

PROSODY AND SYNTACTIC PROCESSING

BY

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DISSERTATION

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Abstract

This dissertation examines whether and how two main aspects of prosody, intonational phrase boundaries and pitch accents, are used in syntactic processing. Traditionally, it has been argued that while intonational phrase boundaries interact with syntactic structure, pitch accents do not. One apparent exception to this view is work by Schafer, Carter, Clifton, and Frazier (1996) that suggests that pitch accents, like intonational phrase boundaries, play a primary role in attachment ambiguity resolution. Chapter 2 provides empirical evidence that resolves these conflicting views in the literature by examining what factors underlie previously established accent attachment effects. The results from four experiments show that these effects are the result of a post-sentence bias to select salient information as the answer to the post-sentence query rather than the result of a syntactic processing mechanism, suggesting that pitch accents may not directly signal syntactic attachment. Chapters 3 and 4 explore two unanswered questions with respect to the role intonational phrase boundaries play in syntactic processing. Chapter 3 presents three visual world eye-tracking experiments that examine what types of information intonational phrase boundaries provide to the processing system. The findings suggest that intonational phrase boundaries provide information about their local syntactic and semantic context that allows listeners to predict upcoming linguistic structure. Chapter 4 investigates individual differences in the use of intonational phrase boundaries in attachment ambiguity resolution. The results suggest that the listeners' ability to use boundary information in syntactic processing is positively correlated with working memory capacity. High span listeners are more likely to use boundary information in syntactic ambiguity resolution than low span listeners.

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Chapter 1

Introduction

In spoken communication, utterances can convey different meanings depending on the way they are produced, independent of the lexical items. Prosody, as the rhythm and melody of speech, controls the way utterances are produced through the modulation of suprasegmental features such as pitch, loudness, and tempo. Two main aspects of prosody examined in this dissertation are intonational phrase boundaries and pitch accents. Intonational phrase boundaries are breaks in the speech stream that roughly correlate with lengthening of a pre-boundary word, changes in fundamental frequency (f_0) and spectral information, and the presence of a pause. Pitch accents are distinctive tonal excursions that occur on a word. Accented words are produced with longer duration and greater intensity than unaccented words. Intonational phrase boundaries and pitch accents contribute to the ultimate interpretation of a sentence in distinctive ways. Traditionally, it has been argued that intonational phrase boundaries are associated primarily with syntactic structure while pitch accents are associated with discourse structure. Consider the examples in (1) below (double slashes indicate the location of intonational phrase boundaries, and accents are indicated with capital letters).

- (1) a. *The man shot the servant // of the actress who was on the balcony.*
 b. *The man shot the servant of the actress // who was on the balcony.*
 c. A: *Who likes pizza?*
 B: *JOHN likes pizza.*

The sentences in (1a) and (1b) are ambiguous because the relative clause *who was on the balcony* can be associated either with the first noun phrase *the servant* (*i.e.*, it was the servant who was on the balcony), which is called high attachment, or with the second noun phrase *the actress* (*i.e.*, it was the actress who was on the balcony), which is called low attachment. The interpretation of

this sentence can be modulated by the placement of intonational phrase boundaries. When an intonational phrase boundary occurs between the two possible attachment sites as in (1a), it creates a bias towards low attachment. In contrast, when an intonational phrase boundary is present before the ambiguous phrase as in (1b), it creates a bias towards high attachment. The interpretation in which the relative clause attaches to *the actress* is more likely in (1a) than in (1b). On the other hand, the sentences in (1c) illustrate how the speaker's choice of pitch accents leads to different discourse implications. In (1c), the presence of a pitch accent on *John* signals that *John* is new information to speaker A or focused information in the discourse or given information that is reintroduced as important information. The above examples show that intonational phrase boundaries and pitch accents contribute to the interpretation of an utterance, each interacting with a distinctive level of linguistic structure.

