphologically Congruent Pseudoword

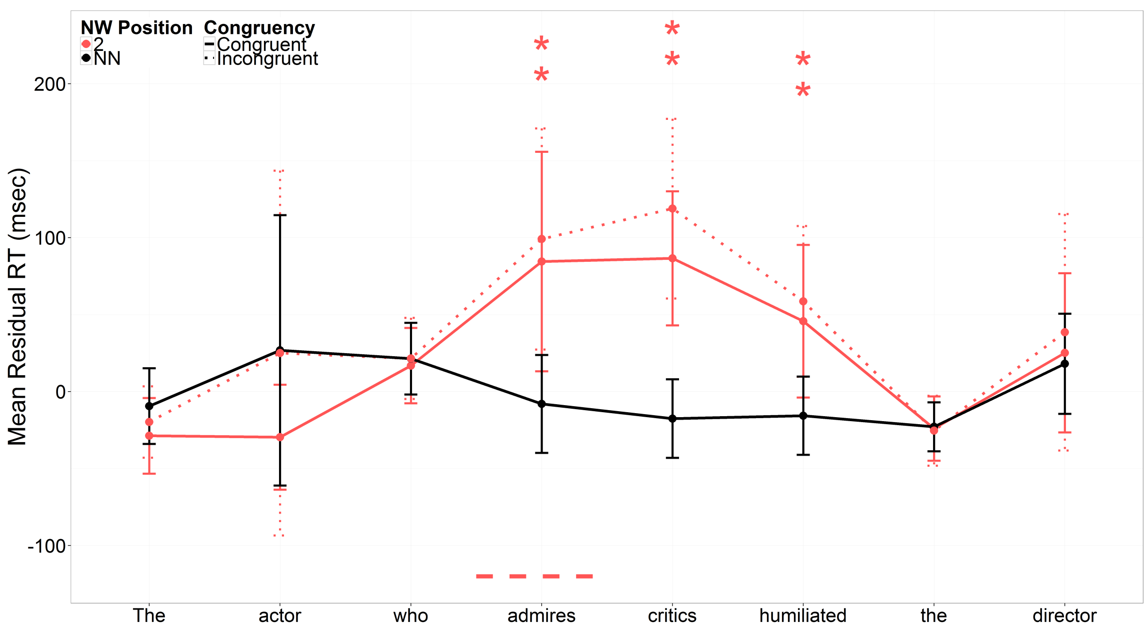


(c) Morphologically Incongruent Pseudoword

Figure 4.9: Line graphs depicting aligned comparisons between ORCs and SRCs in Experiment 6. Error bars represent confidence intervals, and asterisks indicate significant differences.



(a) Object-extracted relative clauses



(b) Subject-extracted relative clauses

Figure 4.10: Line graphs depicting residual reading times for the two pseudoword conditions and the regular sentences in Experiment 6. Error bars represent confidence intervals. Asterisks indicate significant differences between the corresponding position conditions and the no-pseudoword condition.

in the beginning of this section, if morphological information can guide sentence processing, we expect to see a local garden-pathing when morphological content on a pseudoword is inconsistent with the syntactic structure of the sentence. For example, consider the following sentence, *The actor who moldicians critics impressed the director.* At the pseudoword *moldicians*, the available syntactic information is inadequate to identify the right syntactic category of the word. The morphological information on the word itself suggests it is more likely to be a noun than a verb (based on our findings from Experiment 5). Thus, if morphological information can guide sentence processing, we expect the processor to assume it is parsing an object-extracted relative clause sentence, such as *The actor who moldicians like impressed the director.* If that were the case, we expect the processor to be garden-pathed at the next word, *critics*, because it is inconsistent with the object-extracted interpretation.

Contrary to this prediction, our data indicates that for both the morphologically congruent and incongruent cases, there is a greater processing difficulty at words immediately following the pseudoword. Additionally, we found no evidence of any difference between the morphologically congruent and incongruent cases at any position in the two types of relative clause sentences. On the whole, this suggests that even in the absence of unambiguous syntactic information, morphological information does not guide syntactic processing. Moreover, our results indicate that instead of relying on morphological information from unknown words, and hence uncertain input, the sentence processor seems to wait for more reliable information. This would be consistent with the heightened processing difficulty that we observed at words following the pseudowords.

Some evidence for a possible effect of morphological incongruency comes from our accuracy data. Overall, participants were equally good at comprehension questions irrespective of the morphological information on the pseudowords. However, we found a significant interaction between morphological congruency and sentence structure. Curiously, there was a structural effect on comprehension question performance only when morphological information on the pseudowords was incongruent with the syntactic structure. This pattern was also observed in our aligned comparisons of the reading time data. While participants seem to be slower in general for ORC sentences, we found significant difference at the main verb position only when the pseudowords were morphologically incongruent (see Figure 4.9).

We suspected that these unexpected results might be linked with the unusually low accuracy of our participants. Recall that 10 out of 30 participants responded with an accuracy of lower than 70% on all trials, or 60% on target trials. We repeated all the analyses with data from those 10 participants removed. Once more, only sentence structure had any significant effect on comprehension question performance. We no longer found any significant interaction between morphological congruency and sentence structure for the accuracy data. Moreover, our aligned comparisons indicated significant reading time effects at the main verb position for both the congruent and incongruent conditions. Taken together, these results seem consistent with our suspicion that participants' low accuracy might be linked with the differences between the two congruency conditions. This further weakens the only evidence we had for an effect of morphology on sentence processing.

In the next section, we wrap up this chapter by bringing together findings from all four experiments. Also, we discuss the implications of our findings and attempt to connect them with previous work.

4.6 General Discussion

To summarize, we presented four experiments where the goal was examining what linguistic factors—specifically, syntactic and morphological—guide processing of sentences that contain unknown words. In three experiments, we used a self-paced reading paradigm to measure processing difficulties at each word in various sentences, where several sentences contained unknown words. In two of those experiments, we manipulated the morphological content on those unknown words, such that half the cases were morphologically incongruent with the surrounding syntactic context. This allowed us to evaluate the relative importance of the two sources of information by addressing the following question: in case of a disagreement between syntax and morphology, what wins?

4.6.1 Syntax

On the whole, our results seem to strongly suggest that syntactic information is predominantly used in guiding processing of sentences containing unknown words. In Experiment 3, we saw that when pseudowords were present in certain syntactic positions (specifically, the main verb position), they did not significantly disrupt sentence processing. Moreover, for some positions, any disruption in processing was transient and quickly disappeared, whereas, for certain other positions, the processing difficulties carried over through some of the following words (as in position 2 of SRCs, see Figure 4.3b). Furthermore, in Experiments 4 and 6, we found no consistent effect of morphological incongruency. In turn, this further highlights the important role of syntactic information in deciphering unknown words.

How do our findings relate to previous work on comprehension of relative clauses? In Section 2.2.3, we discussed three categories of psycholinguistic models that have previously been used to explain processing of relative clause sentences. Let us first consider models that are based on semantic and pragmatic factors. These models rely on semantic factors, such as *givenness* and animacy, to explain general differences between ORC and SRC sentences. For example, some researchers have argued that ORCs tend to have more familiar embedded NPs whose main purpose is to ground the less familiar extracted NP in discourse (Gordon and Hendrick, 2005). However, as we saw from all 3 reading experiments, having unknown, and thus unfamiliar, embedded NPs does not change the overall pattern of results (see Figures 4.2, 4.5, and 4.9).

The role of animacy has also been used to explain the differences between the two relative clause sentences by several researchers (Gennari and MacDonald, 2008, 2009; Mak et al., 2002, 2006; Traxler et al., 2002, 2005). As mentioned earlier, Lowder and Gordon (2012) found that ORCs that have an inanimate embedded NP are harder to process than ORCs with an animate embedded NP. Thus, sentences like, *The director that the movie pleased received a prize*, tend to be harder to process than sentences like *The director that the actor pleased received a prize.* Technically, one could argue that because pseudowords are semantically vacuous, they are neither animate nor inanimate. Consequently, it is difficult to use our data to argue either for or against the animacy hypothesis. As we can see from Figure 4.3a, our results from Experiment 3 seem to suggest that having pseudowords as embedded NPs does not disrupt processing any more so than having animate embedded NPs. However, in Experiment 4, we found a much more significant disruption due to the presence of pseudowords in the embedded NP position (see Figure 4.6a). Overall, it is unclear whether pseudowords should be treated as animate or inanimate entities, and our data are unable to provide a definitive answer.

The second class of models that have been used to explain ORC/SRC differences are based on working memory constraints. Fundamentally, these models tend to be "backward-looking," and suggest that at each word, the processing difficulty is some measure of how far back in the memory one has to go before the word can be integrated with the preceding structure. For example, in an early proposition, Miller and Chomsky (1963) suggested that ORCs tend to be more difficult to process because the extracted NP must be held in memory across several intervening words. A similar argument is made in Gibson's (1998; 2000) dependency locality theory (DLT) which suggests that the processing difficulty at any word is a function of the number of intervening discourse referents (such as, indefinite NPs) between that word and the head word that it integrates with. Thus, according to the DLT model, ORCs are harder to process because at the relative clause verb, the embedded NP intervenes between the verb and the extracted NP. Likewise, the memory and retrieval model by Lewis and colleagues (Lewis and Vasishth, 2005; Lewis et al., 2006) suggests that the higher processing difficulty for ORCs is a result of lower activation of words that need to be retrieved for integration with the relative clause verb.

Because of the backward-looking nature of these models, one would expect any lexical information available on the word to have some influence on structural integration and sentence comprehension. If at every word, the parser has to retrieve suitable content from memory, it must first determine what the word is and what must be retrieved. In terms of syntactic processing, determining what a word is essentially means determining the syntactic category of that word. Because these models are backward-looking, the preceding syntactic context does not help determine what the word is. Rather, lexico-morphological information is the only thing that can be used.

For example, contrast the following two sentence: *The actor who the director (that) critics like admired pleased the audience* and *The actor who the director (that) croticians like admired pleased the audience*. The crucial difference is at the underlined positions. Now, both sentences are examples of doubly-nested center-embedded relative clause sentences, where there are two relative clause phrases nested within each other. At the critical words, *critics/croticians*, the parser needs to recognize that these words are nouns and cannot be integrated with the preceding structure. The only way that the parser can determine that the word *croticians* is a noun is by using the morphological information present on it.

Essentially, all working memory-based models suggest that morphological information present on pseudowords must be used if the word is to be correctly integrated with the rest of the sentence. From our experiments, we know that these pseudowords can be correctly integrated, because participants can answer comprehension questions based on them. Moreover, for some pseudoword positions, we saw that there are no reading time differences at subsequent words, suggesting that sentence processing recovered quickly. However, contrary to predictions of memory-based models, we did not find any difference between morphologically congruent and incongruent pseudoword cases. Thus, taken together, our results do not seem to support such memory-based models. A fairer conclusion would be that our results do not favor models that are solely backward-looking and do not allow syntactic context to interact with lexical processing.

The third class of models used to explain relative clause processing highlight the role of experience in processing sentences. These models tend to be expectancy-based and associate processing differences with structural frequencies. The fundamental argument is that frequently-occurring structures tend to be easier to process than less frequent structures. Contrary to memory-based models, frequency-based models tend to be "forward-looking," and explain processing difficulty at any word as being a function of how unexpected the word is in a given context (Hale, 2001, 2003, 2006; Levy, 2008a).

This forward-looking nature of these models also makes them the most favorable when it comes to explaining our results. As our results have shown, it is the syntactic information, and not any lexico-morphological information, that guides processing of unknown words. In absence of any reliable information present on a word, it seems sensible that the preceding context is used to determine what the word might be.

As we discussed earlier, one issue with frequency-based models is that they make incorrect predictions about the localization of processing difficulties. Contrary to a host of behavioral findings, these models predict greater difficulty in ORCs to be at the embedded NP and not the relative clause verb (see, Levy, 2008a). Like several other researchers, our results also indicate greatest processing difficulties at the two verb positions, thus contradicting the predictions of frequency-based models.

The answer seems to be a model that is both forward-looking and backward-looking. An ideal model should be able to account for integration effects, such as those explained by memory-based models, while allowing preceding context to influence lexical processing. A similar argument was made by Staub (2010). The results from their eye-tracking studies indicated that neither memory-based models nor frequency-based models can adequately account for behavioral data. Likewise, corpora analyses by Demberg and Keller (2008) found that processing costs from *dependency locality theory*, a memory-based model, and *surprisal*, a frequency-based model, tend to be uncorrelated. Moreover, their results suggested that behavioral data can be fully accounted for only by combining the two models.

One attempt at unifying memory-based and frequency-based models has been made by Demberg and Keller (2008, 2009). Their *Psycholinguistically Motivated Tree Adjoining Grammar* parser (or PLTAG) measures difficulty at a word as being proportional to the inverse probability of all structures that need to be integrated plus the probability of all structures that need to be discarded after encountering that word. They incorporate memory-based effects by adding a decay function which is calculated under the assumption that older structures are harder to integrate than recently-accessed structures. Their evaluations have found PLTAG to be better adept at modeling RC processing differences than either surprisal or DLT (Demberg and Keller, 2009). PLTAG certainly seems the right step forward, however only further studies can determine whether how generally applicable it is.

A separate issue is being able to account for unknown words. Most sentence processing models assume a pre-existing lexicon that maps words to their syntactic categories, which may not necessarily be a one-to-one mapping. Only recently have researchers attempted to develop models that are capable of handling input uncertainty (e.g., Levy, 2008b, 2011). Section 2.1 presents an overview of such models.

However, even these so-called noisy-channel models assume a known lexicon. The current version of the noisy-channel model uses weighted finite-state automata to allow characters to be inserted and deleted from within any word in a sentence (see Levy, 2011). Thus, for a fixed lexicon, {*it, hit, him*}, and an input, *it hit...*, the parser considers the possibility that *it hit* was meant to be *hit him*, but was distorted due to perceptual noise. It is clear that having a fixed lexicon allows the problem to be slightly more computationally tractable. Theoretically, similar approaches can be taken to parse sentences containing unknown words. For example, on encountering an unknown word, perhaps we could find words that look similar to it and substitute them instead. Thus, in *the boy kipped the girl*, we could substitute the word *kissed* for *kipped* and then parse the sentence. In Section 5.1 we evaluate similar models to see if they can capture our data.

4.6.2 Morphology

Unlike the strong support for syntactic information, evidence in favor of morphological information during processing of sentences containing novel words seems to be mixed. In Experiment 4, we found a significant processing difficulty between the morphologically congruent and incongruent cases only when syntactic information was insufficient to determine the syntactic category of the pseudowords (*The actor who* PSEUDOWORD *the critic humiliated the director*; see shaded region in Figure 4.6b). Some evidence indicating processing differences between the congruent and incongruent cases came through differences in the length of the spillover region. For both types of relative clause sentences, we observed a reading time slowdown for a greater number of words following incongruent pseudowords than congruent ones. Possibly, this might be indicative of a greater processing load when parsing such cases. However, as Figure 4.6 shows, despite statistical significance these spillover regions do not stand out as being particularly conclusive. As always, there is a danger of mistakenly assuming statistical variance to be theoretically relevant.

Experiment 6 presented a more explicit evaluation of any effect of morphological information in sentence processing by using tightly constrained sentence constructions and pseudowords. We argued that if morphological information is used, we would observe a syntactic garden-path, with incongruent morphology guiding the sentence processor to an incorrect interpretation. Contrary to our prediction, we could not find any evidence suggesting a garden-path. In both the morphologically congruent and incongruent cases, our data instead indicates that the sentence processor prefers waiting for reliable syntactic information over any, more immediate, morphological information.

Thus, taken together, our reading time data fails to provide consistent support for any influence of morphology on sentence processing. Could it be that people are unable to extract morphological information out of pseudowords? Our third experiment examined that question by asking participants to determine the syntactic category of various pseudowords that differed in the number and type of suffixes on them. We found that participants are capable of correctly determining the syntactic category of pseudowords using only the morphological information on them. Moreover, we found that some suffixes act as stronger cues than others. In particular, when we crossed nominal derivational suffixes (-*ist, -er, -or, -ician*) with a verbal inflectional ending (-*ed*), participants were more inclined to say that the pseudowords were verbs than nouns. Clearly, morphological information present on pseudowords can be extracted, used, and even contrasted. Why then is it unable to guide sentence processing?

To the best of our knowledge, ours is the first study that evaluated what happens when derivational and inflectional morphology is inconsistent with the syntactic context. Previous work on morphological effects on sentence processing has predominantly investigated cases of subject-verb agreement violations (e.g., *the boy likes/*like the girl*) where inflectional morphology on the verb is not consistent with the rest of the sentence. Much of the emphasis has been on how agreement-based processes influence sentence production (e.g., Bock and Miller, 1991; Bock and Eberhard, 1993; Vigliocco and Nicol, 1998; Franck et al., 2002; Hartsuiker et al., 2001; Haskell and MacDonald, 2005). In comparison, fewer researchers have examined the factors that influence subject-verb agreement during sentence comprehension.

In one of the earliest studies on agreement processes in sentence comprehension, Pearlmutter et al. (1999) asked participants to read sentences of the following form:

(5) *The key to the cabinet was rusty from many years of disuse.*

(6) *The key to the cabinets was rusty from many years of disuse.*

(7) *The key to the cabinet *were rusty from many years of disuse.*

(8) *The key to the cabinets *were rusty from many years of disuse.*

Here, there is subject-verb disagreement in sentences (7) and (8). Moreover, the grammatical number on the intervening NP (*cabinet*) was manipulated across the four sentence types. Their results indicated that participants were not only responsive to agreement violations, but also displayed processing difficulties due to "apparent violations" caused by a number mismatch between the verb and the intervening NP, such as in (6) and (7). Cases of unmistakable violations, such as (7), were found to be most difficult, however having an intervening NP with the right number feature, as in (8), seemed to ease processing.

A similar pattern of results has also been observed using other measures of sentence comprehension, such as acceptability judgments (Clifton et al., 1999; Häussler and Bader, 2009), eye-tracking (Pearlmutter et al., 1999), and ERP measures (Kaan, 2002). These effects are now known as "agreement attraction" effects, which refers to the seeming failure of agreement matching due to the presence of a nearby, but syntactically inaccessible, distractor. Two major accounts have been proposed to explain agreement attraction. One account argues that agreement attraction effects are caused by faulty representations of NPs due to inherent properties of hierarchically structured representations. Another account suggests that these effects arise due to errors in retrieval of the NP candidates. The fundamental difference between the two accounts is that the former assumes internal inconsistency in NP representations, whereas the latter does not, instead attributing the effect to the access of those representations during sentence comprehension.

The debate between the two accounts is far from settled, however recent work by Wagers et al. (2009) provided evidence against the former view. Using object-extracted relative clause sentences, they found that agreement attraction can occur even if the intervening noun (also known as, "attractor noun") does not intervene between the verb and the subject NP. For example, they used constructions such as:

(9) *The musician who the reviewer praises so highly will probably win a Grammy.*

(10) *The musicians who the reviewer praises so highly will probably win a Grammy.*

(11) *The musician who the reviewer *praise so highly will probably win a Grammy.*

(12) *The musicians who the reviewer *praise so highly will probably win a Grammy.*

Here, the subject NP is the embedded noun, *reviewer*, whereas the attractor noun is the subject of the main verb, *musician(s)*. Thus, sentences (11) and (12) have a subject-verb agreement violation at the verb *praise*. Unlike (11), (12) additionally has an agreement between the verb and the attractor noun. Wagers et al. found heightened processing difficulty at words following the critical verb (e.g., *so highly*) only when both the subject NP and the attractor noun were mismatched, as in (11).

They argue that their results contradict theories that attribute agreement attraction to faulty representations. Their argument hinges on their finding that attraction can occur even when the attractor noun does not linearly or structurally intervene between the subject and the verb. This rules out any possibility of structural representations influencing representations of NPs. Instead, they argue in favor of the second class of theories which suggest agreement attraction effects may be caused due to retrieval errors.

What do these findings tell us about any influence of morphological information on sentence comprehension? Consider the four sentences used by Wagers et al. (2009). Like us, they found that incongruent morphological information on a verb does not always trigger processing difficulties. Critically, when reading times for ungrammatical cases, such as (12), were compared with grammatical cases, such as (9) and (10), no differences were found at any word position. In general, agreement attraction effects suggest that preceding sentential context heavily influences processing of sentences in which morphological and syntactic information are incongruent. Consistent with our results, these findings also indicate that incongruent morphological information does not always disrupt sentence processing.

Cases of number violations, such as subject-verb agreement violations, as well as tense violations, e.g., *The man will work/*worked on Tuesday*, revolve around improperly used inflectional morphology. At the time of writing this dissertation, we were unable to find any work which investigated how sentence processing is affected if derivational morphology is improperly used. Our results seem to indicate that derivational morphology is unable to guide sentence processing towards a specific interpretation (see Experiment 6). Moreover, we found that when a nominal derivational suffix and a verbal inflectional suffix are present on a word, participants are more inclined to call it a verb than a noun. At least for nouns and verbs, this indicates that inflectional morphology is a stronger cue than derivational morphology.

4.6.3 Summary

To conclude, our results indicate that morphological information is not reliable, and thus is not consistently used to process sentences. Moreover, our findings highlight an important role of syntactic information in processing unknown words, and make a strong case for sentence processing models which combine memory-based and frequency-based approaches. Going forward, the critical challenge is to develop models that are capable of processing unknown words.

5. Further Discussion

"Why, sometimes I've believed as many as six impossible things before breakfast."

— Lewis Carroll, *Through the Looking-Glass*

In this chapter, we carry forward the discussion from the previous chapter. Specifically, we address the following two questions that our findings have raised: 1) How can we extend existing models of sentence processing to handle unknown words? 2) Why is morphological information unable to guide processing of unknown words? In Section 5.1, we propose and evaluate two sentence processing models capable of handling novel words. In Section 5.2, we perform corpora analyses to investigate why morphological information is so easily ignored.

5.1 Noisy Sentence Processing

Here, we discuss two extensions to the *surprisal* model (Hale, 2001; Levy, 2008a) to capture processing of sentences containing unknown words. Like Levy (2008b, 2011), we use surprisal as the baseline model because it facilitates an explicit evaluation of our extensions. Unlike some other, arguably more effective, models of sentence processing, the surprisal model can be implemented and extended easily. For example, the dependency locality theory (Gibson, 2000) can be used to qualitatively model processing difficulties in various sentences, but does not provide explicit, quantitative measurements. On the other hand, with surprisal, we can estimate the amount of predicted processing difficulty quantitatively.

However, as discussed earlier (see Section 2.2.3), the surprisal model is unable to effectively capture behavioral data on relative clause processing. While the model does predict greater difficulty for object-extracted relative clause sentences, it makes incorrect predictions about the exact locality of the processing difficulties. Because of this limitation, the models presented here are best viewed as suggestions for development of "noisy" sentence processing models.

5.1.1 Baseline

We start with the description of the baseline model. The baseline model is our implementation of the surprisal model, which quantifies processing complexity at each word as the negative log-probability of the word given the preceding context:

$$\text{Complexity}(w_i) \propto -\log P(w_i | w_{1 \ldots i-1}, \texttt{CONTEXT})$$

In other words, the surprisal model measures processing complexity as a function of how unexpected a word is given a certain context.

Our implementation is similar to Hale's (2001), who used a stochastic Earley parser (Stolcke, 1995) to compute surprisal scores. Essentially, the surprisal model is a probabilistic parser which computes prefix probabilities at every word. Subsequently, the surprisal value at a word is computed as log of the ratio of the prefix probability until the preceding word to the prefix probability until the current word. That is,

$$\text{surprisal}(w_i) = \log \frac{\texttt{PreProb}(w_1 \ldots i-1)}{\texttt{PreProb}(w_1 \ldots i)}$$

For example, consider the sentence, *the boy kissed the girl.* The surprisal score at *kissed* is given as:

$$\log \frac{\texttt{PreProb}(\textit{the boy})}{\texttt{PreProb}(\textit{the boy kissed})}$$

A more detailed description of the algorithm with details on how to compute the prefix probabilities is provided by Hale (2001) and Stolcke (1995).

We evaluated our implementation of the surprisal model by computing surprisal values at each word in our target relative clause sentences from Experiment 3. We used a grammar similar to the one used by Hale (2001) in their evaluation of relative clause sentences:

S	→	NP VP	[1.0]
NP	→	NP SBAR	[0.148903581549]
NP	→	DT NN	[0.851096418451]
SBAR	→	WP VP	[0.8870863075924724]
SBAR	→	WP S/NP	[0.1129136924075276]
S/NP	→	NP VP/NP	[1.0]
VP/NP	→	VB	[1.0]
VP	→	VB NP	[1.0]

The probabilities of each rule in the grammar were computed by counting the proportion of occurrence of each rule in the Wall Street Journal corpus in the Penn Treebank (Marcus et al., 1993). Moreover, the estimates for the two SBAR rules were obtained by counting the proportion of subject-extracted relative clause in the corpus. Our lexicon comprised all words used in the target sentences. We obtained frequency measures of the words relative to their part-of-speech categories (here, NN, VB, DT, or WP) using the SUBTLEXus corpus (Brysbaert and New, 2009) which contains frequency measures of 51 million words from American movie subtitles. Those measures were subsequently normalized to obtain probabilities for all pre-terminal rules in the grammar (e.g., NN → *boy* [0.0296246703499]).

Given this grammar, we computed surprisal scores for every word in all target relative clause sentences from Experiment 3. An aligned graph depicting the mean surprisal scores the two relative clause sentence types is shown in Figure 5.1. As the graph shows, the model correctly predicts greater difficulty for ORC sentences. However, it localizes that difficulty at the determiner in the embedded noun phrase (*the* of *the critic*). This is consistent with Levy's (2008a) argument (see Section 2.2.3) as well as the computational evaluation performed by Hale (2001).

One concern with the surprisal model has always been the importance of selecting the right grammar. The fundamental argument behind frequency-based models, such as surprisal, is that experience-based prior grammatical knowledge is what determines processing complexity. Thus, the underlying grammar along with the corpus used to determine

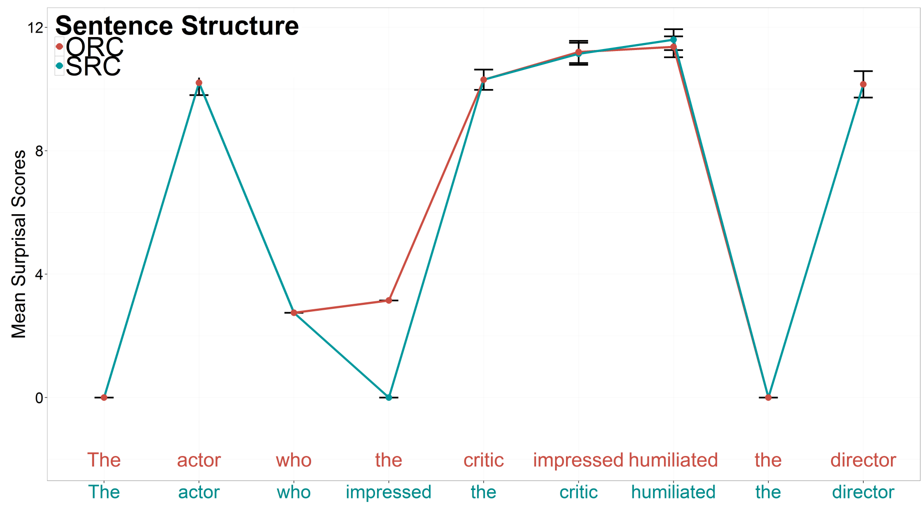


Figure 5.1: Line graph depicting aligned mean surprisal scores for the ORC and SRC sentences in Experiment 3.

the probabilities of the rules in the grammar are crucial. We evaluated how sensitive the model is to changes in the grammar by performing another test with a more comprehensive grammar. Specifically, we used a grammar which covered not only our target relative clause sentences, but also the filler sentences that were used in Experiment 3.

S	→	NP VP	[1.0]
NP	→	NP PP	[0.503806351096]
VP	→	VB NP	[0.210699917539]
NP	→	NP SBAR	[0.0738850114634]
PP	→	IN NP	[0.96232210731]
VP	→	VB PP	[0.1843874159776]
VP	→	VP PP	[7.49643919138e-05]
NP	→	DT NN	[0.42230863744]
PP	→	IN S	[0.0346283037214]
VP	→	VB	[0.0746395462155]
SBAR	→	WP VP	[0.86864638]
SBAR	→	WP S/NP	[0.13135362]
S/NP	→	NP VP/NP	[1.0]
VP/NP	→	VB	[1.0]
VP	→	VB NP PP	[0.0563232464579]
VP	→	AUX VP	[0.409830330593]
PP	→	IN VP	[9.94431185362e-05]
PP	→	IN	[0.00295014584991]
VP	→	VP CC VP	[0.0640445788251]

As before, we computed the probabilities of each rule by counting their frequency in the Wall Street Journal corpus. The lexicon now included words present in the filler sentences, and the probabilities of the pre-terminal rules were computed using the SUBTLEXus corpus. The mean surprisal data is shown in Figure 5.2

The most prominent difference between the two sets of data is the increased surprisal score at the main verb position (*humiliated*) for the SRC sentences. Essentially, the model predicts that for SRC sentences, there should be a heightened processing difficulty at the main verb position. However, we know from behavioral data that this prediction is incorrect. In fact, the difference goes in the opposite direction. Basically, this highlights the importance of defining “experience” correctly.

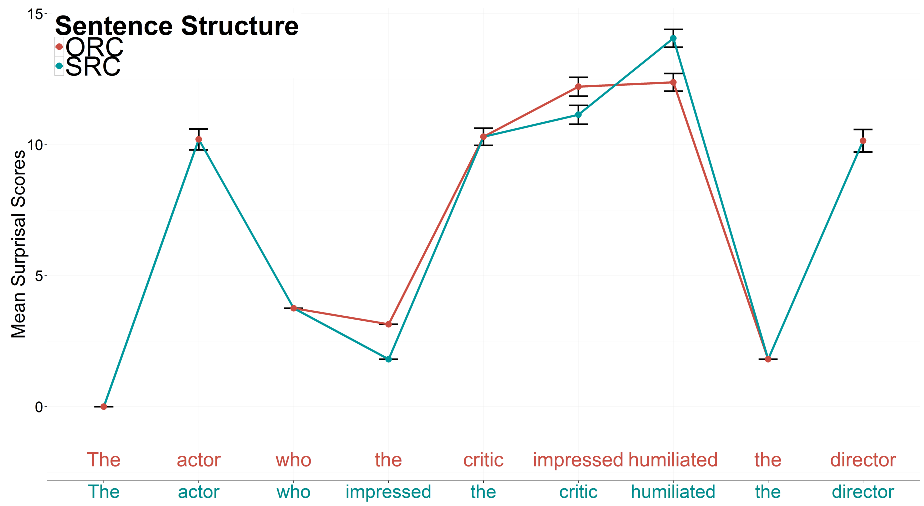


Figure 5.2: Line graph depicting aligned mean surprisal scores for the ORC and SRC sentences in Experiment 3. The grammar used to compute the surprisal scores covered both the target and the filler sentences.

5.1.2 Edit Distance Model

The first model we evaluated is perhaps the simplest. On encountering an unknown word, the model uses *edit distance* to find and substitute the nearest known word in its place. Edit distance is essentially the number of changes required to go from one string to another. For example, the edit distance between `edit` and `dist` is 2: first, `e` is removed (`edit` → `dit`), and second, `s` is inserted between `i` and `t` (`dit` → `dist`). In our implementation, we used *Levenshtein distance* to measure edit distance, which counts the minimum number of insertion, deletion, and substitution operations required to transform one string to another. While other measures of edit distance also exist, we chose Levenshtein distance because others have used it in their noisy-channel models of sentence processing (e.g., Levy, 2008b, 2011).

In Levy's (2011) implementation of the noisy-channel model, they computed a weighted finite state automaton where Levenshtein distance was used to measure the cost associated with inserting, deleting, or substituting words in a sentence. For example, given a phrase, *it hit*, their model considered the possibility of the phrase being *hit him*. Here, one possibility is that the first word is missing an *h*, and the second has a *t* in place of an *m*. In their model, the cost of word substitution falls exponentially with the Levenshtein distance between the two words. Moreover, the cost of insertion and deletion operations falls exponentially with word length. While their model considers the possibility of having a noisy input, it is constrained in having a limited lexicon. Thus, in its current implementation, it only processes sentences that contain words from a fixed lexicon.

Our model carries forward their idea. When the processor encounters an unknown word, it searches through a large lexicon to find the word that is closest to it using Levenshtein distance as the measure of closeness. In case of ties, the most frequently occurring word is selected, essentially making an assumption that more frequent words are more readily accessible.

Like before, our model was a stochastic Earley parser that computes prefix probabilities at each word in a given sentence. The grammar again comprised rules capable of covering both the target and the filler sentences in Experiment 3. The rules of the grammar were weighted using the Wall Street Journal corpus. The grammar is presented here:

S	$\rightarrow$	NP VP	[1.0]
NP	$\rightarrow$	NP PP	[0.503806351096]
VP	$\rightarrow$	VB NP	[0.210699917539]
NP	$\rightarrow$	NP SBAR	[0.0738850114634]
PP	$\rightarrow$	IN NP	[0.96232210731]
VP	$\rightarrow$	VB PP	[0.1843874159776]
VP	$\rightarrow$	VP PP	[7.49643919138e-05]
NP	$\rightarrow$	DT NN	[0.42230863744]
PP	$\rightarrow$	IN S	[0.0346283037214]
VP	$\rightarrow$	VB	[0.0746395462155]
SBAR	$\rightarrow$	WP VP	[0.86864638]
SBAR	$\rightarrow$	WP S/NP	[0.13135362]
S/NP	$\rightarrow$	NP VP/NP	[1.0]
VP/NP	$\rightarrow$	VB	[1.0]
VP	$\rightarrow$	VB NP PP	[0.0563232464579]
VP	$\rightarrow$	AUX VP	[0.409830330593]
PP	$\rightarrow$	IN VP	[9.94431185362e-05]
PP	$\rightarrow$	IN	[0.00295014584991]
VP	$\rightarrow$	VP CC VP	[0.0640445788251]

The critical difference between the baseline model and this model was the lexicon. Unlike the baseline model, the lexicon of this model included the pseudowords that were used in Experiment 3. Initially, the weights of the regular words were computed using the SUBTLEXus corpus like before. Subsequently, for every pseudoword, we obtained the probability of a preterminal (i.e., NN, VB, etc.) producing that word by finding the most frequent nearest word among all words in the SUBTLEXus corpus. The probability of the pseudoword was then taken as the probability of the nearest word times a weight that decreased exponentially with the square of the Levenshtein distance.

For example, consider some pseudoword, w. To measure the probability of it being a noun (i.e., P(NN $\rightarrow w$)), the model first finds the most frequently-occurring nearest noun, say w'. Then, the model estimates the probability of w being a noun using the probability of w' being a noun:

$$P(\text{NN} \rightarrow w) = P(\text{NN} \rightarrow w') * \exp(-\mathcal{N}(\texttt{Leven}(w, w')^2, \gamma)) \tag{5.1}$$

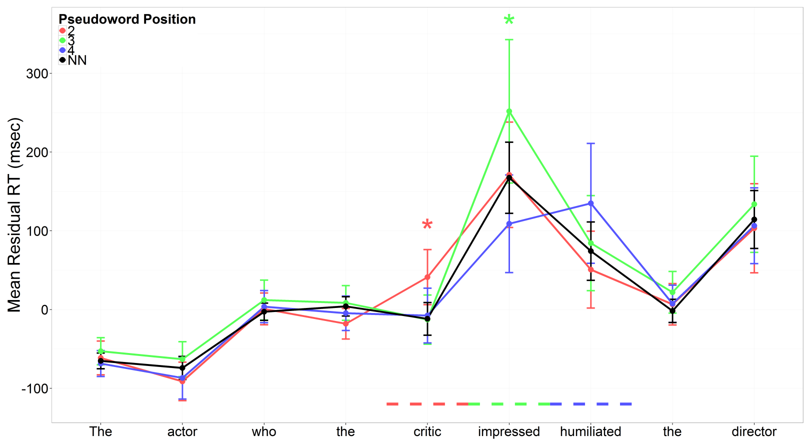
Here, γ is a noise parameter which we varied in our evaluations. When $\gamma = 0$, there is no noise, so the expression inside the exponential function is always the square of the Levenshtein distance. Increasing γ increases the amount of noise, essentially modeling the uncertainty in the mental lexicon.

In our first set of evaluations, we computed the surprisal scores for all target items, including sentences containing pseudowords, in Experiment 3. The results of our evaluations are shown in Figures 5.3 & 5.4. Figures 5.3a & 5.4a depict the behavioral data from Experiment 3, whereas the other graphs depict mean surprisal scores from the model with different noise parameters.

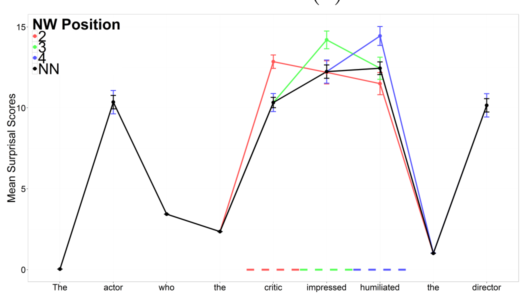
The critical comparison is not between the overall shapes of the curves. Instead, it is at the specific position of the unknown words (highlighted by the respective colors in the graphs). The data indicates that substituting nearest words for unknown words predicts a heightened processing difficulty at all positions. Syntactic context appears to not have any influence on the predicted difficulty associated with unknown words. Moreover, increasing the amount of noise in the model does not change this prediction.

We repeated the evaluations with sentences from Experiment 4. The only change in the model was a revision to the lexicon to reflect the new vocabulary. Like before, the probabilities of known words were measured using SUBTLEXus. Next, the probabilities of unknown words were estimated using the formula described in equation 5.1. The data from our evaluations are shown in Figures 5.5 & 5.6. Figures 5.5a & 5.6a present behavioral data from Experiment 4, whereas the other graphs show model predictions for different noise parameters.

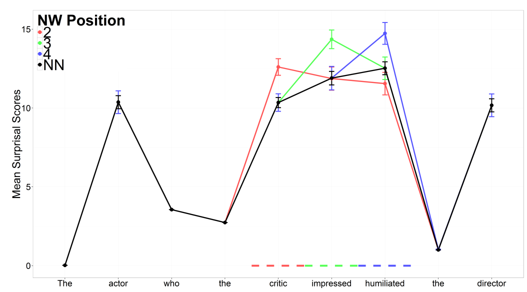
Once again, we find that the model predicts greater processing difficulty at all pseudoword positions. Moreover, the model predicts differences between the two morphological congruency conditions, with morphologically incongruent pseudowords predicted to



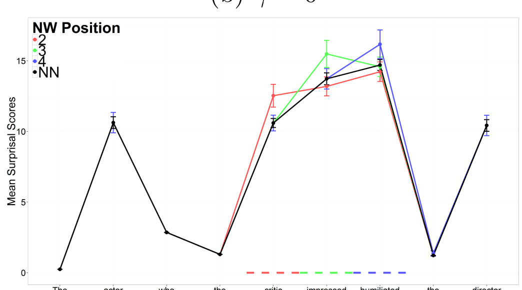
(a) Behavioral data from Experiment 3.



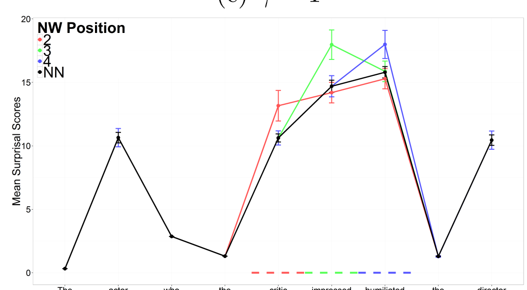
(b) $\gamma = 0$



(c) $\gamma = 1$

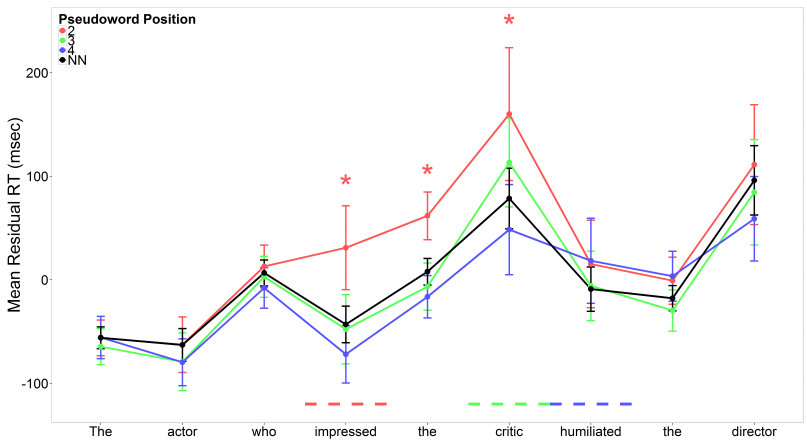


(d) $\gamma = 2$

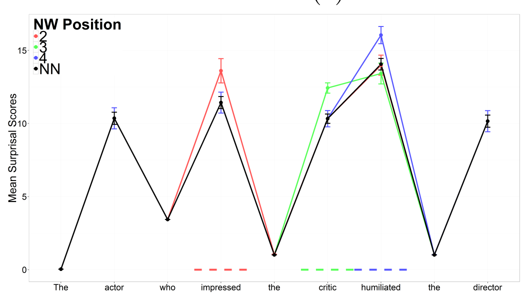


(e) $\gamma = 3$

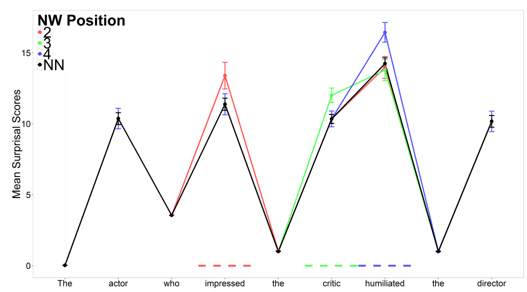
Figure 5.3: Line graphs depicting predictions of the Edit Distance model in processing ORC sentences from Experiment 3. NN = no nonsense word. Error bars represent confidence intervals.



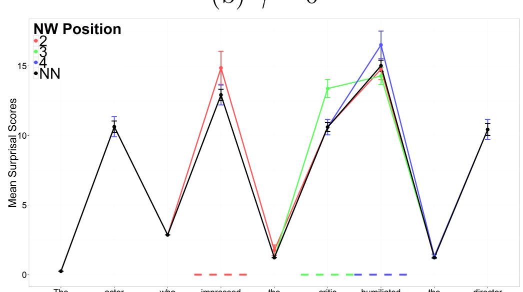
(a) Behavioral data from Experiment 3.



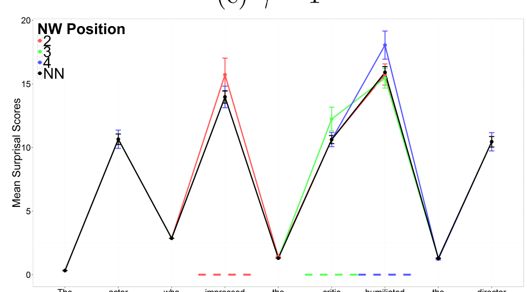
(b) $\gamma = 0$



(c) $\gamma = 1$

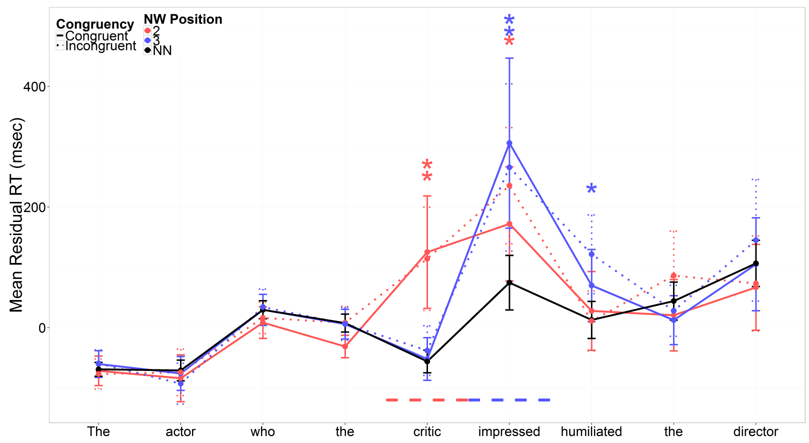


(d) $\gamma = 2$

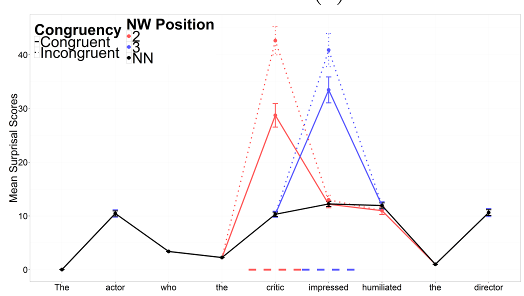


(e) $\gamma = 3$

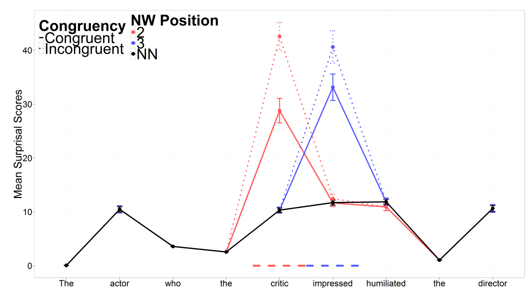
Figure 5.4: Line graphs depicting predictions of the Edit Distance model in processing SRC sentences from Experiment 3. NN = no nonsense word. Error bars represent confidence intervals.