A growing body of literature has argued that intonational phrase boundaries and pitch accents interact with different levels of linguistic representation (*e.g.*, Bolinger, 1961; 1972; Chafe, 1974; Halliday, 1967; Schwarzschild, 1999; Selkirk, 1984; 1986; Terken, 1984; Truckenbrodt, 1999). Many researchers have suggested rules or constraints that govern the relationship between syntactic and prosodic phrases. Selkirk (1986)'s edge-based mapping theory claims that the left or right edges of syntactic phrases should be aligned with those of prosodic phrases. Truckenbrodt (1999)'s Wrap-XP constraint requires major syntactic phrases to be realized into single prosodic phrases. Findings from the processing literature (*e.g.*, Beach 1991; Kjelgaard & Speer 1999; Marslen-Wilson, Tyler, Warren, Grenier, & Lee, 1992; Speer, Kjelgaard, & Dobroth, 1996; Warren, Grabe, & Nolan, 1995) also suggest that there is a mapping between intonational phrase boundaries and syntactic structure. Consider (2).

(2) *Whenever the guard checks the door [is / it's] locked.*

In (2), an intonational phrase boundary after the noun phrase *the door* implies that the noun phrase attaches to the verb *checks* in the subordinate clause while a boundary before the noun

phrase indicates that the ambiguous noun phrase is part of the main clause. Speer et al. (1996) manipulated the placement of an intonational phrase boundary so that the boundary location was either consistent with or conflicted with the underlying syntactic structure of the utterance. In a cross-modal naming study, participants listened to sentence fragments played up to *the door* and named one of two visual targets (*is* or *it's*), which were two possible continuations of what they had heard. Participants' naming was faster when intonational phrase boundaries and syntactic boundaries coincided but slower when they conflicted.

On the other hand, the information status of entities in a discourse has been considered to be an important factor in determining the distribution of accents (*e.g.*, Bolinger, 1972; Brown, 1983; Chafe, 1976; Halliday, 1967; Hirschberg, 1993; Terken, 1984). Accenting decisions are affected by whether the expression conveys new information or given information (*i.e.*, whether the information is recoverable from the prior discourse). Information that is newly introduced to the discourse, and thus non-recoverable, or important information that is reintroduced to the discourse tends to be accented. The presence of a link between accenting and discourse structure has also been demonstrated in the processing literature (*e.g.*, Bock & Mazzella, 1983; Dahan, Tanenhaus, & Chambers, 2002; Hruska, Steinhauer, Alter, & Steube, 2000; Ito & Speer, 2008; Terken & Nootboom, 1987; Watson, Gunlogson, & Tanenhaus, 2008). For example, Terken and Nootboom (1987) tested whether the appropriateness of accenting patterns influences sentence comprehension. They found that the processing of new information was facilitated when it was accented while the comprehension of given information was facilitated when it was not accented. The primary assumption underlying these theories is that while boundaries interact primarily with syntax, accents have relatively little to do with syntactic structure. Yet this assumption has been challenged by recent findings by Schafer, Carter, Clifton, and Frazier (1996). Consider (3).

- (3) a. *The man shot the SERVANT of the actress who was on the balcony.*
 b. *The man shot the servant of the ACTRESS who was on the balcony.*

Schafer et al. (1996) manipulated the presence of pitch accents on potential attachment heads as in (3). They found that relative clauses are more likely to attach to the high noun *servant* when it was accented than when it was not. This suggests that pitch accents may also play a role in syntactic attachment decisions.

It is unclear whether or not the two components of prosody play distinctive roles in processing. The traditional view is that intonational phrase boundaries and pitch accents are interpreted differently in processing such that only intonational phrase boundaries are primarily used in the process of disambiguating syntactic dependencies. This view is supported by the presence of grammatical rules or constraints that govern the mapping between syntactic and prosodic phrases (Selkirk, 1986; Truckenbrodt, 1999) as discussed above. In contrast, there is little work from the linguistic literature that suggests a direct link between pitch accenting and syntactic structure.

A recently emerging view from the processing literature, however, argues that pitch accents may play a primary role in disambiguating sentences whose interpretations are determined by how ambiguous phrases are grouped with potential attachment heads (Schafer et al., 1996). This raises a question of whether there is a processing mechanism by which pitch accents provide the same kind of cue to syntactic structure as that of intonational phrase boundaries.