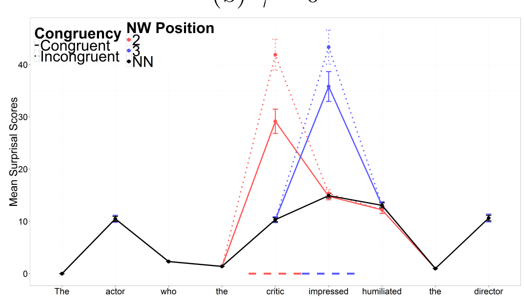
(a) Behavioral data from Experiment 4.



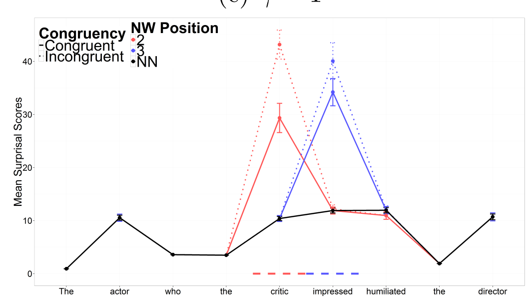
(b) $\gamma = 0$



(c) $\gamma = 1$

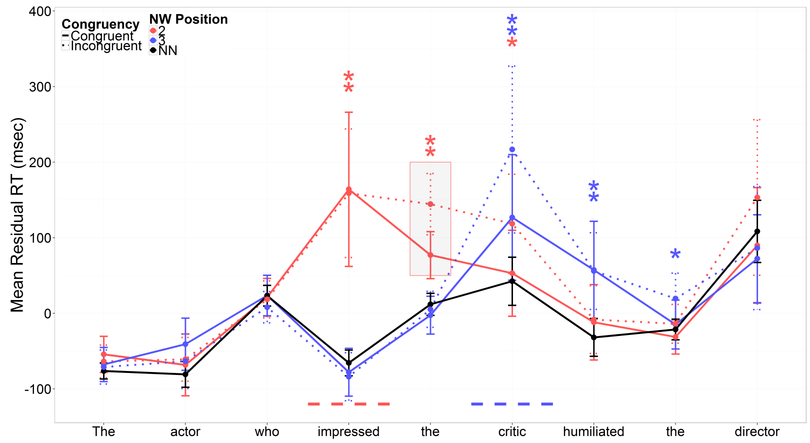


(d) $\gamma = 2$

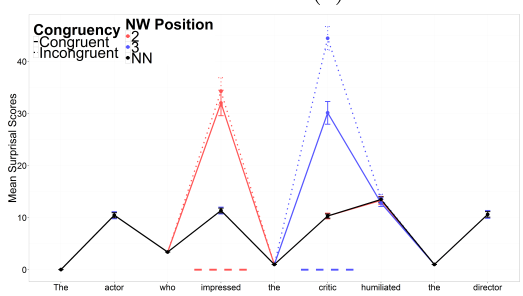


(e) $\gamma = 3$

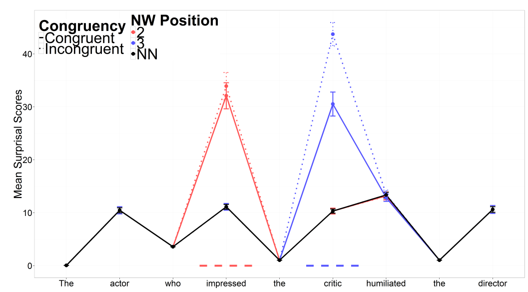
Figure 5.5: Line graphs depicting predictions of the Edit Distance model in processing ORC sentences from Experiment 4. NN = no nonsense word. Error bars represent confidence intervals.



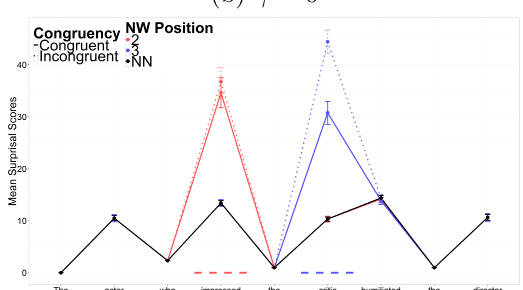
(a) Behavioral data from Experiment 4.



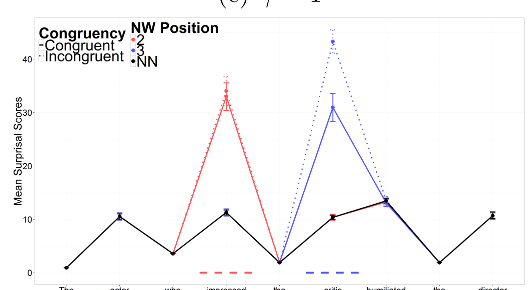
(b) $\gamma = 0$



(c) $\gamma = 1$



(d) $\gamma = 2$



(e) $\gamma = 3$

Figure 5.6: Line graphs depicting predictions of the Edit Distance model in processing SRC sentences from Experiment 4. NN = no nonsense word. Error bars represent confidence intervals.

be harder to process than congruent ones. However, at the syntactically ambiguous position in SRCs (*The actor who impressed the critic humiliated the director*), the model predicts no processing difference between the two congruency conditions.

This completely contrasts with our behavioral data. We did not find any differences between the two congruency conditions at the actual pseudoword positions. Moreover, the only difference that we did find was at the position following the syntactically ambiguous position where the model predicts no difference. Clearly, this model is unable to account for our data.

5.1.3 Bayesian Reader model

Next, we turned to computational modeling work on visual word recognition and lexical detection. Put simply, lexical detection is a task where participants view character strings (e.g., `JUDGE` and `JUPGE`) and determine whether they are real words. Performance is measured as response times and judgments accuracy, and the aim of such studies is to investigate cognitive and linguistic processes involved in reading.

Researchers have proposed several computational models to capture behavioral data, and a recent review of those models is provided by Norris (2013). Arguably, some of the more prominent models are Ratcliff's drift-diffusion model (Ratcliff, 1978; Ratcliff et al., 2004) and Norris's Bayesian Reader (Norris, 2006, 2009; Norris and Kinoshita, 2012). Of the two, Bayesian Reader seems most promising for our purposes of developing sentence processing models capable of handling unknown words because of two reasons. The most appealing feature is its Bayesian nature, which makes integrating it with a probabilistic sentence processing model, such as surprisal, seamless. Moreover, like Levy's (2011) model of sentence processing, it too is based on noisy channel processes from information theory, which make the two approaches fundamentally similar.

Norris's Bayesian Reader

Here, we present a condensed account of the Bayesian Reader model. Further detail is provided in the Appendices of Norris (2006, 2009) and Norris and Kinoshita (2012). Several versions of the model have been proposed, and our implementation is based on the model described in Norris and Kinoshita (2012). Each character string is represented as a concatenation of position-specific letter vectors, each of which is a 27-element binary vector. The first 26 positions of the vector correspond to the 26 letters in the alphabet, and the 27th position corresponds to a null element representing a missing character. All but one positions of the letter vectors are set to 0, and the position corresponding to the letter being represented is set to 1. For example, the letter `c` is represented with 0s in all positions except the 3rd. Thus, a four-letter word is represented as a 108 dimensional vector.

The model assumes the input is noisy, and has to be processed from several independent samples. Each sample is derived by adding a zero-mean Gaussian noise to each coordinate of the input vector. The standard deviation σ of the Gaussian noise is a model parameter, representing perceptual uncertainty. On receiving any sample, the running mean $\bar{x}$ and the standard error σ_M of the samples received so far are computed. The likelihood of each feature (bit-value in the vector), F_j, having a given state (0 or 1) is given as:

$$LF_j = \frac{\exp(-d_j^2 \,/\, 2\sigma_M^2)}{\sigma_M\sqrt{2\pi}}$$

Where,

$$d_j = \bar{x} - F_j$$

Given these feature likelihoods, the model computes the probability of a letter using the product of feature likelihoods. For example, to compute the likelihood of character `c`, the model multiplies the product of likelihoods of 1 in the third position of the bit-vector and 0 everywhere else. These likelihoods are normalized to get probabilities.

$$P(L_x) = \frac{FS_x}{\sum_{i=1}^{i=27} FS_i}$$

$$FS_x = \prod_{j=1}^{j=27} LF_{xj}$$

Lastly, the likelihood of an input string being a word W_x is given as the product of the probabilities of the letters within that word:

$$P(W_x|I) = \frac{P(W_x) \times LS_x}{\sum_{k=1}^{k=N} P(W_k) \times LS_k}$$

$$LS_x = \sum_{i=1}^{i=len(W_x)} P(L_{x_i})$$

Here, $P(W_x)$ is the prior probability of W_x in the lexicon, N is the size of the lexicon, and LS_x is the product of the probabilities of the letters in that word.

To account for the possibility of character insertions and deletions, the model also performs string alignment with words of greater or smaller length. For example, given an input string `SAW`, the model compares it with a word *JIGSAW* in the following manner. First, the length difference is accounted for by padding the string with a null character (the 27th position in the bit-vector). Instead of appending the null characters only at the front or the back of the string, the model considers several possibilities. For example, to compare `SAW` with *JIGSAW*, the model creates 4 strings for comparisons: `###SAW`, `##SAW#`, `#SAW##`, and `SAW###`.

Word likelihood is computed for all aligned strings using the same method as described earlier, and the best likelihood value is selected. In our implementation, we modified the likelihoods by adding an extra penalty for insertion and deletion. Specifically, we multiplied the word likelihoods by 0.1 times the Levenshtein distance between the aligned string and the word. For computational tractability, their model and our implementation only compares the input string with words that differ in length by at most 3 letters.

Finally, for the lexicon decision task, the model determines whether an input string is a word or a nonword by assuming that the sum of the word and the nonword priors is each set to 0.5. The likelihood of the input being a nonword is given as:

$$NL = 1.0 - \sum_{i=1}^{i=N} LS_i$$

Also, the likelihood of the input being a word is given as:

$$WL = \sum_{i=1}^{i=N} P(W_i) \times LS_i$$

Lastly, the probability that the input is a real word is given as:

$$P(word|I) = \frac{WL}{WL + NL}$$

Noisy Sentence Reader

The fundamental idea behind the Bayesian Reader model is that perceptual input tends to be noisy, which is an idea shared by Levy (2011) in their noisy channel model of sentence processing. This similarity between the two approaches eases the integration of the Bayesian Reader model with a surprisal-based approach towards sentence processing. We attempted such an integration using a similar approach as in our Edit Distance model.

Our "Noisy Sentence Reader" was essentially a surprisal model, with a fixed grammar and a lexicon. Critically, we transferred the perceptual uncertainty of the input to the lexicon itself. Thus, we made the assumption that all words of an input sentence can be clearly perceived, however there was uncertainty about what part-of-speech category they belonged too. For example, on reading a word, *actor*, the system needed to determine whether the word was a noun, a verb, or something else.

To compute the likelihood of a syntactic category given an input string, we used the Bayesian Reader model described earlier. For any input string, we computed the likelihood of it being a noun as:

$$NounL = \sum_{W_i \in \texttt{NOUN}} P(W_i|\texttt{NOUN}) \times LS_i$$

Here, $P(W_i|\texttt{NOUN})$ is the prior probability of W_i being a noun, and LS_i is the likelihood of getting the given input from that word. Likewise, we computed likelihoods of all syntactic categories.

For our first set of evaluations, we used a grammar capable of covering both the target and the filler sentences from Experiment 3:

S	$\rightarrow$	NP VP	[1.0]
NP	$\rightarrow$	NP PP	[0.503806351096]
VP	$\rightarrow$	VB NP	[0.210699917539]
NP	$\rightarrow$	NP SBAR	[0.0738850114634]
PP	$\rightarrow$	IN NP	[0.96232210731]
VP	$\rightarrow$	VB PP	[0.1843874159776]
VP	$\rightarrow$	VP PP	[7.49643919138e-05]
NP	$\rightarrow$	DT NN	[0.42230863744]
PP	$\rightarrow$	IN S	[0.0346283037214]
VP	$\rightarrow$	VB	[0.0746395462155]
SBAR	$\rightarrow$	WP VP	[0.86864638]
SBAR	$\rightarrow$	WP S/NP	[0.13135362]
S/NP	$\rightarrow$	NP VP/NP	[1.0]
VP/NP	$\rightarrow$	VB	[1.0]
VP	$\rightarrow$	VB NP PP	[0.0563232464579]
VP	$\rightarrow$	AUX VP	[0.409830330593]
PP	$\rightarrow$	IN VP	[9.94431185362e-05]
PP	$\rightarrow$	IN	[0.00295014584991]
VP	$\rightarrow$	VP CC VP	[0.0640445788251]

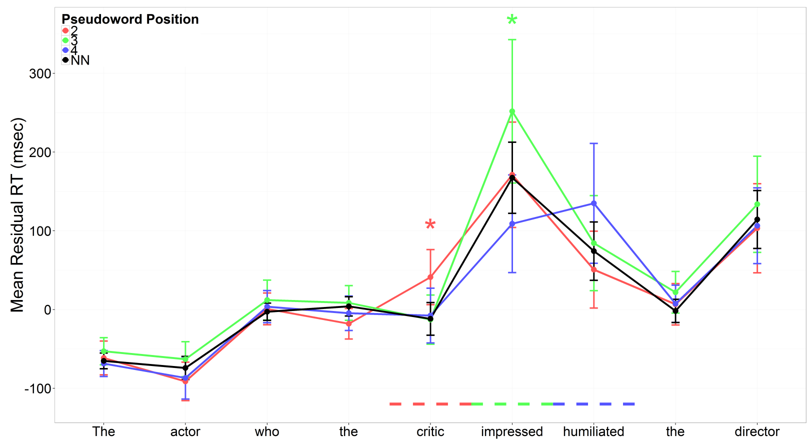
The lexicon consisted of all words in the target sentences. For every word in the lexicon, we computed the likelihoods of the syntactic categories in the grammar using words from SUBTLEXus. That is, to compute the probability of *actor* being a noun, we compared the string `actor` with all nouns in the SUBTLEXus corpus using the method described earlier. These likelihoods of the various syntactic categories were normalized and taken as probabilities of pre-terminal rules, such as, NN $\rightarrow$ *actor*.

Given this grammar and lexicon, the system computed surprisal values at all words in the target sentences to get an estimate of processing difficulty. The crucial parameter in the system was the perceptual noise σ which distorted the input samples in the Bayesian Reader model. The results of our evaluations are shown in Figures 5.7 & 5.8. Figures 5.7a & 5.8a depict the behavioral data from Experiment 3, whereas the other graphs depict mean surprisal scores from the model with different noise parameters.

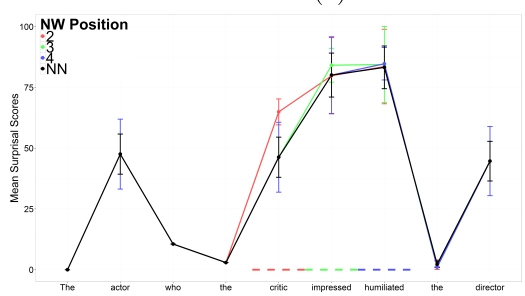
Like the Edit Distance model from earlier, this model too does not seem to fully capture the behavioral results. However, at least for lower values of σ, we found that the model predicts no extra processing difficulties due to pseudowords at certain positions. This is similar to our findings that unknown words do not always cause processing difficulties, though the model's predictions do not align consistently with our behavioral data. Interestingly, the model seems to treat pseudonouns differently from pseudoverbs, and pseudonouns are predicted to be harder to process than pseudoverbs. We believe this might be a reflection of the words in the SUBTLEXus corpus, and perhaps our pseudonouns are relatively more dissimilar from nouns in the corpus than our pseudoverbs from verbs. Moreover, the *-ed* suffix at the end of our pseudoverbs may make them appear better verbs, ensuring higher probability of them being verbs, and consequently, lower surprisal while processing them.

We repeated the analyses with sentences from Experiment 4. The only change in the system was the lexicon, which now contained words from the newer set of sentences. The probabilities of the pre-terminal rules were computed in the same way as before using the Bayesian Reader model. The results of our evaluations are shown in Figures 5.9 & 5.10. Figures 5.9a & 5.10a present behavioral data from Experiment 4, whereas the other graphs show model predictions for different noise parameters.

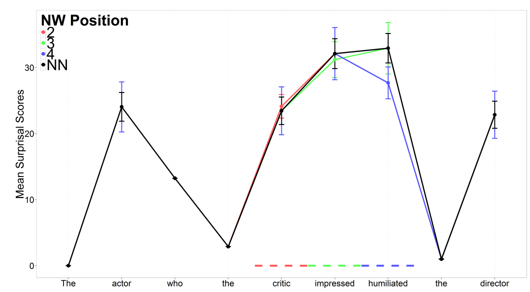
Again, the predictions of this model seem much better than the predictions of the Edit Distance model. Consistent with our behavioral data, the model predicted increased processing difficulty at all pseudoword positions. Moreover, unlike the Edit Distance model, the model does not always predict differences between the morphologically congruent and incongruent pseudowords. As in our earlier evaluations, pseudonouns seem to be treated differently from pseudoverbs, but this time, pseudoverbs are predicted to be harder to process than pseudonouns. Again, we believe this to suggest that our pseudoverbs were overall less similar to verbs in SUBTLEXus than pseudonouns from nouns.



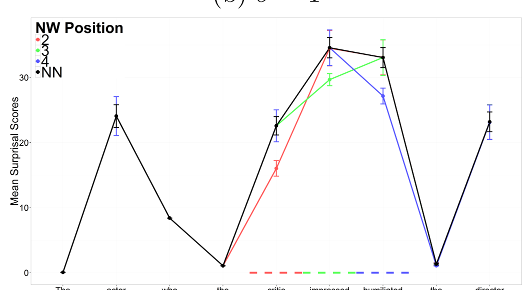
(a) Behavioral data from Experiment 3.



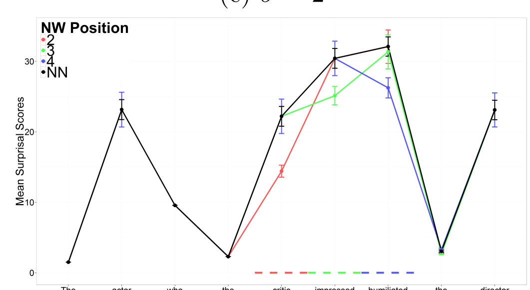
(b) $\sigma = 1$



(c) $\sigma = 2$

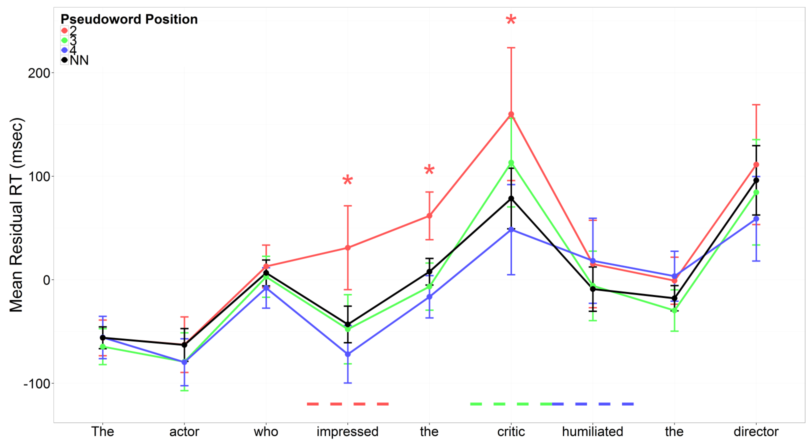


(d) $\sigma = 3$

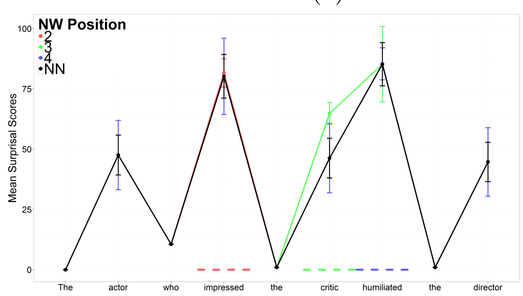


(e) $\sigma = 4$

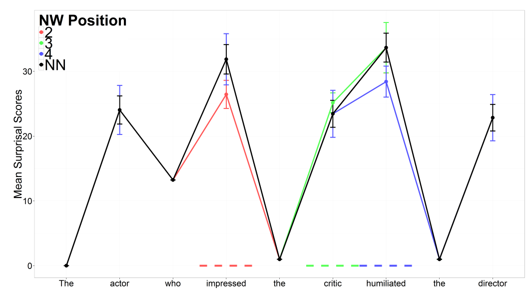
Figure 5.7: Line graphs depicting predictions of the Noisy Sentence Reader model in processing ORC sentences from Experiment 3. NN = no nonsense word. Error bars represent confidence intervals.



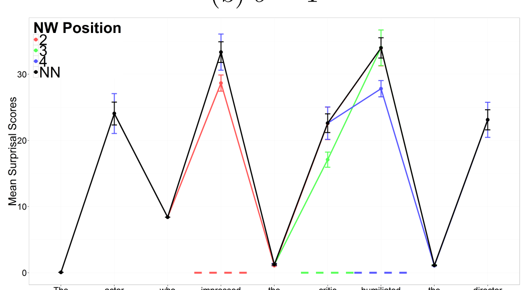
(a) Behavioral data from Experiment 3.



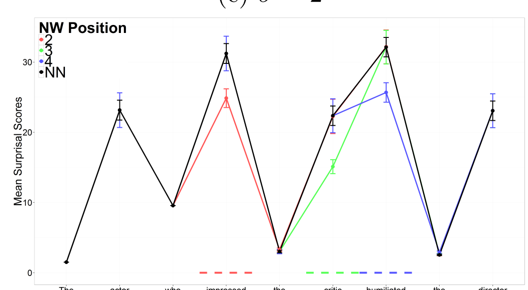
(b) $\sigma = 1$



(c) $\sigma = 2$

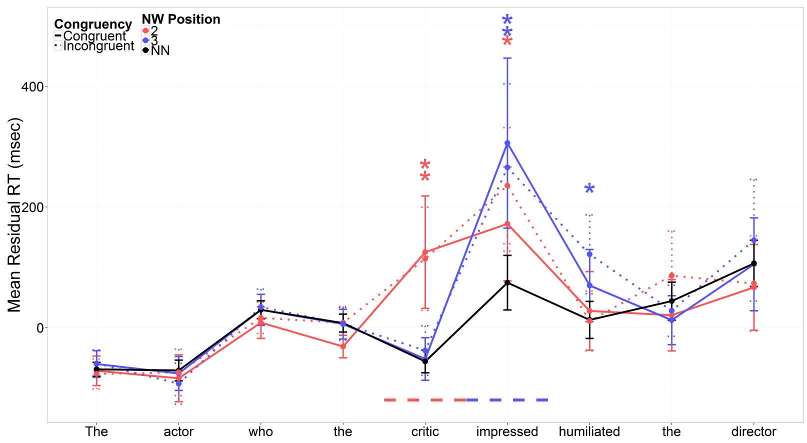


(d) $\sigma = 3$

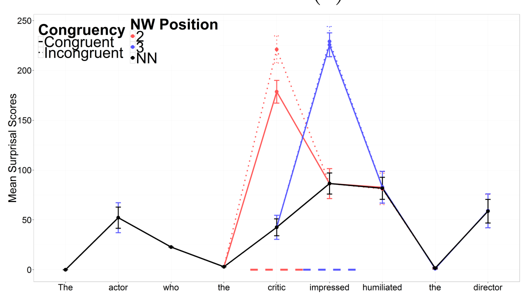


(e) $\sigma = 4$

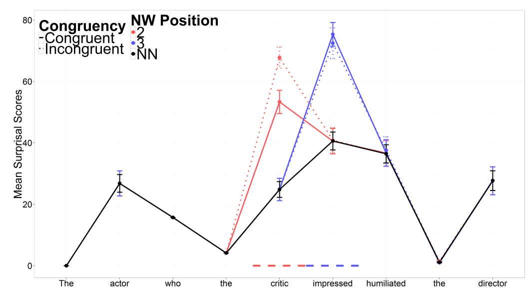
Figure 5.8: Line graphs depicting predictions of the Noisy Sentence Reader model in processing SRC sentences from Experiment 3. NN = no nonsense word. Error bars represent confidence intervals.



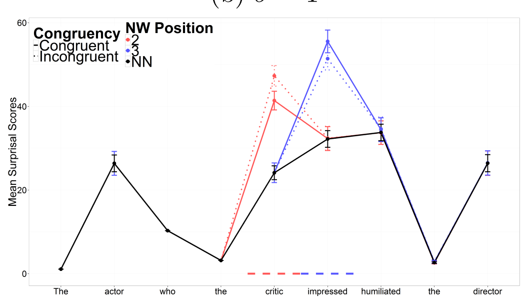
(a) Behavioral data from Experiment 4.



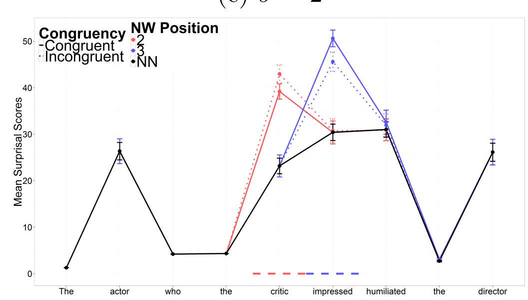
(b) $\sigma = 1$



(c) $\sigma = 2$

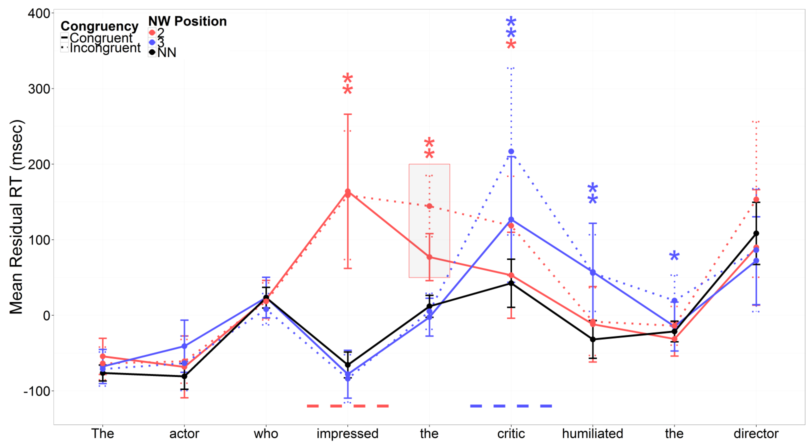


(d) $\sigma = 3$

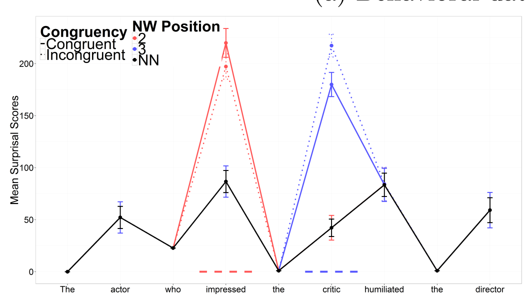


(e) $\sigma = 4$

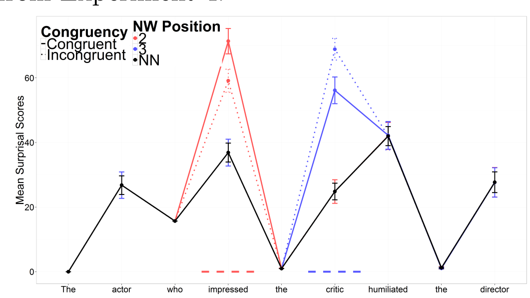
Figure 5.9: Line graphs depicting predictions of the Noisy Sentence Reader model in processing ORC sentences from Experiment 4. NN = no nonsense word. Error bars represent confidence intervals.



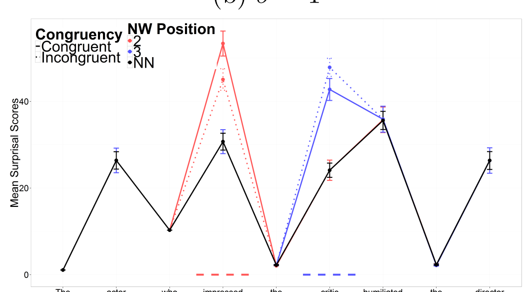
(a) Behavioral data from Experiment 4.



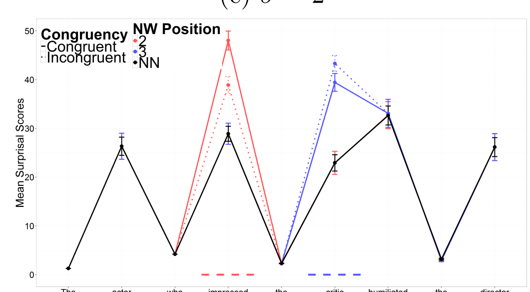
(b) $\sigma = 1$



(c) $\sigma = 2$



(d) $\sigma = 3$



(e) $\sigma = 4$

Figure 5.10: Line graphs depicting predictions of the Noisy Sentence Reader model in processing SRC sentences from Experiment 4. NN = no nonsense word. Error bars represent confidence intervals.

5.1.4 Summary

In this section, we presented two models capable of processing sentences containing unknown words. Both models were built upon the *surprisal* model of sentence processing (Hale, 2001; Levy, 2008a), which is known to be ineffective in modeling behavioral data on relative clause processing. Thus, we view our exercise as an attempt to suggest ways to model sentence processing with unknown words.

Our first model, the Edit Distance model, was similar to the noisy channel approach used by Levy (2008b, 2011). Unlike Levy, we found that an edit distance based approach was ineffective in capturing our behavioral data on sentence processing with uncertain input. Next, we turned to computational work on visual word recognition, and developed a model that integrated surprisal with Bayesian Reader (Norris, 2006, 2009; Norris and Kinoshita, 2012). This model turned out to be slightly more effective than the Edit Distance model in terms of capturing novel word processing effects that we observed.

Going forward, the next step should be more extensive evaluations of the Noisy Sentence Reader model with a larger grammar and lexicon. Crucially, the inherent limitations of the surprisal model need to be addressed. As we argued earlier, surprisal was an appealing choice only because of its computational nature which allows for easier implementation and extension. A similar model of sentence processing is the *Psycholinguistically Motivated Tree Adjoining Grammar* (PLTAG) model (Demberg and Keller, 2008, 2009). Crucially, their model appears to capture behavioral data on relative clause processing better than surprisal (Demberg and Keller, 2009). More importantly, it is also computational in nature, and can be efficiently implemented. Together, these features make it a promising avenue, and in the future, we plan on extending their model using ideas similar to the Noisy Sentence Reader presented here.

5.2 Morphological Information in Languages

In this section, we investigate why morphological information appears to have no consistent effects on sentence processing in our studies. In Section 5.2.1, we use corpora analyses to examine whether morphological information in English is a reliable cue of a word's syntactic category (i.e., whether a word is a noun or a verb). In Section 5.2.2, we present analyses that investigate how morphological and syntactic information interact cross-linguistically. Specifically, we examine whether languages that are morphologically richer tend to be syntactically more flexible (i.e., have less rigid word order constraints), and vice versa.

5.2.1 English Morphology

The behavioral findings from Experiment 6 indicated that derivational morphology is unable to guide sentence processing. Moreover, in Experiment 5, we found that when a nominal derivational suffix and a verbal inflectional suffix are present on a word, participants were more inclined to call it a verb than a noun. At least for nouns and verbs, this indicates that inflectional morphology is a stronger cue than derivational morphology. Could it be that derivational suffixes are not used simply because they are not reliable cues?

We addressed this question by conducting corpus analyses on the Wall Street Journal section of the Penn Treebank (Marcus et al., 1993). In our analyses, we looked at four nominal derivational suffixes— *-ician, -or, -er, -ist* —and a nominal inflectional ending, *-s*. We also evaluated four verbal derivational suffixes— *-ify, -ize, -ise, -ate* —and a verbal inflectional ending, *-ed*. We counted how frequently they occurred in the corpus, and also how often they occurred as nouns and verbs. Next, we computed the relative frequencies of nouns and verbs with the corresponding suffixes. Lastly, we measured how reliably they indicated the correct syntactic categories (based on our labels). The reliability of nominal suffixes was measured as the ratio of their count in nouns to their frequency in general:

$$\texttt{reliability}(\text{suffix}_{nom}) = \frac{\texttt{count}(\text{nouns with suffix})}{\texttt{count}(\text{words with suffix})}$$

Likewise, the reliability of verbal suffixes was the ratio of their count in verbs to their overall frequency:

$$\texttt{reliability}(\text{suffix}_{verb}) = \frac{\texttt{count}(\text{verbs with suffix})}{\texttt{count}(\text{words with suffix})}$$

Suffix	Total	Nom[1]	Verb	Nom/AllNouns	Nom/Total	Nom/(Nom+Verb)
-ician	108	105	0	$\frac{105*100}{355039} = .03\%$	97.22%	100%
-or	17693	4835	120	1.36%	27.33%	97.58%
-er	37645	17883	1169	5.04%	47.50%	93.86%
-ist	1553	1088	198	.31%	70.06%	84.60%
-s	135295	73964	26436	20.83%	54.67%	73.67%

Table 5.1: Counts and relative frequencies of five nominal suffixes from the Wall Street Journal corpus.

Tables 5.1 and 5.2 present all the data. As we can see, both nominal and verbal derivational suffixes were surprisingly infrequent in general. Of the 4 nominal derivational suffixes that we considered, only one, *-er*, occurred in 5% of all nouns, whereas the rest all occurred as nominal suffixes with a frequency of less than 2%. Except for one suffix (*-ician*), most were quite poor indicators of nouns and had low reliability, with both *-or* and *-er* occurring less than 50% of times as nouns. However, considering only nouns and verbs, the reliability of the nominal suffixes was quite high, and they were more likely to occur as nouns rather than verbs.

Likewise, all 4 verbal derivational suffixes also occurred very infrequently, and each suffix individually occurred in at most 2% of verbs. In addition, except for *-ify*, which occurred as a verbal suffix 80% of the times, the other three suffixes were poor verbal indicators. Furthermore, considering only nouns and verbs, the reliability of the verbal suffixes was not as high as their nominal counterparts. In particular, *-ise* and *-ate* had low reliability and were almost equally likely to be in nouns.

As far as the inflectional suffixes are concerned, we see that both the nominal and the verbal inflections occur much more frequently than derivational suffixes. For example, the plural ending, *-s*, occurred in 21% of all nouns. Earlier, we had pointed out that the *-s*

[1]Only words having the tags NN and NNS were counted as being nominals.

Suffix	Total	Verb	Nom	Verb/AllVerbs	Verb/Total	Verb/(Nom+Verb)
-ify	453	365	0	$\frac{365*100}{154975} = .23\%$	80.57%	100%
-ize	936	657	120	.42%	70.19%	84.55%
-ise	1425	803	472	.52%	56.35%	62.98%
-ate	7433	2747	2033	1.77%	36.96%	57.47%
-ed	37443	32944	1365	21.26%	87.98%	96.02%

Table 5.2: Counts and relative frequencies of five verbal suffixes from the Wall Street Journal corpus.

ending is ambiguous, and can double as a verbal third-person singular present tense marker. Indeed, of all words that ended with *-s*, only about half were nouns. Despite this, between nouns and verbs, an *-s* ending indicated a plural noun almost 3 out of 4 times . However, its reliability was still lower that of the nominal derivational suffixes.

Similarly, the verbal inflectional suffix, *-ed*, was also more frequent and more reliable than its derivational counterparts. Of all verbs, 21% contained the *-ed* suffix, and between all nouns and verbs, having an *-ed* suffix almost always indicated that the word was a verb. In comparison with the verbal derivational suffixes, the reliability of the ending was also quite high. This is consistent with our findings in Experiment 3. In cases where pseudowords contained a nominal derivational suffix and an *-ed* ending, our participants were biased towards a verbal interpretation. It is likely that the reason for the bias was because words ending with *-ed* are more likely to be verbs than nouns.

In Experiment 4, we found that participants did not use derivational information available on pseudowords while processing the sentences. Perhaps the reason is because derivational information tends to be a weak indicator of the syntactic category of words. According to our corpus analyses, the four most reliable indicators of syntactic category—*-ician, -ist, -ify*, and *-ize* —were also the most infrequent overall. It is likely that because of this infrequent nature of derivational morphology, sentence processing mechanisms choose to either weakly rely on them or ignore them completely. In English, at least, sentences tend to have a fairly fixed word-order, and cases of local syntactic ambiguity (e.g., *the boy who...*) tend to be few and far between. Thus, when syntactic information is inadequate, waiting for a few more words is perhaps a better strategy than using morphological information on unknown, meaningless words.

5.2.2 Cross-linguistic Morphology

In this section, we investigate whether the reason English morphology is unreliable is because of English's syntactic rigidity (i.e., tendency to have a fixed word order). Some linguists have noted a relation between morphological characteristics of languages and their word order preferences (Blake, 2001; McFadden, 2003; Müller, 2002). Specifically, it has been suggested that morphologically richer languages tend to have more flexible word order preferences, and vice versa. However, these claims have been made using empirical data from a relatively small number of languages, such as Dutch, German, Russian, and Old/Middle English.

Here, we present large-scaled cross-linguistic analyses to broadly examine the relation between syntax and morphology across languages. For our analyses, we used the World Atlas of Language Structures (WALS) Online database, which classifies a number of languages based on several linguistic (phonological, grammatical, and lexical) properties (Dryer and Haspelmath, 2013). A total of 2,679 languages were marked with 151 linguistic features using data from a team of 55 authors, although not all languages are marked with all feature values.

In the WALS database, 17 of the 151 linguistic features identify different word order properties in languages. One such feature, called "Order of Subject, Object, and Verb," identifies the relative order of the three grammatical entities (Dryer, 2013e). For example, languages classified as Subject-Verb-Object were more likely to have sentences with that order. Languages are classified as having one of six such feature values, corresponding to the 6 possible arrangements, or are marked as having no dominant order. Other features likewise classify languages based on their preferences for ordering other grammatical entities, such as Subject and Verb (Dryer, 2013d), Object and Verb (Dryer, 2013b), Adjective and Noun (Dryer, 2013a), Relative Clause and Noun (Dryer, 2013c). Some of the other features identify relationships between various orderings, such as Relationship between Order of Object and Verb and Order of Adjective and Noun (Dryer, 2013g) and Relationship between Order of Object and Verb and Order of Relative Clause and Noun (Dryer, 2013h). Note that all features are not independent of one another. For example, knowing the general word order preference of a language, say Subject-Verb-Object, we can also determine the order preference between Subject and Verb, and Verb and Object.

In our analyses, we used the more general, "Order of Subject, Object, and Verb" feature to discriminate between languages with a fixed word order and those with no dominant word order. Without any theoretical motivation for selecting any of the more specific features, we decided to select the most general measure of languages' syntactic rigidity. Moreover, we decided to not discriminate between fixed word order languages with different word order preferences (e.g., Subject-Verb-Object vs. Subject-Object-Verb). Thus, we converted the multi-value feature into a binary one that only classified languages as either having a dominant word order or not having any. Of the 1,377 languages that the WALS database had classified by this feature, 189 had no dominant order and 1,188 had a fixed order.

Unlike languages' word order preferences, quantifying their morphological richness is more difficult. We could not identify any single feature in the WALS database which quantified languages' morphological complexity. Instead, we identified several different features which we used in our analyses. One such feature classified languages based on their preference for prefixing or suffixing in inflectional morphology (Dryer, 2013f). Of the 969 languages marked with this feature, 141 were identified as having little or no inflectional morphology. Having no justification for discriminating between languages that prefer prefixing with languages that prefer suffixing, we decided to consider all such languages together. Thus, we categorized the other 828 languages together as languages that have inflectional morphology.

We analyzed the relation between languages' word order preferences and the amount of inflectional morphology by first identifying the 876 languages that were marked with both

	Word Order Preference		
Amount of Infl. Morph.	Dominant Order	No Dominant Order	Total by Morphology
Affixation	624	118	742
Little affix.	122	12	134
Total by Word Order Pref.	746	130	876

Table 5.3: Contingency table presenting distribution of languages based on their Word Order Preference and Amount of Inflectional Morphology.

features. The distribution of those 876 languages split by the two features being considered is presented in Table 5.3. We performed a chi-square test of independence to examine the relation between the two features, which revealed a significant relation between them ($\chi^2(1) = 4.34, p < .05$). As Table 5.3 shows, languages which have little inflectional morphology are significantly more likely to have a dominant word order preference (91%) than languages with greater inflectional morphology (84%). This trend suggests an inverse relation between morphological and syntactic information across languages, with languages that have a less complex morphological system being more likely to be syntactically constrained.

Another relevant feature in the WALS database identifies the number of case categories in the inflectional system of 261 languages (Iggesen, 2013). Of the 261 languages, 100 languages were found to lack morphological case marking (e.g., Vietnamese), and in such languages word order or function words are used to express grammatical relations. As before, we categorized the languages into two separate bins, those that had morphological case markers and those that did not.[2] Next, we identified the subset of languages for which information about their word order preference was also available.

We performed a chi-square test of independence using the remaining 217 languages

[2]One of the feature values separately identified languages that had "exclusively borderline case marking." Twenty-four languages used morphological case marking for specific, isolated cases and thus could not be categorized as having case marking in general. We chose to discard those 24 languages for our analyses.

	Word Order Preference		
Morph. Case-marking	Dominant Order	No Dominant Order	Total by Morph. Case
Case-marking	99	21	120
No Case-marking	86	11	97
Total by Word Order Pref.	185	32	217

Table 5.4: Contingency table presenting distribution of languages based on their Word Order Preference and Presence of Morphological Case-markers.

to investigate the relation between the presence of morphological case-marking and languages' word order preference. The results of the chi-square test failed to indicate a significant relation between the two features ($\chi^2(1) = 1.62, p = .20$). Table 5.4 presents the contingency table depicting the distribution of the data. As the data shows, languages that had morphological case-marking were no more likely to have a freer word order than languages without morphological case-marking.

Additionally, we repeated the analyses without binning all languages with morphological case-marking together. The data is presented as a contingency table in Table 5.5. Once again, a chi-square test of independence failed to indicate any relation between the number of morphological case markers in a language and its word order preference ($\chi^2(7) = 10.57, p = .16$).

Apart from the number of morphological case-markers, another factor which determines the morphological complexity of a language is the amount of ambiguity in the markers. For example, we saw earlier that the *-s* marker in English is likely to be either a plural nominal suffix or a verbal third-person singular present tense suffix. Languages which have ambiguous markers require additional sources of information to disambiguate them. Arguably, this undermines the reliability and importance of the morphological system in such languages. Moreover, we expect such languages to be syntactically less flexible, to facilitate disambiguation of the markers using syntactic position, such as in English.

The WALS database has a feature, called case syncretism, which identifies whether

	Word Order Preference		
Num. Case	Dominant Order	No Dominant Order	Total by Num. Case
No Case-marking	86	11	97
2 cases	20	1	21
3 cases	6	3	9
4 cases	7	2	9
5 cases	6	2	8
6-7 cases	29	4	33
8-9 cases	18	3	21
10 or more cases	13	6	19
Total by Word Order Pref.	185	32	217

Table 5.5: Contingency table presenting distribution of languages based on their Word Order Preference and Number of Morphological Case-markers.

a language has syncretic, i.e., ambiguous, case-markers (Baerman and Brown, 2013a). Of the 198 languages marked with that feature, 123 are noted as having minimal or absent inflectional case marking. To evaluate the relation between inflectional case syncretism and word order preference, we chose to disregard those 123 languages. Of the remaining 75 languages, 10 languages did not have corresponding information on their word order preference and thus were discounted.

Moreover, the WALS database distinguishes between languages where syncretism occurs for "core cases" (e.g., subject and object) only, and languages where syncretism occurs for all cases. Because this distinction was not relevant to our analyses, we chose to consider the two sets of languages together in one group. The data are presented in Table 5.6, and clearly indicate no relation between case syncretism and word order preference. This was confirmed by a chi-square test of independence which failed to indicate any significant relation between the two factors ($\chi^2(1) = .13, p = .72$).