In this dissertation, I provide empirical evidence that resolves the two conflicting views mentioned above. In order to explore whether intonational phrase boundaries and pitch accents are used differently in processing, I examine whether the previously established effects of pitch accents on relative clause attachment provide solid evidence against the traditional view (Chapter 2). I also explore two unanswered questions in the literature on intonational phrase boundaries and syntactic processing: 1) whether intonational phrase boundaries by themselves are sufficient for allowing listeners to predict upcoming syntactic structure (Chapter 3) and 2) whether there are individual differences with respect to the use of boundary information in syntactic processing (Chapter 4).

In Chapter 2, I analyze whether the findings from Schafer et al. (1996) may be taken as evidence against the traditional view by examining whether the accent attachment effects are driven by a direct relationship between accenting and syntactic structure (the Syntax Hypothesis) or whether they are simply the result of a bias to select salient information as the answer to a post-sentence query (the Saliency Hypothesis). The results show that the accent attachment effects found in Schafer et al. (1996) were simply a product of a post-sentence selection bias towards salient information, not the result of a syntactic processing mechanism.

In Chapter 3, I investigate what types of information intonational phrase boundaries provide to the processing system. Recently, Carlson, Clifton, & Frazier (2009) have argued that boundaries do not provide local cues to the parser in interpretation. Instead, listeners are influenced only by prosodic phrasing. I argue that if an intonational phrase boundary can be used by listeners to predict upcoming material, that boundary must be conveying information to the processing system about the local context in which it appears. The results demonstrate that boundaries provide information about their local syntactic and semantic context that allows listeners to predict upcoming linguistic structure even before the next lexical input is encountered.

In Chapter 4, I further examine the relationship between intonational phrase boundaries and syntactic structure, focusing on individual differences. Prior work (e.g., Pearlmutter & MacDonald, 1995) shows that comprehenders with high working memory capacity are better at utilizing probabilistic information such as plausibility in syntactic interpretation than those with low working memory capacity. I explore whether the individual listener's ability to use boundary information in syntactic processing may be modulated by working memory capacity. The findings show that working memory capacity is a good predictor of the individuals' capability of using boundary information in attachment ambiguity resolution. Listeners with high working memory capacity are more likely to use boundary information in attachment decisions than those with low working memory capacity.

Based on a series of experiments, I provide evidence supporting the traditional view:

While intonational phrase boundaries have a direct influence on syntactic attachment, pitch accents do not. I also provide empirical evidence that the sensitivity to the relationship between intonational phrase boundaries and syntax can vary across individuals.

In the remainder of the current chapter, I will briefly review the prosodic framework that will be assumed throughout the present study.

Prosodic Framework

Prosodic structure encodes prosodic phrasing and prosodic prominence. While prosodic phrasing serves to group words into sense units, it is prosodic prominence (stress/phrasal accent) that marks the location of perceptually prominent syllables and words. According to Pierrehumbert and colleagues (Beckman & Ayers, 1997; Beckman & Pierrehumbert, 1986), prosodic structure is instantiated as a strictly layered hierarchy. Prosodic structure consists of various sizes of prosodic constituents that are hierarchically organized with smaller/lower level prosodic constituents exhaustively grouped into a larger/higher level prosodic constituent. Prominent units defined within a higher level constituent are projections of prominent units defined in successively lower level constituent. Three major prosodic constituents in American English utterances are (1) a phonological word (Wd), (2) an intermediate phrase (ip), and (3) an intonational phrase (IP). The phonological word is a prosodic constituent that often corresponds to one lexical word but sometimes to more or less than one lexical word. Phonological words are exhaustively grouped into an intermediate phrase, which is another prosodic constituent that is larger than the phonological word and smaller than the intonational phrase. Each intermediate phrase contains at least one pitch accent. Pitch accents, which are associated with a stressed syllable, mark a perceptually prominent element at the phrase level. Intermediate phrases are grouped into an intonational phrase, which is a larger prosodic constituent. A group of intonational phrases eventually form an utterance. Because these prosodic constituents are hierarchically layered, a syllable that is final in an intonational phrase is necessarily also final in the lower level prosodic constituents.