In a separate analysis, we used the same feature to distinguish between languages

	Word Order Preference		
Case Syncretism	Dominant Order	No Dominant Order	Total by Syncretism
Case Syncretism	25	9	34
No Case Syncretism	24	7	31
Total by Word Order Pref.	49	16	65

Table 5.6: Contingency table presenting distribution of languages based on their Word Order Preference and Presence of Case Syncretism.

	Word Order Preference		
Infl. Case-marking	Dominant Order	No Dominant Order	Total by Case
Inflectional Case-marking	49	16	65
No case-marking	107	14	121
Total by Word Order Pref.	156	30	186

Table 5.7: Contingency table presenting distribution of languages based on their Word Order Preference and Inflectional Case-marking.

	Word Order Preference		
Person/Number Sync.	Dominant Order	No Dominant Order	Total by Syncretism
Syncretic	53	5	58
Not Syncretic	57	21	78
Total by Word Order Pref.	110	26	136

Table 5.8: Contingency table presenting distribution of languages based on their Word Order Preference and Syncretism in Person/Number Marking.

that have inflectional case-marking and languages with minimal or absent case-marking. As mentioned earlier, the WALS database identifies 128 languages with minimal case-marking (defined to have no more than two nominal forms), and 75 with more extensive case-marking. We used this set of languages to evaluate the relation between inflectional case-marking and word order preference. To that end, we identified the 186 languages which were marked with both features, and performed a chi-square test of independence. The results showed a significant relation between the two factors ($\chi^2(1) = 5.32, p < .05$). As Table 5.7 shows, languages having minimal case-marking were more likely to have a fixed word order (88%) than languages having extensive case-marking (75%). In turn, this suggests that languages which are morphologically richer are more likely to be syntactically flexible by having a freer word order.

In our last set of analyses, we used the feature in the WALS database which identified syncretic patterns in inflectional subject person/number marking in verbs (Baerman and Brown, 2013b). Out of 198 languages, 57 were identified as having no inflectional subject person/number marking. These 57 languages were discarded for our first evaluation where we examined the relation between syncretism in person/number marking and word order preference. We performed a chi-square test of independence using the 136 languages for which information about both factors was available. The results indicated a significant relation between the two factors ($\chi^2(1) = 7.21, p < .01$). As shown in Table 5.8, languages which exhibited person/number syncretism were more likely to have a fixed word order (91%) than languages with no syncretism (73%). As argued earlier, syncretism corresponds

	Word Order Preference		
Person/Number Marking	Dominant Order	No Dominant Order	Total by Marking
Inflectional Marking	110	26	136
No Marking	45	5	50
Total by Word Order Pref.	155	31	186

Table 5.9: Contingency table presenting distribution of languages based on their Word Order Preference and Inflectional Person/Number Marking.

to the reliability of the morphological system in general. Thus, these results indicate that languages with less reliable morphological information tend to be syntactically rigid. Possibly, this syntactic rigidity reflects the greater importance of syntactic information over the less reliable morphological one.

Lastly, we used the same feature to distinguish between languages with no inflectional person/number marking and languages which have inflectional markers which convey person/number information. We found 186 languages for which this information as well as information about their word order preference was present. This data is presented in Table 5.9. We performed a chi-square test of independence to evaluate the relation between the two features. The results indicated no significant relation between languages' word order preferences and presence of inflectional person/number number ($\chi^2(1) = 2.19, p = .14$).

5.2.3 Summary

The goal of the work presented in this section was to try and understand why our behavioral results yielded no consistent effect of morphological information on sentence processing. First, we used the Wall Street Journal corpus of the Penn Treebank (Marcus et al., 1993) to evaluate whether morphological information in English is a reliable cue in determining the syntactic category of words. We found that derivational morphology tends to be rarely used and, more often than not, does not reliably determine the syntactic category of a word. In contrast, inflectional morphology is much more frequently used. However, while the verbal inflectional suffix that we used (*-ed*) was found to be a reliable verbal cue, the nominal inflectional suffix (the plural *-s*) was found to not be very reliable. This is consistent with the suffix being both a nominal and a verbal inflectional marker, and hence being ambiguous. Overall, we found that morphological information in English tends to be infrequent and unreliable, which may explain why it is easily ignored/overruled while processing sentences.

Next, we performed large-scaled cross-linguistic evaluations using the WALS database (Dryer and Haspelmath, 2013) to examine whether the unreliability of English morphology is related to its relatively fixed word order preference. The results of those evaluations provided a mixed picture. For different kinds of morphological information, we found different relations with languages' word order preferences. Whereas inflectional person/number marking had no relation with syntactic flexibility, languages with no inflectional case marking were more likely to have a fixed word order. An opposite pattern of results was observed when we considered morphological syncretism, i.e., ambiguity. Languages with syncretic person/number markers were more likely to have a freer word order, but word order preferences seemed independent of whether languages had syncretic case markers.

Moreover, different features from the WALS database provided different results. When we used the feature that marked case syncretism in languages to distinguish between languages with/without inflectional case-marking, we found a significant relation between that factor and languages' word order preferences. However, when we used the feature that identified the number of case markers in languages to perform the same analysis, we failed to find a significant relation between the two features. This inconsistency potentially undermines the importance of these findings.

Crucially, when we considered inflectional marking in general, we found a significant relation between the amount of inflectional morphology in a language and its word order preference. Specifically, languages with little inflectional morphology tended to have a fixed word order. This highlights a critical interaction between the two sources of information, with morphologically richer languages having greater syntactic flexibility. Conversely, this suggests that languages like English, which tend to have little syntactic flexibility, might be more likely to have a simpler morphological system. This is consistent with our findings from the evaluation of the Wall Street Journal corpus.

The results of our cross-linguistic analyses are also consistent with arguments made by theoretical linguistics (Blake, 2001; McFadden, 2003; Müller, 2002). Despite this, it is important to note that the analyses presented here only allow us to speak of the general relation between syntax and morphology. Thus, while it is safe to say that the unreliability of English morphology and its rigid word order constraints might be related, it is hasty to posit that one is caused by the other. Our mixed results, along with the general difficulty in quantifying qualitative notions of "morphological richness" and "syntactic flexibility," suggest that any conclusions should be derived cautiously. Future work will need to more extensively evaluate the relation between the two linguistic factors.

6. Conclusion

"'Speak English!' said the Eaglet. 'I don't know the meaning of half those long words, and I don't believe you do either!'"
— Lewis Carroll, *Alice's Adventures in Wonderland*

6.1 General Summary

Lewis Carroll's (1883) Jabberwocky demonstrated that people are able to interpret fantastical sentences containing novel, meaningless words. Empirical findings by neurolinguists and behavioral researchers also suggest that sentences containing novel words are processed the same way as regular ones (e.g., Canseco Gonzalez et al., 1997; Fedorenko et al., 2009; Hahne and Jescheniak, 2001; Rothermich et al., 2009; Silva-Pereyra et al., 2007; Stromswold et al., 1996; Yamada and Neville, 2007). Despite these findings, much remained unexplained about what linguistic factors allow us to extract meaning out of seemingly meaningless sentences. Through behavioral studies, we examined how people process sentences containing unknown words.

In Chapter 3, we presented two novel word detection studies where participants read whole sentences and had to determine whether they contained a pseudoword. Previous work by Stromswold et al. (1996) had indicated an effect of syntactic structure on task performance. We replicated their findings in Experiment 1, and found evidence suggesting an influence of syntactic information on novel word identification. In Experiment 2, we attempted to generalize these findings using a larger set of target sentences with greater structural variety, along with a number of filler sentences. However, the results of Experiment 2 were found to be inconsistent with a syntactic influence on novel word detection. Despite these mixed results, we did find consistent evidence that people processed sentences regardless of the presence of pseudowords. In addition, the fact that people syntactically process sentences even in a task where it is not required suggests an automatic nature of sentence processing (Fodor, 1983).

In Chapter 4, we further examined the processing of sentences containing novel words. In the previous two experiments, we were limited by the coarse measurements from the whole-sentence word detection paradigm, which did not allow us to evaluate the time frame and localization of sentence processing in presence of novel words. Recognizing that limitation, we performed non-cumulative word-by-word self-paced reading studies, which allowed us to get reading time information at every word position. In Experiment 3, we used pseudowords which were morphologically constrained to evaluate whether the syntactic position of novel words affects sentence processing. Our results indicated that preceding syntactic context heavily influences processing of novel words. In fact, for some syntactic positions, we found that processing novel words incurred no additional processing cost.

In subsequent studies, we manipulated morphological information on pseudowords to investigate how syntax and morphology interact during sentence processing. In Experiment 4, we manipulated the morphological congruency of pseudowords in sentences: morphologically congruent pseudowords contained derivational and inflectional suffixes consistent with their syntactic position, whereas morphologically incongruent pseudowords did not. Overall, our results indicated that syntactic information far outweighs morphological, and we failed to find any consistent effect of morphology in sentence processing. Critically, we observed a morphological effect on processing only when syntactic information was ambiguous and, hence, inadequate. We hypothesized two possibilities: 1) people are unable to use morphological information on pseudowords to identify the syntactic category of such words; and 2) sentence processing is predominantly guided by preceding syntactic information, so much so that any morphological information is vetoed by the syntactic context. We separately evaluated both hypotheses in two experiments.

In Experiment 5, we conducted a pseudoword classification task, where participants judged whether a pseudoword was likely to be a noun or a verb. Crucially, we manipulated the morphological information on pseudowords using several derivational and inflectional suffixes. The results indicated that participants used morphological information on words to determine their syntactic category. Moreover, the amount of morphological information, as well as their reliability, also influenced participants' performance. These findings suggest that morphological information on pseudowords is available and can be used to determine the syntactic category of words. In addition, these results speak against the hypothesis that such information cannot be used during sentence processing.

In Experiment 6, we evaluated the hypothesis that syntactic information outweighs morphological. Specifically, we investigated whether the absence of reliable, unambiguous syntactic information allows morphological information to guide sentence processing. Again, we used a self-paced reading study to measure reading times, and hence processing difficulties, at every word. Our results indicated that even when syntactic information is ambiguous, morphological information does not guide sentence processing. Moreover, the results suggest that instead of relying on information from unknown words, the sentence processor rather waits for more reliable information.

Taken together, the results of Experiments 5 and 6 further suggest that the processing of sentences containing unknown words is guided predominantly by syntactic information. Even though morphological information on novel words can be used to identify their syntactic categories in isolation, such information does not seem to be used during sentence processing. We suspected that this might have something to do with reliability, or lack thereof, of English morphology. To investigate this, we conducted corpora analyses and found that derivational and inflectional suffixes tend to be infrequent in English. Moreover, most suffixes tend to be weak indicators of the syntactic category of words. In sum, English morphology tends to be unreliable and infrequent, and perhaps that is why is underutilized during sentence processing.

6.2 Implications

This dissertation provides us new insights on how people understand sentences. At least for English, we see that prior syntactic information plays a crucial role in sentence comprehension, more so than any morphological information present on words. Moreover, our findings allow us to better understand how we process sentences containing novel, meaningless words. Apart from these insights, there are two other reasons why we believe our work here is relevant.

First, understanding how unknown words in sentences are processed further allows us to evaluate psycholinguistic models of sentence comprehension. In Section 2.2.3, we reviewed three approaches that have been used to model human sentence comprehension. Almost all current models assume a clean input where sentences are separated into words and all words are known beforehand. Thus, quite generally, our behavioral data present a challenge to all existing psycholinguistic models.

Moreover, the content-less nature of novel words also challenges the fundamental nature of many of these models. For example, several meaning-based models use semantic factors, such as animacy, or pragmatic factors, such as focus and perspective, to describe sentence comprehension (e.g., Gennari and MacDonald, 2008, 2009; Gordon and Hendrick, 2005; MacWhinney, 1977; MacWhinney and Pleh, 1988; Mak et al., 2002, 2006; Traxler et al., 2002, 2005). Because novel words are meaningless, such explanations cannot adequately account for them.

Other models attribute sentence processing difficulties to working memory limitations (e.g., Gibson, 1998, 2000; King and Just, 1991; Lewis and Vasishth, 2005; Lewis et al., 2006; Miller and Chomsky, 1963). For example, the dependency locality theory (Gibson, 1998, 2000) associates processing difficulties with accessibility issues as well as the amount of working memory resources used during comprehension. In all such models, processing difficulties at specific words are tied to difficulties in integrating those words with preceding structure(s). Generally, these models tend to be backward-looking only, and integration of a word involves retrieval based on the content of the word. As such, the content-less nature of unknown words presents a challenge to these models. Without knowing what the word is, it cannot be integrated with the preceding structure, and thus, its processing complexity cannot be estimated.

The third category of models are based on experience, and assume that processing difficulties are inherently linked with the frequency of usage (e.g., Hale, 2001; Levy, 2008a). Difficulty in comprehension is inversely linked with frequency, and more frequent words and structures are assumed to be easier to process and understand. As novel words are by definition words that have never been encountered previously, these models generally predict greater difficulty in processing them regardless of any linguistic information. However, our data suggests that in certain syntactic positions, novel words are no more difficult to process than regular words. Thus, these models too cannot generally explain our findings.

The second reason why we believe our work is relevant is because it allows us to directly evaluate how syntactic and morphological information interact during sentence processing. To the best of our knowledge, our work is the first to investigate the influence of derivational morphology on sentence processing. Typically, previous work on morphological effects on sentence processing has focused on inflectional morphology, such as cases of subject-verb disagreement and tense violations (e.g., Bock and Miller, 1991; Bock and Eberhard, 1993; Franck et al., 2002; Hartsuiker et al., 2001; Haskell and MacDonald, 2005; Vigliocco and Nicol, 1998). One possible reason for this could be that, in English, inflectional morphology is easier to manipulate than derivational.

Novel words allow us to examine how derivational morphology influences sentence processing by offering a simpler way to manipulate and control derivational suffixes. Despite finding negative results, we believe that future evaluations using a larger set of sentences and further morphological manipulation will allow us to more generally examine how morphology influences sentence comprehension. We feel that the use of novel words is the best way to achieve that goal as it allows for an evaluation in a strictly controlled manner, something which is not likely to be possible with regular words.

6.3 Future Directions

There are several open questions raised by our work in this dissertation. Here, we list some of them and discuss ways to carry forward this work.

Computational Modeling

Going forward, the critical challenge is developing models of human sentence comprehension that can account for our data. Recent work by Levy (2008b, 2011) is certainly the right step forward. Their noisy-channel model assumes an uncertain perceptual input and allows for incorrect word insertions, deletions, and substitutions. They use an edit-distance based metric to consider several such possibilities, and process a given input using the most likely intended sentence. However, as we saw in Section 5.1, a similar edit-distance based model fails to adequately capture our behavioral data.

One promising avenue is computational work from the word identification and recognition literature (for a review, see Norris, 2013). We evaluated a model which integrated surprisal (Hale, 2001; Levy, 2008a), a sentence processing model, with Bayesian Reader (Norris, 2006, 2009; Norris and Kinoshita, 2012), a lexical detection model. As our simulations showed, this model performed better than the simpler edit-distance model. In future work, we wish to carry forward our investigations using a larger test-bed of sentences.

Another critical issue is the inability of current sentence processing models to effectively model behavioral data on relative clause sentences. As Staub (2010) showed, frequency-based and working memory-based models capture different aspects of behavioral data. Thus, an equally important project would be the development of a model that can fully capture relative clause processing.

The *Psycholinguistically Motivated Tree Adjoining Grammar* (PLTAG) model by Demberg and Keller (2008, 2009) is a promising step forward. In their model, they combined ideas from surprisal, a frequency-based model, and dependency locality theory (Gibson, 1998, 2000), a working memory-based model. While the PLTAG model performs better than both those models individually, it too fails to completely capture behavioral data. Despite this, we feel PLTAG holds promise, and in the future, we plan to extend the model to enable the processing of unknown words.

Syntax and Morphology

Our work suggests that in English, morphology does not guide sentence processing. Going forward, another promising line of work is investigating why that is. In Section 5.2, we presented preliminary work examining this question. In our analyses, we used a small subset of English suffixes and a limited corpus. In the future, we plan to extend our analyses using a larger set of suffixes and a more comprehensive corpus.

We also presented large scale cross-linguistic analyses where we investigated how syntax and morphology interact across languages. Our findings suggest that morphologically richer languages tend to have flexible word order preferences, which is consistent with arguments made by several theoretical linguists (e.g., Blake, 2001; McFadden, 2003; Müller, 2002). These findings indicate an inverse relation between syntax and morphology. Furthermore, they suggest that in languages with a richer morphological system, morphology might play a greater role during sentence processing. Through cross-linguistic behavioral studies, we wish to evaluate this question directly in the future.

Bilingualism

Research on bilingual word recognition has suggested that during word recognition, lexical representations from both languages are activated regardless of the nature of the target language (see, Van Assche et al., 2012, for a review). Furthermore, recent findings have reported this non-selective language access occurs during word recognition even in sentence contexts. In other words, the language of the preceding sentence context is insufficient to restrict lexical access to only that language.

An interesting follow-up question would be whether monolinguals and bilinguals process sentences containing unknown words differently. If bilinguals have to access both languages before determining if a word is unknown, we expect greater processing difficulties for novel words. Another interesting question would be whether cross-linguistic morphological factors interact during sentence processing. Novel words allow us to manipulate morphological information in ways regular words cannot. Thus, we can construct words such that the root is from one language and the suffix from another. For example, we could construct a word *jugar-ed*, where *jugar* is Spanish and *-ed* English. Another interesting question would be whether the fact that such words can be separated into meaningful, but cross-linguistic, suffixes helps bilinguals process them better than "regular" nonsense words.

A. Appendices

A.1 Generating Pseudowords

All pseudowords used in our study were generated using the ARC Nonword Database (Rastle et al., 2002), which is accessible at `ttp://www.cogsci.mq.edu.au/~nwdb/nwdb.`tml. The ARC database contains 358,534 monosyllabic nonwords, which are further divided into two groups. One group, totaling 48,534 nonwords, comprises pseudohomophones, which are nonwords that are phonetically identical to some real word, e.g., *brane/brain*. On the other thand, the other group of 310,000 nonwords comprised non-pseudohomophones.

The database identifies several properties of the nonwords: such as, whether they contain orthographically existing onsets and bodies, whether they contain an illegal bigram, number of orthographic or phonological neighbors, and so on. In generating our pseudowords, we restricted the search to only consider pseudohomophones that contained orthographically existing onsets and bodies, and only legal bigrams. Moreover, we restricted the number of letters in the nonwords to be between 3 and 12, so as to be consistent with the range of the number of letters of our regular words.

Despite the best attempts of the authors of the database, we encountered several pseudowords which we felt did not seem orthographically plausible, such as *ghroavs*, *fourgn*, and *wrele*. Thus, having generated several such pseudowords, we manually selected, and where required, modified, them such that they were both orthographically and phonologically plausible. Later, a group of native and monolingual English-speaking undergraduate research assistants also verified that the selected pseudowords seemed plausible.

In the initial experiments (Experiments 1, 2, and 3), where pseudowords were morphologically simple, we ensured that the selected pseudowords did not contain any apparent suffixes. Subsequently, half of those pseudowords were appended with an *-ed* ending to generate pseudoverbs. In the experiments where pseudowords were morphologically more complex (Experiments 4, 5, and 6), we used these pseudowords as base-forms, and manually added nominal or verbal suffixes. Specifically, our nominal suffixes were: *-ician*, *-ist*, *-or*, *-er*, and *-s*, whereas our verbal suffixes were: *-ify*, *-ize*, *-ate*, and *-ed*. Throughout such modifications, we emphasized orthographic and phonological plausibility, and at each step, native and monolingual English-speakers helped verify that the pseudowords seemed plausible.

A.2 Experiment 1 Stimuli

```
(1)  The pupil that the tremode benefited neglected the course.
(2)  The businessman that the video showed bribed the narter.
(3)  The tenant that the leak irritated renalled the landlord.
(4)  The article discussed the ambassador that met the dictator.
(5)  The activist planned the slibe that began the rebellion.
(6)  The pitcher threw the ball that broke the window.
(7)  The snow that the janitor shoveled coated the sidewalk.
(8)  The prisoner made the noise that distracted the guard.
(9)  The secret that the aide divulged scotted the banker.
(10) The shirt that the butler ironed fit the man.
(11) The comment rebinked the woman that slapped the man.
(12) The wolf that the campfire ploved circled the area.
(13) The actor rehearsed the scene that concluded the play.
(14) The diver that the weather hindered sought the treasure.
(15) The joke that the comedian told upset the woman.
(16) The candy tempted the dieter that called the friend.
(17) The arsonist set the fire that destroyed the merdom.
(18) The jogger that the water cooled ran the harmack.
(19) The gun that the thief loaded intimidated the victim.
(20) The politician that the scandal ruined quit the race.
(21) The meal that the waiter recommended disgusted the lild.
(22) The rain soaked the woman that hailed the cab.
(23) The mural that the artist painted depicted the battle.
(24) The boy that the haircut pleased tipped the barber.
(25) The candy that the merchant displayed sosticed the child.
(26) The doctor that the foom mentioned eradicated the disease.
(27) The captain lamaced the boat that won the race.
(28) The fort that the soldier slagged housed the ammunition.
(29) The teenager wore the miniskirt that horrified the mother.
(30) The box that the mailman delivered intrigued the redullor.
(31) The bell alerted the rucker that raced the horse.
(32) The cape provoked the bull that charged the matador.
(33) The reminder goaded the man that paid the bill.
(34) The commuter that the construction delayed took the detour.
(35) The woman that the toothache annoyed saw the dentist.
(36) The girl that the thorn pricked applied the didden.
(37) The spice that the chef added flavored the soup.
```

(38) The crime alarmed the woman that hired the relpine.
(39) The caterer cooked the food that poisoned the guest.
(40) The button that the maid pressed started the warmage.
(41) The artist designed the dallow that honored the hero.
(42) The lighthouse trubbed the sailor that piloted the boat.
(43) The bomb blinded the soldier that received the medal.
(44) The critic that the opera amazed wrote the review.
(45) The athlete that the towel dried brummed the English Channel.
(46) The nurse administered the shot that hurt the patient.
(47) The lawyer cited the precedent that supported the case.
(48) The knife cut the lutcher that summoned the doctor.
(49) The girl that the ballet enchanted became the dancer.
(50) The robber that the alarm surprised seized the hostage.
(51) The award thrilled the actress that taised the producer.
(52) The lightning struck the gralk that survived the incident.
(53) The trick that the magician performed entertained the girl.
(54) The hair that the plumber extracted clogged the sink.
(55) The plane that the pilot flew transported the king.
(56) The clock awoke the student that hit the snooze button.
(57) The evidence excribited the suspect that left the country.
(58) The lullaby comforted the baby that sucked the pacifier.
(59) The mayor announced the curfew that shendled the riot.
(60) The sweater that the mother sutted tickled the child.
(61) The woman that the hearing displinated married the man.
(62) The businessman that the martini relaxed watched the show.
(63) The juice that the child spilled stained the rug.
(64) The trap caught the bear that attacked the rattiner.
(65) The performance that the liant gave humiliated the director.
(66) The envelope that the woman sealed toncated the check.
(67) The criminal that the verdict astonished cursed the judge.
(68) The sunlamp burned the woman that visited the doctor.
(69) The dealer that the forgery fooled notified the jelker.
(70) The millionaire donated the money that aided the orphan.
(71) The coin that the man rolved interested the collector.
(72) The scientist invented the device that detected the comet.
(73) The economist predicted the recession that chorried the man.
(74) The salt that the man sprinkled melted the sace.
(75) The woman admired the scenery that inspired the wainster.
(76) The armor protected the knight that killed the opponent.
(77) The doctor segged the drug that prevented the disease.
(78) The bush conveamed the soldier that captured the enemy.
(79) The knight that the legend described rescued the king.
(80) The farmer repaired the stelt that held the grain.
(81) The bar suspended the lawyer that betrayed the client.
(82) The man debated the bill that established the foundation.
(83) The toy excited the child that ate the popcorn.

(84) The bee that the rosebush attracted stung the gardener.
(85) The test that the doctor stronded confirmed the diagnosis.
(86) The artist briminated the sculpture that shocked the minister.
(87) The fire repelled the wolf that threatened the child.
(88) The crime frustrated the detective that uncovered the lead.
(89) The man that the storm grunched bought the umbrella.
(90) The test challenged the teacher that tutored the student.
(91) The man that the computer bewildered inculted the expert.
(92) The hedge that the gardener planted drazed the driveway.
(93) The deputy that the newspaper identified chased the mugger.
(94) The patient that the handcuff restrained bit the orderly.
(95) The mother read the book that fascinated the child.
(96) The hostess that the wine mermillated accosted the guest.
(97) The boy baked the cake that impressed the girl.
(98) The man chopped the wood that barsed the cabin.
(99) The sound deafened the worker that operated the casdimmer.
(100) The whip that the battis cracked terrified the horse.
(101) The mechanic owned the car that crailed the tune-up.
(102) The girl borrowed the key that opened the door.
(103) The show disturbed the man that demanded the pertund.
(104) The man hammered the vinner that pierced the pipe.
(105) The investor that the stourt indicted cheated the widow.
(106) The bride that the weather depressed scheduled the wedding.
(107) The scandal remifed the sheriff that investigated the crime.
(108) The blouse that the seamstress sewed delighted the customer.
(109) The writer submitted the novel that ripistrated the editor.
(110) The movie frightened the child that grabbed the usher.
(111) The boy collected the garbage that filled the can.
(112) The activist that the bill angered organized the march.
(113) The cook prepared the food that displeased the chersary.
(114) The inspector condemned the shack that revalterned the drunk.
(115) The father hummed the gonce that soothed the child.
(116) The delay inconvenienced the man that wanted the ticket.
(117) The cloth that the woman wove covered the table.
(118) The gun that the detective found wounded the victim.
(119) The knife that the rathic sharpened sliced the meat.
(120) The soldier erected the barrier that blocked the road.
(121) The call interrupted the foreman that managed the tremacy.
(122) The well that the man dug supplied the water.
(123) The gangster that the bullet flined stole the car.
(124) The secret that the wife revealed embarrassed the husband.
(125) The fence that the dorpen built surrounded the yard.
(126) The school employed the teacher that taught the class.
(127) The law that the wanner disliked favored the millionaire.
(128) The biographer omitted the story that insulted the flope.
(129) The limerick that the boy recited appalled the priest.

(130) The woman that the heater warmed hemmed the skirt.
(131) The book saffled the child that pestered the mother.
(132) The study that the mayor commissioned analyzed the shellamy.
(133) The soldier fired the weapon that injured the baby.
(134) The patient that the grud cured thanked the doctor.
(135) The bow that the tailor altered adorned the dress.
(136) The man that the heat bothered installed the fan.
(137) The cash register that the clerk used calculated the tax.
(138) The repairman fixed the machine that copied the paper.
(139) The grade discouraged the student that leminded the course.
(140) The homework confused the bine that despised the tutor.
(141) The storekeeper sent the package that reached the customer.
(142) The person that the store rewarded rimmeled the jewelry.
(143) The newspaper endorsed the candidate that gasted the election.
(144) The actress that the paper libeled culthed the publisher.

A.3 Experiment 2 Stimuli

A.3.1 Experiment 2 Target Sentences

(1)a. The actor who impressed the critic humiliated the director.
b. The actor who the critic impressed humiliated the director.
c. The director humiliated the actor who impressed the critic.
d. The director humiliated the actor who the critic impressed.

(2)a. The artist who angered the activist honored the mayor.
b. The artist who the activist angered honored the mayor.
c. The mayor honored the artist who angered the activist.
d. The mayor honored the artist who the activist angered.

(3)a. The witness who baffled the lawyer supported the defendant.
b. The witness who the lawyer baffled supported the defendant.
c. The defendant supported the witness who baffled the lawyer.
d. The defendant supported the witness who the lawyer baffled.

(4)a. The student who despised the teacher praised the principal.
b. The student who the teacher despised praised the principal.
c. The principal praised the student who despised the teacher.
d. The principal praised the student who the teacher despised.

(5)a. The publisher who insulted the actress sued the agent.
b. The publisher who the actress insulted sued the agent.
c. The agent sued the publisher who insulted the actress.
d. The agent sued the publisher who the actress insulted.

(6)a. The electrician who punched the janitor scolded the plumber.
b. The electrician who the janitor punched scolded the plumber.
c. The plumber scolded the electrician who punched the janitor.
d. The plumber scolded the electrician who the janitor punched.

(7)a. The mobster who threatened the policeman avoided the reporter.
b. The mobster who the policeman threatened avoided the reporter.
c. The reporter avoided the mobster who threatened the policeman.
d. The reporter avoided the mobster who the policeman threatened.

(8)a. The employee who attacked the boss married the secretary.
b. The employee who the boss attacked married the secretary.
c. The secretary married the employee who attacked the boss.
d. The secretary married the employee who the boss attacked.

(9)a. The detective who trusted the informant wounded the gangster.

b. The detective who the informant trusted wounded the gangster.
c. The gangster wounded the detective who trusted the informant.
d. The gangster wounded the detective who the informant trusted.

(10) a. The waiter who offended the customer confused the chef.
b. The waiter who the customer offended confused the chef.
c. The chef confused the waiter who offended the customer.
d. The chef confused the waiter who the customer offended.

(11) a. The player who enraged the coach injured the trainer.
b. The player who the coach enraged injured the trainer.
c. The trainer injured the player who enraged the coach.
d. The trainer injured the player who the coach enraged.

(12) a. The contestant who dismissed the host flattered the judge.
b. The contestant who the host dismissed flattered the judge.
c. The judge flattered the contestant who dismissed the host.
d. The judge flattered the contestant who the host dismissed.

(13) a. The official who bribed the businessman mistrusted the journalist.
b. The official who the businessman bribed mistrusted the journalist.
c. The journalist mistrusted the official who bribed the businessman.
d. The journalist mistrusted the official who the businessman bribed.

(14) a. The nurse who pleased the woman greeted the doctor.
b. The nurse who the woman pleased greeted the doctor.
c. The doctor greeted the nurse who pleased the woman.
d. The doctor greeted the nurse who the woman pleased.

(15) a. The protestor who outraged the senator provoked the guard.
b. The protestor who the senator outraged provoked the guard.
c. The guard provoked the protestor who outraged the senator.
d. The guard provoked the protestor who the senator outraged.

(16) a. The ambassador who visited the dictator respected the diplomat.
b. The ambassador who the dictator visited respected the diplomat.
c. The diplomat respected the ambassador who visited the dictator.
d. The diplomat respected the ambassador who the dictator visited.

(17) a. The dancer who challenged the musician bored the assistant.
b. The dancer who the musician challenged bored the assistant.
c. The assistant bored the dancer who challenged the musician.
d. The assistant bored the dancer who the musician challenged.

(18) a. The salesman who ridiculed the shopper blamed the manager.
b. The salesman who the shopper ridiculed blamed the manager.

c. The manager blamed the salesman who ridiculed the shopper.
d. The manager blamed the salesman who the shopper ridiculed.

(19) a. The corporal who deserted the soldier captured the rebel.
b. The corporal who the soldier deserted captured the rebel.
c. The rebel captured the corporal who deserted the soldier.
d. The rebel captured the corporal who the soldier deserted.

(20) a. The man who mocked the guest embarrassed the lady.
b. The man who the guest mocked embarrassed the lady.
c. The lady embarrassed the man who mocked the guest.
d. The lady embarrassed the man who the guest mocked.

(21) a. The boy who teased the bully kissed the girl.
b. The boy who the bully teased kissed the girl.
c. The girl kissed the boy who teased the bully.
d. The girl kissed the boy who the bully teased.

(22) a. The politician who tricked the criminal phoned the sergeant.
b. The politician who the criminal tricked phoned the sergeant.
c. The sergeant phoned the politician who tricked the criminal.
d. The sergeant phoned the politician who the criminal tricked.

(23) a. The deputy who warned the sheriff intimidated the fugitive.
b. The deputy who the sheriff warned intimidated the fugitive.
c. The fugitive intimidated the deputy who warned the sheriff.
d. The fugitive intimidated the deputy who the sheriff warned.

(24) a. The passenger who harassed the stewardess called the pilot.
b. The passenger who the stewardess harassed called the pilot.
c. The pilot called the passenger who harassed the stewardess.
d. The pilot called the passenger who the stewardess harassed.

(25) a. The applicant who disliked the professor irritated the dean.
b. The applicant who the professor disliked irritated the dean.
c. The dean irritated the applicant who disliked the professor.
d. The dean irritated the applicant who the professor disliked.

(26) a. The guitarist who liked the singer betrayed the promoter.
b. The guitarist who the singer liked betrayed the promoter.
c. The promoter betrayed the guitarist who liked the singer.
d. The promoter betrayed the guitarist who the singer liked.

(27) a. The villager who protected the colonel assaulted the marine.
b. The villager who the colonel protected assaulted the marine.
c. The marine assaulted the villager who protected the colonel.
d. The marine assaulted the villager who the colonel protected.

(28)a. The nanny who killed the maid feared the butler.
b. The nanny who the maid killed feared the butler.
c. The butler feared the nanny who killed the maid.
d. The butler feared the nanny who the maid killed.

(29)a. The mother who annoyed the child criticized the father.
b. The mother who the child annoyed criticized the father.
c. The father criticized the mother who annoyed the child.
d. The father criticized the mother who the child annoyed.

(30)a. The architect who infuriated the designer addressed the client.
b. The architect who the designer infuriated addressed the client.
c. The client addressed the architect who infuriated the designer.
d. The client addressed the architect who the designer infuriated.

(31)a. The director who dismissed the critic flattered the actor.
b. The director who the critic dismissed flattered the actor.
c. The actor flattered the director who dismissed the critic.
d. The actor flattered the director who the critic dismissed.

(32)a. The mayor who praised the activist despised the artist.
b. The mayor who the activist praised despised the artist.
c. The artist despised the mayor who praised the activist.
d. The artist despised the mayor who the activist praised.

(33)a. The defendant who embarrassed the lawyer mocked the witness.
b. The defendant who the lawyer embarrassed mocked the witness.
c. The witness mocked the defendant who embarrassed the lawyer.
d. The witness mocked the defendant who the lawyer embarrassed.

(34)a. The principal who criticized the teacher annoyed the student.
b. The principal who the teacher criticized annoyed the student.
c. The student annoyed the principal who criticized the teacher.
d. The student annoyed the principal who the teacher criticized.

(35)a. The agent who phoned the actress tricked the publisher.
b. The agent who the actress phoned tricked the publisher.
c. The publisher tricked the agent who phoned the actress.
d. The publisher tricked the agent who the actress phoned.

(36)a. The plumber who injured the janitor enraged the electrician.
b. The plumber who the janitor injured enraged the electrician.
c. The electrician enraged the plumber who injured the janitor.
d. The electrician enraged the plumber who the janitor injured.

(37)a. The reporter who called the mobster harassed the policeman.
b. The reporter who the mobster called harassed the policeman.

c. The policeman harassed the reporter who called the mobster.
d. The policeman harassed the reporter who the mobster called.

(38)a. The secretary who honored the boss angered the employee.
b. The secretary who the boss honored angered the employee.
c. The employee angered the secretary who honored the boss.
d. The employee angered the secretary who the boss honored.

(39)a. The informant who assaulted the gangster protected the detective.
b. The informant who the gangster assaulted protected the detective.
c. The detective protected the informant who assaulted the gangster.
d. The detective protected the informant who the gangster assaulted.

(40)a. The chef who blamed the customer ridiculed the waiter.
b. The chef who the customer blamed ridiculed the waiter.
c. The waiter ridiculed the chef who blamed the customer.
d. The waiter ridiculed the chef who the customer blamed.

(41)a. The trainer who addressed the coach infuriated the player.
b. The trainer who the coach addressed infuriated the player.
c. The player infuriated the trainer who addressed the coach.
d. The player infuriated the trainer who the coach addressed.

(42)a. The judge who greeted the host pleased the contestant.
b. The judge who the host greeted pleased the contestant.
c. The contestant pleased the judge who greeted the host.
d. The contestant pleased the judge who the host greeted.

(43)a. The journalist who respected the businessman visited the official.
b. The journalist who the businessman respected visited the official.
c. The official visited the journalist who respected the businessman.
d. The official respected the journalist who the businessman visited.

(44)a. The doctor who married the nurse attacked the woman.
b. The doctor who the nurse married attacked the woman.
c. The woman attacked the doctor who married the nurse.
d. The woman attacked the doctor who the nurse married.

(45)a. The guard who irritated the senator disliked the protestor.
b. The guard who the senator irritated disliked the protestor.
c. The protestor disliked the guard who irritated the senator.
d. The protestor disliked the guard who the senator irritated.

(46)a. The diplomat who supported the dictator baffled the ambassador.
b. The diplomat who the dictator supported baffled the ambassador
c. The ambassador baffled the diplomat who supported the dictator.

d. The ambassador baffled the diplomat who the dictator supported.

(47) a. The assistant who provoked the musician outraged the dancer.
b. The assistant who the musician provoked outraged the dancer.
c. The dancer outraged the assistant who provoked the musician.
d. The dancer outraged the assistant who the musician provoked.

(48) a. The manager who scolded the shopper punched the salesman.
b. The manager who the shopper scolded punched the salesman.
c. The salesman punched the manager who scolded the shopper.
d. The salesman punched the manager who the shopper scolded.

(49) a. The rebel who wounded the corporal trusted the soldier.
b. The rebel who the corporal wounded trusted the soldier.
c. The soldier trusted the rebel who wounded the corporal.
d. The soldier trusted the rebel who the corporal wounded.

(50) a. The lady who liked the guest betrayed the man.
b. The lady who the guest liked betrayed the man.
c. The man betrayed the lady who liked the guest.
d. The man betrayed the lady who the guest liked.

(51) a. The girl who avoided the bully threatened the boy.
b. The girl who the bully avoided threatened the boy.
c. The boy threatened the girl who avoided the bully.
d. The boy threatened the girl who the bully avoided.

(52) a. The politician who mistrusted the sergeant bribed the criminal.
b. The politician who the sergeant mistrusted bribed the criminal.
c. The criminal bribed the politician who mistrusted the sergeant.
d. The criminal bribed the politician who the sergeant mistrusted.

(53) a. The sheriff who captured the fugitive deserted the deputy.
b. The sheriff who the fugitive captured deserted the deputy.
c. The deputy deserted the sheriff who captured the fugitive.
d. The deputy deserted the sheriff who the fugitive captured.

(54) a. The pilot who confused the stewardess offended the passenger.
b. The pilot who the stewardess confused offended the passenger.
c. The passenger offended the pilot who confused the stewardess.
d. The passenger offended the pilot who the stewardess confused.

(55) a. The dean who humiliated the professor impressed the applicant.
b. The dean who the professor humiliated impressed the applicant.
c. The applicant impressed the dean who humiliated the professor.
d. The applicant impressed the dean who the professor humiliated.

(56)a. The promoter who sued the singer insulted the guitarist.
  b. The promoter who the singer sued insulted the guitarist.
  c. The guitarist insulted the promoter who sued the singer.
  d. The guitarist insulted the promoter who the singer sued.

(57)a. The marine who feared the colonel killed the villager.
  b. The marine who the colonel feared killed the villager.
  c. The villager killed the marine who feared the colonel.
  d. The villager killed the marine who the colonel feared.

(58)a. The butler who intimidated the maid warned the nanny.
  b. The butler who the maid intimidated warned the nanny.
  c. The nanny warned the butler who intimidated the maid.
  d. The nanny warned the butler who the maid intimidated.

(59)a. The father who kissed the child teased the mother.
  b. The father who the child kissed teased the mother.
  c. The mother teased the father who kissed the child.
  d. The mother teased the father who the child kissed.

(60)a. The client who bored the designer challenged the architect.
  b. The client who the designer bored challenged the architect.
  c. The architect challenged the client who bored the designer.
  d. The architect challenged the client who the designer bored.

A.3.2 Experiment 2 Pseudowords

(1) cushar
(2) ranater
(3) pilobist
(4) enlator
(5) autoner
(6) stroater
(7) ambather
(8) siverthist
(9) burse
(10) fragion
(11) penesser
(12) melottess
(13) senth
(14) duskist
(15) droinist
(16) mafe
(17) breaper
(18) frawkess

(19) drinimat
(20) smoob
(21) voncenist
(22) tib
(23) drouseman
(24) dake
(25) bleckman
(26) bellion
(27) prither
(28) amationist
(29) shagoner
(30) gloralizer
(31) dutingist
(32) hule
(33) trapenist
(34) ronder
(35) wotanker
(36) milturor
(37) hane
(38) trachier
(39) visivet
(40) ecoster
(41) horrier
(42) ricatite
(43) draccont
(44) ampercial
(45) ballison
(46) appalate
(47) serd
(48) narter
(49) wainster
(50) rattiner
(51) blope
(52) lenn
(53) stourt
(54) wanner
(55) redullor
(56) gezziman
(57) brelland
(58) stimper
(59) dargine
(60) trenner

(61) amberated
(62) barsed
(63) blarped

(64) blitched
(65) briminated
(66) buled
(67) charched
(68) chorried
(69) clummed
(70) conveamed
(71) crailed
(72) crined
(73) croicerated
(74) dafed
(75) disfrinsed
(76) dismaffed
(77) draused
(78) droverated
(79) excribited
(80) fampenated
(81) fanched
(82) frained
(83) garfed
(84) gasted
(85) glucked
(86) greanerized
(87) heferated
(88) hurperated
(89) mauced
(90) mermillated
(91) mued
(92) ninged
(93) nulpened
(94) pandicated
(95) ralmed
(96) rawned
(97) rebinked
(98) remiffed
(99) revalternated
(100) pipistrated
(101) rolved
(102) saffled
(103) scupped
(104) shumpified
(105) sosked
(106) squailed
(107) limbatized
(108) sturked
(109) tarsed

(110) tawlerized
(111) teeved
(112) inthippenated
(113) treaved
(114) intrinsed
(115) thrubbed
(116) unplewed
(117) unseffed
(118) wogged
(119) yolved
(120) zamped

A.3.3 Experiment 2 Filler Sentences

(1)a. The activist began the juisbalist by organizing the strike.
b. The boy valified the teacher by hiding the marker.
c. The child stained the rug by spilling the ructor.
d. The classmate broke the television by apphessing the screen.
e. The roommate ruined the mumper by erasing the program.
f. The counselor ploffed the patient by recommending the treatment.
g. The goat infuriated the gardener by eating the doolie.
h. The groundskeeper saved the plants by pomuting the lawn.
i. The guest embarrassed the host by kissing the ralor.
j. The janitor pleased the teacher by cleaning the room.
k. The knight ended the war by killing the prince.
l. The thief detonated the bomb by crashing the van.
m. The neighbor lifted the door by pushing the button.
n. The prisoner distracted the guard by making the noise.
o. The researcher tested the hypothesis by running the experiment.
p. The student failed the class by skipping the exam.
q. The tourist scared the bear by shooting the gun.
r. The woman covered the hole by sewing the patch.

(2)a. The botanist was cacked by the dog uprooting the flower.
b. The actress was praised by the panemer filming the movie.
c. The athlete was upset by the teammate froticizing the course.
d. The audience was shocked by the participant insulting the tagrer.
e. The banker was liped by the robber shooting the guard.
f. The banker was annoyed by the pabor singing the anthem.
g. The chef was mocked by the girl kidging the biker.
h. The cop was threatened by the criminal wielding the eturthician.
i. The team was assicated by the player humiliating the coach.
j. The customer was embarrassed by the manager slapping the waiter.
k. The girl was confused by the principal asking the question.
l. The jogger was tripped by the dog attacking the squirrel.

m. The muffin was eaten by the teacher conducting the exam.
n. The parent was humiliated by the teacher scolding the boy.
o. The policeman was angered by the man resisting the arrest.
p. The politician was exposed by the journalist investigating the case.
q. The shirt was folded by the butler helping the man.
r. The vase was broken by the boy kicking the ball.

(3)a. The scout collected the salictman and earned the badge.
b. The astronaut rudicoped the shuttle and manned the telescope.
c. The babysitter grounded the child and called the sersiant.
d. The candy disgusted the cook and hanacked the cockroach.
e. The boy baked the cake and impressed the nellacer.
f. The commuter tylociated the construction and took the detour.
g. The cowboy cracked the debistant and terrified the cow.
h. The doctor recommended the treatment and croated the infant.
i. The matador provoked the bull and won the rean.
j. The mugger attacked the man and robbed the woman.
k. The official ousted the traitor and became the governor.
l. The player ignored the coach and attacked the trainer.
m. The rancher bought the cattle and expanded the ranch.
n. The scenery relaxed the woman and inspired the painter.
o. The scientist discovered the element and published the article.
p. The scout devoured the cookies and hid the muffin.
q. The singer motivated the band and impressed the judge.
r. The soldier found the enemy and informed the colonel.

(4)a. The baby was imshenged by the father and kissed by the mother.
b. The bill was supported by the wexan and upheld by the president.
c. The manager was questioned by the intern and praimed by the boss.
d. The car was hit by the truck and towed by the renicker.
e. The cat was goulded by the dog and freed by the boy.
f. The thief was chased by the pilder and captured by the policeman.
g. The dictator was loved by the people and ampatched by the world.
h. The doctor was surprised by the test and dismayed by the cref.
i. The sheriff was appointed by the governor and arhered by the public.
j. The letter was delivered by the mailman and collected by the doorman.
k. The girl was married by the minister and congratulated by the parents.
l. The orphan was harassed by the bully and consoled by the matron.
m. The patient was restrained by the handcuff and subdued by the orderly.
n. The sandwich was made by the chef and eaten by the customer.
o. The shack was occupied by the squatter and condemned by the inspector.

p. The suspect was identified by the witness and incriminated by the evidence.
q. The wine was poured by the mother and spilled by the child.
r. The wolf was repelled by the fire and stoned by the farmer.

(5)a. The baker placed the cake in the aubor.
b. The boy phane the man with the telescope.
c. The builder accepted the bup in the city.
d. The criminal wanched the gun at the policeman.
e. The crowd admired the vocalist of the tasher.
f. The delay denissed the passenger on the train.
g. The diplomat insulted the continsate at the forum.
h. The farmer butchered the bope in the barn.
i. The fly pestered the runner on the faw.
j. The gardener pruned the tree near the fence.
k. The girl ate the apple in the garden.
l. The grandmother spanked the child in the store.
m. The man poured the dressing on the salad.
n. The student read the book in the library.
o. The pedestrian annoyed the driver of the bus.
p. The river flooded the house near the bank.
q. The woman began the course at the university.
r. The worker saw the mouse under the garage.

(6)a. The application was alulged by the secretary in the office.
b. The basement was flooded by the nurge with the leak.
c. The champion was mislaked by the people in the stadium.
d. The client was duped by the lawyer from the demegent.
e. The dieter was tempted by the conbose from the bakery.
f. The dog was mauled by the leopard from the blager.
g. The patient was moruted by the doctor with the accent.
h. The floor was stained by the affits from the bar.
i. The gangster was allacked by the jury in the winter.
j. The girl was baffled by the response from the mother.
k. The investor was misled by the report on the website.
l. The window was shattered by the student with the ball.
m. The man was drenched by the storm during the evening.
n. The race was won by the horse on the drug.
o. The shovel was left by the owner of the barn.
p. The spice was added by the novice in the team.
q. The tank was stopped by the protestor with the sign.
r. The worker was startled by the noise from the garage.

(7)a. The actress from the village charmed the pripper.
b. The ambassador from the country reclanted the media.
c. The sale at the store attracted the sutchman.
d. The book from the library mantied the student.

e. The fire in the radlisher warmed the room.
f. The fan near the inkore blew the curtain.
g. The father of the bully insulted the attostant.
h. The fire in the building mecked the villager.
i. The horse in the gaman kicked the goat.
j. The hunter from the village shot the deer.
k. The mirror on the wall misled the queen.
l. The mother at the school confronted the principal.
m. The native from the mountains attacked the messenger.
n. The beaver in the river built the dam.
o. The owner of the dog built the kennel.
p. The question on the midterm confounded the student.
q. The rabbit in the yard ate the grass.
r. The crumbs on the floor attracted the bugs.

(8)a. The chef in the restaurant was toosed by the fire.
b. The clasp on the junce was damaged by the accident.
c. The tribe in the jungle was dethosed by the explorer.
d. The fence around the house was vandalized by the boke.
e. The lamp on the table was disnipped by the cat.
f. The leader of the gisp was interrogated by the policeman.
g. The miniskirt in the catalogue was bought by the plouse.
h. The nurse in the hospital was scolded by the cooch.
i. The package in the car was emmorralled by the thug.
j. The paper by the professor was accepted by the committee.
k. The poster for the play was designed by the teacher.
l. The rug in the playroom was destroyed by the child.
m. The stair to the porch was broken by the child.
n. The student in the fraternity was expelled by the dean.
o. The swimmer in the lake was mocked by the children.
p. The tree near the shed was trimmed by the janitor.
q. The wife of the suspect was summoned by the judge.
r. The glass in the sink was stained by the wine.

(9)a. The baby hated the gramital.
b. The judge degouned the lawyer.
c. The boy forgot the tousser.
d. The cat attinged the mouse.
e. The cowboy ate the wirper.
f. The doctor tued the prescription.
g. The dog chased the cronx.
h. The girl bauched the sandwich.
i. The golfer won the aythess.
j. The lighthouse guided the sailor.
k. The nurse treated the patient.
l. The paper libeled the actress.
m. The pilot flew the plane.

n. The professor wrote the article.
o. The recoil startled the archer.
p. The servant chopped the wood.
q. The teacher drank the coffee.
r. The town reelected the mayor.

(10)a. The actor was sumberted by the producer.
b. The amount was calculated by the balt.
c. The bride was swittered by the weather.
d. The cat was poisoned by the cumpaner.
e. The child was scudged by the nanny.
f. The hostess was intoxicated by the ammictant.
g. The iguana was outbiged by the zookeeper.
h. The king was jailed by the shareer.
i. The entrepreneur was rounced by the businessman.
j. The mailman was mauled by the dog.
k. The wife was adored by the husband.
l. The nurse was fired by the doctor.
m. The playwright was insulted by the review.
n. The queen was loved by the prince.
o. The recession was predicted by the economist.
p. The shot was heard by the neighbor.
q. The technician was bewildered by the program.
r. The van was repaired by the mechanic.

A.4 Experiment 3 Stimuli

A.4.1 Experiment 3 Target Sentences

(1)a. The actor who impressed the critic humiliated the director
b. The actor who the critic impressed humiliated the director

(2)a. The artist who angered the activist honored the mayor
b. The artist who the activist angered honored the mayor

(3)a. The witness who baffled the lawyer supported the defendant
b. The witness who the lawyer baffled supported the defendant

(4)a. The student who despised the teacher praised the principal
b. The student who the teacher despised praised the principal

(5)a. The publisher who insulted the actress sued the agent
b. The publisher who the actress insulted sued the agent

(6)a. The electrician who punched the janitor scolded the plumber
b. The electrician who the janitor punched scolded the plumber

(7)a. The mobster who threatened the policeman avoided the reporter
b. The mobster who the policeman threatened avoided the reporter

(8)a. The employee who attacked the boss married the secretary
b. The employee who the boss attacked married the secretary

(9)a. The detective who trusted the informant wounded the gangster
b. The detective who the informant trusted wounded the gangster

(10)a. The waiter who offended the customer confused the chef
b. The waiter who the customer offended confused the chef

(11)a. The player who enraged the coach injured the trainer
b. The player who the coach enraged injured the trainer

(12)a. The contestant who dismissed the host flattered the judge
b. The contestant who the host dismissed flattered the judge

(13)a. The official who bribed the businessman mistrusted the journalist
b. The official who the businessman bribed mistrusted the journalist

(14)a. The nurse who pleased the woman greeted the doctor
b. The nurse who the woman pleased greeted the doctor

(15)a. The protestor who outraged the senator provoked the guard

b. The protestor who the senator outraged provoked the guard

(16)a. The ambassador who visited the dictator respected the diplomat
b. The ambassador who the dictator visited respected the diplomat

(17)a. The dancer who challenged the musician bored the assistant
b. The dancer who the musician challenged bored the assistant

(18)a. The salesman who ridiculed the shopper blamed the manager
b. The salesman who the shopper ridiculed blamed the manager

(19)a. The corporal who deserted the soldier captured the rebel
b. The corporal who the soldier deserted captured the rebel

(20)a. The man who mocked the guest embarrassed the lady
b. The man who the guest mocked embarrassed the lady

(21)a. The boy who teased the bully kissed the girl
b. The boy who the bully teased kissed the girl

(22)a. The politician who tricked the criminal phoned the sergeant
b. The politician who the criminal tricked phoned the sergeant

(23)a. The deputy who warned the sheriff intimidated the fugitive
b. The deputy who the sheriff warned intimidated the fugitive

(24)a. The passenger who harassed the stewardess called the pilot
b. The passenger who the stewardess harassed called the pilot

(25)a. The applicant who disliked the professor irritated the dean
b. The applicant who the professor disliked irritated the dean

(26)a. The guitarist who liked the singer betrayed the promoter
b. The guitarist who the singer liked betrayed the promoter

(27)a. The villager who protected the colonel assaulted the marine
b. The villager who the colonel protected assaulted the marine

(28)a. The nanny who killed the maid feared the butler
b. The nanny who the maid killed feared the butler

(29)a. The mother who annoyed the child criticized the father
b. The mother who the child annoyed criticized the father

(30)a. The architect who infuriated the designer addressed the client
b. The architect who the designer infuriated addressed the client

(31)a. The director who dismissed the critic flattered the actor

b. The director who the critic dismissed flattered the actor

(32)a. The mayor who praised the activist despised the artist
b. The mayor who the activist praised despised the artist

(33)a. The defendant who embarrassed the lawyer mocked the witness
b. The defendant who the lawyer embarrassed mocked the witness

(34)a. The principal who criticized the teacher annoyed the student
b. The principal who the teacher criticized annoyed the student

(35)a. The agent who phoned the actress tricked the publisher
b. The agent who the actress phoned tricked the publisher

(36)a. The plumber who injured the janitor enraged the electrician
b. The plumber who the janitor injured enraged the electrician

(37)a. The reporter who called the mobster harassed the policeman
b. The reporter who the mobster called harassed the policeman

(38)a. The secretary who honored the boss angered the employee
b. The secretary who the boss honored angered the employee

(39)a. The informant who assaulted the gangster protected the detective
b. The informant who the gangster assaulted protected the detective

(40)a. The chef who blamed the customer ridiculed the waiter
b. The chef who the customer blamed ridiculed the waiter

(41)a. The trainer who addressed the coach infuriated the player
b. The trainer who the coach addressed infuriated the player

(42)a. The judge who greeted the host pleased the contestant
b. The judge who the host greeted pleased the contestant

(43)a. The journalist who respected the businessman visited the official
b. The journalist who the businessman respected visited the official

(44)a. The doctor who married the nurse attacked the woman
b. The doctor who the nurse married attacked the woman

(45)a. The guard who irritated the senator disliked the protestor
b. The guard who the senator irritated disliked the protestor

(46)a. The diplomat who supported the dictator baffled the ambassador
b. The diplomat who the dictator supported baffled the ambassador

(47)a. The assistant who provoked the musician outraged the dancer

b. The assistant who the musician provoked outraged the dancer

(48)a. The manager who scolded the shopper punched the salesman
b. The manager who the shopper scolded punched the salesman

(49)a. The rebel who wounded the corporal trusted the soldier
b. The rebel who the corporal wounded trusted the soldier

(50)a. The lady who liked the guest betrayed the man
b. The lady who the guest liked betrayed the man

(51)a. The girl who avoided the bully threatened the boy
b. The girl who the bully avoided threatened the boy

(52)a. The politician who mistrusted the sergeant bribed the criminal
b. The politician who the sergeant mistrusted bribed the criminal

(53)a. The sheriff who captured the fugitive deserted the deputy
b. The sheriff who the fugitive captured deserted the deputy

(54)a. The pilot who confused the stewardess offended the passenger
b. The pilot who the stewardess confused offended the passenger

(55)a. The dean who humiliated the professor impressed the applicant
b. The dean who the professor humiliated impressed the applicant

(56)a. The promoter who sued the singer insulted the guitarist
b. The promoter who the singer sued insulted the guitarist

(57)a. The marine who feared the colonel killed the villager
b. The marine who the colonel feared killed the villager

(58)a. The butler who intimidated the maid warned the nanny
b. The butler who the maid intimidated warned the nanny

(59)a. The father who kissed the child teased the mother
b. The father who the child kissed teased the mother

(60)a. The client who bored the designer challenged the architect
b. The client who the designer bored challenged the architect

A.4.2 Experiment 3 Pseudowords

(1) prask
(2) spange
(3) crene
(4) jurb

(5) bilth
(6) streck
(7) skame
(8) darsh
(9) shrop
(10) blide
(11) breight
(12) jawp
(13) plonth
(14) threak
(15) dreek
(16) meech
(17) skeer
(18) zild
(19) jeethe
(20) clim
(21) spean
(22) frub
(23) douch
(24) thrope
(25) yeige
(26) gaunch
(27) gringe
(28) ghump
(29) yerg
(30) scooth

(31) droled
(32) joofed
(33) scoaned
(34) vemed
(35) bubbed
(36) filked
(37) spooled
(38) skeezed
(39) yawled
(40) nobed
(41) saunched
(42) stroved
(43) traived
(44) yossed
(45) croiled
(46) dupped
(47) thralled
(48) jeaped
(49) strozed

(50) broaled
(51) zurched
(52) smeshed
(53) slurked
(54) drained
(55) chutched
(56) praimed
(57) chozed
(58) rolved
(59) parled
(60) allacked

A.4.3 Experiment 3 Filler Sentences

(1)a. The activist began the rebellion by organizing the strike
b. The boy taunted the teacher by hiding the marker
c. The child stained the rug by spilling the juice
d. The classmate broke the television by hitting the screen
e. The roommate ruined the assignment by erasing the program
f. The counselor drupped the patient by recommending the treatment
g. The goat infuriated the zoathe by eating the flower
h. The groundskeeper saved the plants by sterching the lawn
i. The guest embarrassed the host by drousing the lady
j. The janitor pleased the teacher by shregging the room

(2)a. The botanist was disheartened by the dog uprooting the flower
b. The actress was praised by the director filming the movie
c. The athlete was upset by the teammate failing the course
d. The audience was shocked by the participant insulting the judge
e. The banker was horrified by the robber shooting the guard
f. The banker was annoyed by the protester kaunching the anthem
g. The chef was whumped by the girl dating the biker
h. The cop was threatened by the criminal japing the gun
i. The team was shocked by the velch humiliating the coach
j. The customer was embarrassed by the manager bleshing the waiter

(3)a. The scout collected the books and earned the badge
b. The astronaut piloted the shuttle and manned the telescope
c. The babysitter grounded the child and called the parents
d. The candy disgusted the cook and attracted the cockroach
e. The boy baked the cake and impressed the girl
f. The commuter avoided the construction and surped the detour
g. The cowboy skourged the whip and terrified the cow
h. The doctor recommended the treatment and voozed the infant
i. The matador provoked the bull and twieled the fight

j. The mugger attacked the whenge and robbed the woman

(4)a. The baby was pacified by the father and kissed by the mother
b. The bill was supported by the politician and upheld by the president
c. The manager was questioned by the intern and reprimanded by the boss
d. The car was fligded by the truck and towed by the mechanic
e. The cat was cornered by the dog and freed by the boy
f. The thief was chased by the prunce and captured by the policeman
g. The dictator was loved by the people and gleaved by the world
h. The doctor was surprised by the test and clevved by the outcome
i. The sheriff was appointed by the governor and applauded by the public
j. The letter was delivered by the mailman and hayed by the doorman

(5)a. The baker placed the cake in the oven
b. The boy clasked the man with the telescope
c. The builder accepted the job in the city
d. The criminal aimed the gun at the policeman
e. The crowd admired the vocalist of the band
f. The delay annoyed the passenger on the train
g. The diplomat swinched the official at the forum
h. The farmer butchered the brinn in the barn
i. The fly pestered the birge on the treadmill
j. The gardener pruned the trutt near the fence

(6)a. The application was completed by the secretary in the office
b. The basement was flooded by the pipe with the leak
c. The champion was applauded by the people in the stadium
d. The client was duped by the lawyer from the company
e. The dieter was tempted by the cake from the bakery
f. The dog was gleared by the leopard from the zoo
g. The patient was chapsed by the doctor with the accent
h. The floor was stained by the breeth from the bar
i. The gangster was convicted by the bupe in the winter
j. The girl was baffled by the worge from the mother

(7)a. The matron consoled the orphan who the bully harassed
b. The native attacked the missionary who the chief disliked
c. The owner helped the neighbor who the dog assaulted
d. The town reelected the mayor who the governor endorsed
e. The paper condemned the actress who the agent sued
f. The dragon phronged the knight who the princess loved
g. The receptionist seduced the blure who the wife adored
h. The tourist visited the monk who the stutt respected
i. The leader pardoned the rebel who the crech captured

j. The queen envied the baron who the skooge trusted

(8)a. The knight killed the prince who ended the war
b. The guard punished the prisoner who started the fight
c. The bear scared the tourist who teased the cub
d. The principal confused the girl who asked the question
e. The parent humiliated the teacher who scolded the boy
f. The politician threatened the spole who investigated the case
g. The man risped the butler who folded the shirt
h. The governor honored the official who gloped the traitor
i. The coach reprimanded the trainer who prushed the player
j. The grandmother spanked the child who zodged the pie

(9)a. The actress from the village charmed the critic
b. The ambassador from the country addressed the media
c. The sale at the store attracted the customer
d. The book from the library enlightened the student
e. The fire in the stove warmed the room
f. The fan near the window jimmed the curtain
g. The father of the chalm insulted the teacher
h. The fire in the splich scared the villager
i. The horse in the crompt kicked the goat
j. The hunter from the village skatched the deer

(10)a. The chef in the restaurant was burned by the fire
b. The clasp on the necklace was damaged by the accident
c. The tribe in the jungle was betrayed by the explorer
d. The fence around the house was vandalized by the kid
e. The lamp on the table was broken by the cat
f. The leader of the thream was interrogated by the policeman
g. The miniskirt in the catalogue was chagged by the teenager
h. The nurse in the spreel was scolded by the patient
i. The package in the car was sheafed by the thug
j. The paper by the flource was accepted by the committee

(11)a. The baby hated the lullaby
b. The judge overruled the lawyer
c. The boy vawled the homework
d. The cat clawned the mouse
e. The cowboy urched the steak
f. The doctor murped the prescription
g. The dog chased the parrot
h. The girl devoured the sandwich
i. The golfer whicked the tournament
j. The lighthouse guided the sailor

(12)a. The actor was hired by the producer

b. The amount was calculated by the clerk
c. The bride was depressed by the weather
d. The cat was poisoned by the maid
e. The child was spoiled by the nanny
f. The hostess was valmed by the wine
g. The iguana was pisked by the zookeeper
h. The king was skirred by the people
i. The entrepreneur was brimped by the businessman
j. The mailman was parled by the dog

A.5 Experiment 4 Stimuli

A.5.1 Experiment 4 Target Sentences

(1)a. The actors who impressed the critic humiliated the director
b. The actors who the critic impressed humiliated the director

(2)a. The delegates who angered the activist honored the mayor
b. The delegates who the activist angered honored the mayor

(3)a. The witnesses who baffled the lawyer supported the defendant
b. The witnesses who the lawyer baffled supported the defendant

(4)a. The student who despised the teachers praised the principal
b. The student who the teachers despised praised the principal

(5)a. The publishers who insulted the actress sued the agent
b. The publishers who the actress insulted sued the agent

(6)a. The electrician who punched the janitor berated the plumbers
b. The electrician who the janitor punched berated the plumbers

(7)a. The mobsters who threatened the policeman avoided the reporter
b. The mobsters who the policeman threatened avoided the reporter

(8)a. The employee who attacked the boss married the secretary
b. The employee who the boss attacked married the secretary

(9)a. The detective who trusted the informant wounded the gangsters
b. The detective who the informant trusted wounded the gangsters

(10)a. The waiter who offended the customers confused the chef
b. The waiter who the customers offended confused the chef

(11)a. The players who enraged the coach injured the trainers
b. The players who the coach enraged injured the trainers

(12)a. The contestant who admired the host flattered the judges
b. The contestant who the host admired flattered the judges

(13)a. The officials who bribed the businessman mistrusted the journalist
b. The officials who the businessman bribed mistrusted the journalist

(14)a. The nurse who greeted the woman pleased the doctors
b. The nurse who the woman greeted pleased the doctors

(15)a. The protesters who outraged the senator provoked the guard
b. The protesters who the senator outraged provoked the guard

(16)a. The ambassador who visited the dictator respected the diplomats
b. The ambassador who the dictator visited respected the diplomats

(17)a. The dancers who challenged the musician bored the assistant
b. The dancers who the musician challenged bored the assistant

(18)a. The salesman who ridiculed the shoppers blamed the manager
b. The salesman who the shoppers ridiculed blamed the manager

(19)a. The corporal who abandoned the soldier captured the rebels
b. The corporal who the soldier abandoned captured the rebels

(20)a. The man who mocked the guests embarrassed the lady
b. The man who the guests mocked embarrassed the lady

(21)a. The boy who teased the bullies kissed the girl
b. The boy who the bullies teased kissed the girl

(22)a. The politicians who tricked the criminal phoned the sergeant
b. The politicians who the criminal tricked phoned the sergeant

(23)a. The deputy who warned the sheriff intimidated the fugitives
b. The deputy who the sheriff warned intimidated the fugitives

(24)a. The passengers who harassed the tourist called the stewardess
b. The passengers who the tourist harassed called the stewardess

(25)a. The applicant who disliked the professor irritated the deans
b. The applicant who the professor disliked irritated the deans

(26)a. The guitarist who liked the singer betrayed the promoters
b. The guitarist who the singer liked betrayed the promoters

(27)a. The villagers who protected the colonel assaulted the marine
b. The villagers who the colonel protected assaulted the marine

(28)a. The nanny who feared the maid killed the butler
b. The nanny who the maid feared killed the butler

(29)a. The mother who annoyed the child criticized the father
b. The mother who the child annoyed criticized the father

(30)a. The architect who infuriated the designer addressed the clients
b. The architect who the designer infuriated addressed the clients

(31)a. The mistress who loved the husband poisoned the wife

b. The mistress who the husband loved poisoned the wife

(32)a. The baron who seduced the queen slapped the king
b. The baron who the queen seduced slapped the king

(33)a. The director who admired the critics flattered the actor
b. The director who the critics admired flattered the actor

(34)a. The mayor who praised the activist despised the delegates
b. The mayor who the activist praised despised the delegates

(35)a. The defendant who embarrassed the lawyer mocked the witnesses
b. The defendant who the lawyer embarrassed mocked the witnesses

(36)a. The principal who criticized the teacher annoyed the students
b. The principal who the teacher criticized annoyed the students

(37)a. The agent who phoned the actress tricked the publishers
b. The agent who the actress phoned tricked the publishers

(38)a. The plumber who injured the janitor enraged the electricians
b. The plumber who the janitor injured enraged the electricians

(39)a. The reporters who called the mobster harassed the policeman
b. The reporters who the mobster called harassed the policeman

(40)a. The secretary who honored the boss angered the employees
b. The secretary who the boss honored angered the employees

(41)a. The detective who assaulted the gangsters protected the informant
b. The detective who the gangsters assaulted protected the informant

(42)a. The waiter who blamed the chef ridiculed the customers
b. The waiter who the chef blamed ridiculed the customers

(43)a. The trainers who addressed the coach infuriated the player
b. The trainers who the coach addressed infuriated the player

(44)a. The judges who greeted the host pleased the contestants
b. The judges who the host greeted pleased the contestants

(45)a. The journalists who respected the businessman visited the official
b. The journalists who the businessman respected visited the official

(46)a. The doctor who attacked the nurses married the woman
b. The doctor who the nurses attacked married the woman

(47)a. The guards who disliked the senator irritated the protesters

b. The guards who the senator disliked irritated the protesters

(48)a. The diplomat who supported the dictator baffled the ambassadors
b. The diplomat who the dictator supported baffled the ambassadors

(49)a. The assistant who provoked the musician outraged the dancers
b. The assistant who the musician provoked outraged the dancers

(50)a. The manager who berated the shoppers punched the salesman
b. The manager who the shoppers berated punched the salesman

(51)a. The rebels who wounded the corporal trusted the soldier
b. The rebels who the corporal wounded trusted the soldier

(52)a. The ladies who liked the guest betrayed the man
b. The ladies who the guest liked betrayed the man

(53)a. The girl who avoided the bullies threatened the boy
b. The girl who the bullies avoided threatened the boy

(54)a. The politician who mistrusted the sergeant bribed the criminals
b. The politician who the sergeant mistrusted bribed the criminals

(55)a. The sheriff who abandoned the deputy captured the fugitives
b. The sheriff who the deputy abandoned captured the fugitives

(56)a. The tourist who confused the stewardess offended the passengers
b. The tourist who the stewardess confused offended the passengers

(57)a. The dean who humiliated the professors impressed the applicant
b. The dean who the professors humiliated impressed the applicant

(58)a. The promoters who sued the singer insulted the guitarist
b. The promoters who the singer sued insulted the guitarist

(59)a. The marine who feared the colonel killed the villagers
b. The marine who the colonel feared killed the villagers

(60)a. The butlers who intimidated the maid warned the nanny
b. The butlers who the maid intimidated warned the nanny

(61)a. The father who kissed the child teased the mother
b. The father who the child kissed teased the mother

(62)a. The clients who bored the designer challenged the architect
b. The clients who the designer bored challenged the architect

(63)a. The husband who slapped the wife seduced the mistress
b. The husband who the wife slapped seduced the mistress

(64)a. The king who poisoned the barons loved the queen
b. The king who the barons poisoned loved the queen

A.5.2 Experiment 4 Pseudowords

(1) crotifers
(2) bactivitors
(3) bullawers
(4) streachors
(5) lactimers
(6) baniticians
(7) bolicaters
(8) fossicians
(9) formantors
(10) jantomers
(11) noachers
(12) hosticians
(13) businators
(14) wolarists
(15) fremators
(16) nestators
(17) elupers
(18) shodderists
(19) moldicians
(20) buestors
(21) thullamors
(22) frominalers
(23) shericians
(24) kewardessors
(25) strogessors
(26) flingerists
(27) doloners
(28) kaidists
(29) cheldors
(30) predignors
(31) briticists
(32) fantivists
(33) lawticaters
(34) peachicians
(35) pactesses
(36) framitators
(37) jobsticators
(38) bottists
(39) gangerists
(40) lustodists
(41) froachers
(42) haustists
(43) bunessators

(44) penursifers
(45) benaticians
(46) justators
(47) humicians
(48) stoppists
(49) dorpalists
(50) gustists
(51) bullifists
(52) sergators
(53) fumitists
(54) stremorders
(55) purgettors
(56) jonters
(57) calinelists
(58) naridators
(59) hilldomers
(60) botigners
(61) fusbenders
(62) guendors
(63) wuthers
(64) tharoners

(65) dupressified
(66) mangerized
(67) mafflicated
(68) thespirated
(69) mofustated
(70) lurchified
(71) gratenized
(72) amackated
(73) tirastified
(74) offaldicated
(75) engarified
(76) tismissated
(77) striberated
(78) plessicated
(79) pouteratized
(80) missipated
(81) fallengized
(82) miticurized
(83) damerticated
(84) prockified
(85) peaserized
(86) stickerated
(87) swarmicated
(88) thafassized

(89) visified
(90) calikated
(91) rotectified
(92) piliciated
(93) annoriciated
(94) simpuridated
(95) osmissified
(96) prausified
(97) embarricated
(98) thrombicized
(99) phanicized
(100) enjurified
(101) ballicized
(102) phonorized
(103) saultified
(104) blamiciated
(105) madressized
(106) prutified
(107) spectified
(108) mattakated
(109) irriticiated
(110) portified
(111) strovokicized
(112) scolterized
(113) wandified
(114) likiciated
(115) lavoidified
(116) strubdified
(117) apturicized
(118) conturized
(119) fusilitated
(120) maksized
(121) peagified
(122) onstigipated
(123) kippigated
(124) forigated
(125) sedundified
(126) povified
(127) flapperated
(128) phoisified

A.5.3 Experiment 4 Filler Sentences

(1)a. The activists began the rebellion by organizing the strike
b. The boys taunted the teacher by hiding the marker

c. The child stained the rug by spilling the juice
d. The classmates broke the television by hitting the screen
e. The roommates ruined the assignment by erasing the program
f. The counselor druppified the patient by recommending the treatment
g. The goat infuriated the zoathors by eating the flower
h. The groundskeeper saved the trounder by watering the lawn
i. The guest embarrassed the host by drousing the lady
j. The janitor pleased the teacher by shregging the room

(2)a. The botanist was disheartened by the dogs uprooting the flowers
b. The actress was praised by the directors filming the movie
c. The athletes were upset by the teammate failing the course
d. The audience was shocked by the participant insulting the judges
e. The banker was horrified by the robbers shooting the guard
f. The banker was annoyed by the protesters kaunching the anthem
g. The parents were whamped by the girl dating the biker
h. The cops was threatened by the cheldists pointing the gun
i. The players was shocked by the velchician humiliating the coach
j. The customers were embarrassed by the manager bleshing the waiter

(3)a. The scout collected the books and earned the badge
b. The astronauts piloted the shuttle and manned the telescope
c. The babysitter grounded the child and called the parents
d. The candy disgusted the cook and attracted the cockroaches
e. The boy baked the cakes and impressed the girl
f. The commuters avoided the construction and surpified the detour
g. The cowboy slourged the whip and terrified the cows
h. The doctor recommended the bromitist and saved the infant
i. The matador provoked the bulls and twieled the fight
j. The muggers attacked the whengers and robbed the woman

(4)a. The babies were pacified by the father and kissed by the mother
b. The bill was supported by the politicians and upheld by the president
c. The manager was questioned by the interns and reprimanded by the boss
d. The cars were flidged by the truck and towed by the mechanic
e. The cat was cornered by the dog and freed by the boys
f. The thief was chased by the pruncers and captured by the policeman
g. The dictator was loved by the grootist and loathed by the world
h. The doctor was surprised by the test and clemmed by the outcome
i. The sheriff was appointed by the governor and applauded by the public
j. The letters were delivered by the glokician and collected by the doorman

(5)a. The baker placed the cakes in the oven

b. The boys clasked the man with the telescope
c. The builders accepted the job in the city
d. The criminals aimed the guns at the policeman
e. The crowd admired the vocalist of the band
f. The delay annoyed the passengers on the train
g. The diplomats swinched the officials at the forum
h. The farmer butchered the brinners in the barn
i. The fly pestered the birgician on the treadmill
j. The gardener pruned the truttors near the fence

(6)a. The applications were completed by the secretary in the office
b. The basement was flooded by the water from the leak
c. The champion was applauded by the spectators in the stadium
d. The client was tricked by the lawyers from the company
e. The dieters were tempted by the cakes from the bakery
f. The dogs were gleared by the leopard from the zoo
g. The patient was chapsed by the doctors with the accent
h. The floor was stained by the breetists from the bar
i. The gangster was convicted by the thoberist in the winter
j. The girl was baffled by the worges from the mother

(7)a. The matron consoled the orphans who the bully harassed
b. The natives attacked the missionary who the chief disliked
c. The owner helped the neighbor who the dogs assaulted
d. The town reelected the mayor who the governors endorsed
e. The paper condemned the actress who the agents sued
f. The dragon phronged the knight who the princess loved
g. The receptionist seduced the blurician who the wife adored
h. The tourists visited the monk who the stuttist respected
i. The leader pardoned the rebel who the crechicians captured
j. The queen envied the baron who the skooges trusted

(8)a. The knights killed the prince who ended the war
b. The guards punished the prisoners who started the fight
c. The bears scared the tourist who teased the cub
d. The principal confused the girl who asked the questions
e. The parents humiliated the teacher who scolded the boy
f. The politician threatened the spolers who investigated the case
g. The man risped the butler who folded the shirts
h. The governor honored the forchician who identified the traitors
i. The coach reprimanded the kenthor who ignored the players
j. The grandmother spanked the child who zodged the pies

(9)a. The actress from the village charmed the critics
b. The ambassadors from the country addressed the media
c. The sale at the store attracted the customers
d. The book from the library enlightened the students

e. The fire in the stove warmed the rooms
f. The fan near the window jimmed the curtains
g. The father of the chalmer insulted the teachers
h. The fire in the splichor scared the villagers
i. The horses in the crompt kicked the goat
j. The hunters from the village skatched the deer

(10)a. The chef in the restaurant was burned by the fire
b. The clasp on the necklace was damaged by the accident
c. The tribe in the jungle was betrayed by the explorers
d. The fence around the house was vandalized by the kids
e. The lamps on the table were broken by the cat
f. The leader of the threamors was interrogated by the policeman
g. The miniskirts in the catalogue were chagged by the teenagers
h. The nurses in the spreelor were scolded by the patients
i. The package in the car was sheafed by the thugs
j. The paper by the flouricians was accepted by the committee

(11)a. The baby hated the lullabies
b. The judge overruled the lawyers
c. The boys vawled the homework
d. The cats urched the mouse
e. The cowboys clawned the steak
f. The doctors murped the prescription
g. The dogs chased the parrots
h. The girl devoured the sandwiches
i. The golfer whicked the tournament
j. The lighthouse guided the sailors

(12)a. The actor was hired by the producers
b. The amount was calculated by the clerk
c. The bride was depressed by the weather
d. The cats were poisoned by the maid
e. The child was spoiled by the nanny
f. The hostess was valmed by the wine
g. The iguana was pisked by the zookeepers
h. The king was skirred by the villagers
i. The entrepreneurs were brimped by the businessman
j. The mailman was parled by the raccoons

A.6 Experiment 5 Stimuli

(1)a. crotician
b. bactivitor
c. bullawer
d. streachor
e. lactissist
f. banitician
g. bolitist
h. fossician
i. formantor
j. jantomer
k. noacher
l. hostist
m. businer
n. wolarist
o. fremator
p. nestator

(2)a. elusists
b. shodderists
c. moldicians
d. buestors
e. thullicians
f. frominalists
g. shericians
h. kewardessors
i. strogessors
j. flingericians
k. dolonicians
l. kaidists
m. cheldors
n. predignors
o. briticists
p. fantivists

(3)a. lawticianed
b. peachicianed
c. pactessed
d. framitatored
e. jobsticatored
f. bottisted
g. gangeristed
h. lustodisted
i. froachered
j. haustisted

k. bunessisted
l. penursifered
m. benaticianed
n. justatored
o. humicianed
p. stoppisted

(4)a. dorpals
b. nusts
c. bullifs
d. sergs
e. fumits
f. stremords
g. purgetts
h. jonts
i. calins
j. naids
k. hilds
l. botigs
m. fusbends
n. guends
o. wuths
p. tharons

(5)a. phoisify
b. flapperate
c. povify
d. sedundify
e. forigate
f. kippigate
g. onstigipate
h. peagify
i. maksize
j. fusilitate
k. conturize
l. apturicize
m. strubdify
n. lavoidify
o. likiciate
p. wandify

(6)a. scolterizes
b. strovokicizes
c. portifies
d. irriticiates
e. mattakates
f. spectifies

g. prutifies
h. madressizes
i. blamiciates
j. saultifies
k. phonorizes
l. ballicizes
m. enjurifies
n. phanicizes
o. thrombicizes
p. embarricates

(7)a. prausified
b. osmissified
c. simpuridated
d. annoriciated
e. piliciated
f. rotectified
g. calikated
h. visified
i. thafassized
j. swarmicated
k. stickerated
l. peaserized
m. prockified
n. damerticated
o. miticurized
p. fallengized

(8)a. missiped
b. poutered
c. plessicked
d. stribered
e. tissed
f. engaried
g. offalded
h. tirasted
i. amacked
j. gratened
k. kurched
l. mofusted
m. thespired
n. maffliced
o. mangered
p. dupressed

A.7 Experiment 6 Stimuli

A.7.1 Experiment 6 Target Sentences

(1)a. The actor who admires critics humiliated the director
b. The actor who critics admire humiliated the director

(2)a. The delegate who angers activists honored the mayor
b. The delegate who activists anger honored the mayor

(3)a. The student who despises teachers praised the principal
b. The student who teachers despise praised the principal

(4)a. The publisher who insults actresses sued the agent
b. The publisher who actresses insult sued the agent

(5)a. The employee who frustrates coworkers married the secretary
b. The employee who coworkers frustrate married the secretary

(6)a. The detective who trusts informants wounded the gangster
b. The detective who informants trust wounded the gangster

(7)a. The waiter who offends customers confused the chef
b. The waiter who customers offend confused the chef

(8)a. The trainer who enrages players injured the coach
b. The trainer who players enrage injured the coach

(9)a. The official who bribes journalists mistrusted the businessman
b. The official who journalists bribe mistrusted the businessman

(10)a. The nurse who respects doctors pleased the woman
b. The nurse who doctors respect pleased the woman

(11)a. The senator who outrages protesters provoked the guard
b. The senator who protesters outrage provoked the guard

(12)a. The musician who bores dancers challenged the assistant
b. The musician who dancers bore challenged the assistant

(13)a. The salesman who ridicules shoppers blamed the manager
b. The salesman who shoppers ridicule blamed the manager

(14)a. The lady who mocks guests embarrassed the man
b. The lady who guests mock embarrassed the man

(15)a. The girl who avoids boys threatened the boy

b. The girl who boys avoid threatened the boy

(16)a. The politician who tricks criminals phoned the sergeant
b. The politician who criminals trick phoned the sergeant

(17)a. The stewardess who harasses passengers called the pilot
b. The stewardess who passengers harass called the pilot

(18)a. The professor who dislikes deans irritated the applicant
b. The professor who deans dislike irritated the applicant

(19)a. The guitarist who likes promoters betrayed the singer
b. The guitarist who promoters like betrayed the singer

(20)a. The architect who infuriates designers addressed the client
b. The architect who designers infuriate addressed the client

(21)a. The director who flatters actors admired the critic
b. The director who actors flatter admired the critic

(22)a. The mayor who praises activists despised the delegate
b. The mayor who activists praise despised the delegate

(23)a. The principal who criticizes teachers annoyed the student
b. The principal who teachers criticize annoyed the student

(24)a. The agent who tricks actresses phoned the publisher
b. The agent who actresses trick phoned the publisher

(25)a. The boy who harasses girls called the bully
b. The boy who girls harass called the bully

(26)a. The employee who angers coworkers honored the secretary
b. The employee who coworkers anger honored the secretary

(27)a. The informant who provokes gangsters outraged the detective
b. The informant who gangsters provoke outraged the detective

(28)a. The waiter who ridicules customers blamed the chef
b. The waiter who customers ridicule blamed the chef

(29)a. The coach who infuriates trainers addressed the player
b. The coach who trainers infuriate addressed the player

(30)a. The official who respects journalists pleased the businessman
b. The official who journalists respect pleased the businessman

(31)a. The nurse who avoids doctors threatened the woman

b. The nurse who doctors avoid threatened the woman

(32) a. The guard who trusts senators wounded the protester
b. The guard who senators trust wounded the protester

(33) a. The assistant who frustrates dancers married the musician
b. The assistant who dancers frustrate married the musician

(34) a. The salesman who dislikes shoppers irritated the manager
b. The salesman who shoppers dislike irritated the manager

(35) a. The lady who likes guests betrayed the man
b. The lady who guests like betrayed the man

(36) a. The politician who bribes criminals mistrusted the sergeant
b. The politician who criminals bribe mistrusted the sergeant

(37) a. The stewardess who confuses passengers offended the pilot
b. The stewardess who passengers confuse offended the pilot

(38) a. The dean who humiliates professors impressed the applicant
b. The dean who professors humiliate impressed the applicant

(39) a. The promoter who insults singers sued the guitarist
b. The promoter who singers insult sued the guitarist

(40) a. The architect who bores clients challenged the designer
b. The architect who clients bore challenged the designer

A.7.2 Experiment 6 Pseudowords

(1) duppists
(2) croticians
(3) bactivitors
(4) theslirists
(5) streachors
(6) mofustators
(7) lactissists
(8) baniticians
(9) gratenists
(10) bolicians
(11) amackists
(12) tirasters
(13) formantors
(14) jantomers
(15) fossicians

(16) striberists
(17) wolarists
(18) fremators
(19) elusists
(20) nestators
(21) madetors
(22) bullagers
(23) mafflitists
(24) lurchists
(25) noachers
(26) fallengists
(27) elupers
(28) midicians
(29) pleddists
(30) mespicians
(31) protters
(32) kuestors
(33) thullamors
(34) bottists
(35) denaticians
(36) gumitists
(37) sergators
(38) jonters
(39) peagerists
(40) povicians

(41) duppifies
(42) crotifies
(43) bactivitates
(44) theslirates
(45) streachifies
(46) mofustates
(47) lactissates
(48) baniticates
(49) gratenizes
(50) bolicizes
(51) amackates
(52) tirastizes
(53) formanates
(54) jantomizes
(55) fossicates
(56) striberates
(57) wolarifies
(58) frematizes
(59) elusifies
(60) nestatates

(61) madetizes
(62) bullegates
(63) mafflitates
(64) lurchifies
(65) noachates
(66) fallengizes
(67) elupizes
(68) midicates
(69) pleddisates
(70) mespicates
(71) prottizes
(72) kuestifies
(73) thullamizes
(74) botticates
(75) denaticates
(76) gumitifies
(77) sergatizes
(78) jontifies
(79) peagerizes
(80) povicates

A.7.3 Experiment 6 Filler Sentences

(1)a. The activists began the rebellion by organizing the strike
b. The boys taunted the teacher by hiding the marker
c. The child stained the rug by spilling the juice
d. The classmates broke the television by hitting the screen
e. The counselor druppified the patient by recommending the treatment
f. The goat infuriated the zoathers by eating the flower
g. The landscaper saved the trounderized by watering the lawn
h. The guest embarrassed the host by droundering the lady

(2)a. The botanist was disheartened by the dogs uprooting the flowers
b. The actress was praised by the directors filming the movie
c. The athletes were upset by the teammate failing the course
d. The audience was shocked by the participant insulting the judges
e. The parents were whampified by the girl dating the biker
f. The cop was threatened by the cheldists pointing the gun
g. The player was shocked by the blesherized humiliating the coach
h. The customers were embarrassed by the manager vellicianing the waiter

(3)a. The scout collected the books and earned the badge
b. The astronauts piloted the shuttle and manned the telescope
c. The babysitter grounded the child and called the parents

d. The candy attracted the cockroaches and disgusted the cook
e. The cowboy cracked the whip and sluberated the cows
f. The doctor recommended the bromitists and saved the infant
g. The matador provoked the bulls and trielored the fight
h. The muggers attacked the whengered and robbed the woman

(4)a. The babies were burped by the father and kissed by the mother
b. The bill was supported by the politicians and upheld by the president
c. The manager was questioned by the interns and reprimanded by the boss
d. The sheriff was appointed by the governor and applauded by the public
e. The thief was chased by the pruncerized and captured by the policeman
f. The dictator was loved by the grootists and loathed by the world
g. The doctor was surprised by the test and clemmified by the outcome
h. The cars were flemisted by the truck and towed by the mechanic

(5)a. The baker placed the cakes in the oven
b. The builders accepted the job in the city
c. The criminals aimed the guns at the policeman
d. The crowd admired the vocalist of the band
e. The boys claskized the man with the telescope
f. The farmer butchered the brinners in the barn
g. The fly pestered the birgified on the treadmill
h. The gardener pruned the truttized near the fence

(6)a. The applications were completed by the secretary in the office
b. The basement was flooded by the water from the leak
c. The champion was applauded by the spectators in the stadium
d. The client was tricked by the lawyers from the company
e. The patient was chapserated by the doctors with the accent
f. The floor was stained by the breetists from the bar
g. The gangster was convicted by the thoberified in the winter
h. The girl was baffled by the worberated from the mother

(7)a. The matron consoled the orphans who the bully harassed
b. The natives attacked the missionary who the chief disliked
c. The owner helped the neighbor who the dogs mauled
d. The town reelected the mayor who the governors endorsed
e. The dragon killed the knight who the moopists loved
f. The tourists visited the monk who the stuttists respected
g. The leader melicianed the rebel who the villagers captured
h. The queen envied the baron who the skootified trusted

(8)a. The knights killed the prince who ended the war

b. The guards punished the prisoners who started the fight
c. The bears scared the tourist who teased the cub
d. The principal confused the girl who asked the questions
e. The man risperized the butler who folded the shirts
f. The governor honored the agent who forcherated the traitors
g. The coach reprimanded the referee who kenthored the players
h. The grandmother spanked the child who zodgicianed the pies

(9)a. The actress from the village charmed the critics
b. The ambassadors from the country addressed the media
c. The sale at the store attracted the customers
d. The book from the library enlightened the students
e. The father of the chalmers insulted the teachers
f. The fire in the barn splicherated the villagers
g. The horse in the stable cromptered the goat
h. The hunter from the village skatchisted the deer

(10)a. The chef in the restaurant was burned by the fire
b. The clasp on the necklace was damaged by the accident
c. The tribe in the jungle was betrayed by the explorers
d. The fence around the house was vandalized by the kids
e. The miniskirts in the catalogue were chaggified by the teenagers
f. The nurses in the spreelors were scolded by the patients
g. The package in the car was sheafered by the thugs
h. The paper by the froulized was accepted by the committee

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