Both intonational and intermediate phrase boundaries are correlated with acoustic cues such as pre-boundary word lengthening, changes in pitch, and pauses. The acoustic correlates of intonational phrase junctures are more extreme than those of intermediate phrase junctures. Thus, intonational phrase boundaries create a stronger juncture than intermediate phrase boundaries. Accented words are accompanied by increased duration and intensity compared to unaccented words.

The ToBI (Tones and Break Indices) transcription system (Beckman & Ayers, 1997), based on the hierarchical model of prosodic structure, describes tonal movement associated with prosodic boundaries and pitch accents using the H and L tones. The end of an intermediate phrase is marked by an H- or L- phrase accent and an intonational phrase boundary is delimited by an H% or L% boundary tone. Pitch accents are marked by either a single tone (H* or L*) or a combination of the two single tones (L+H*). Pre-boundary words and accented words are usually lengthened to accommodate pitch movement associated with them.

In this dissertation, the test materials will be described within the prosodic framework and the transcription system discussed above. Yet the claims proposed here are independent of using this particular prosodic framework. The ideas I propose here would work in any theoretical framework or transcription system that describes prosodic structure in terms of prosodic phrasing and prominence.

Chapter 2

Effects of Pitch Accents in Attachment Ambiguity Resolution

Although it is known that pitch accents interact primarily with discourse structure (*e.g.*, Dahan et al., 2002; Hruska et al., 2000; Ito & Speer, 2008; Terken & Nöteboom, 1987; Watson, Gunlogson, & Tanenhaus, 2008), several studies suggest that there is a role for pitch accents in the processing of syntactically ambiguous sentences (*e.g.*, Carlson, 2001; Nivedita, 2004; Schafer, Carlson, Clifton, & Frazier, 2000; Speer, Robert, Crowder, & Lisa, 1993; Weber, Grice, & Crocker, 2006). However, in most of these studies, pitch accents, unlike boundaries, do not provide listeners with information about where to attach ambiguous constituents. Instead, pitch accents provide information about discourse structure or grammatical functions, which then has consequences for how surface structure is interpreted. For example, Nivedita (2004) argued that the sentences in (4) convey different meanings depending on whether pitch accents are located on *packing* or *cases* (see also Speer et al., 1993).

- (4) a. *PACKING cases are always newsworthy.*
 b. *Packing CASES is always newsworthy.*

The results from a cross-modal naming study, where participants were asked to name one of two visual targets (*are/is*) after listening to *packing cases*, showed that the entire phrase *packing cases* was interpreted as a noun phrase when *packing* was accented and as a nominalized verb phrase when *cases* was accented. In this experiment, pitch accents signal whether the initial word of the sentence *packing* is part of a noun phrase or part of a nominalized verb phrase, but they do not affect its attachment with the following word *cases* or other words in the sentence. Similarly, Weber et al. (2006) demonstrated that pitch accents can influence the interpretation of the grammatical role of the word being mentioned. When sentence-initial words were accented, German listeners were more likely to interpret them as objects than as subjects in the absence of

other disambiguating information.

Schafer et al. (2000) showed that pitch accents also play a role in resolving the embedded question vs. relative clause ambiguity.

- (5) a. *I asked the pretty little girl WHO's cold.*
 b. *I asked the pretty little girl who's COLD.*

In sentence (5a) where a pitch accent is present on the *wh*-word (*i.e.*, *who*), the clause *who is cold* is interpreted preferentially as an embedded question (*i.e.*, I asked the pretty little girl something, namely, I asked her who is cold.). De-accenting the *wh*-word elicits a relative clause interpretation (*i.e.*, It was the pretty little girl who was cold that I asked about something.). One possible reason that accented *wh*-words might be preferentially associated with an interrogative pronoun interpretation is because of the prosody-discourse interface. *Wh*-words in embedded questions may be more likely to be accented than those in relative clauses because asking questions elicits new information. In contrast, relative pronouns refer to the referent of a preceding antecedent (*i.e.*, girl). They do not typically add new information to the discourse. Thus, *wh*-words may be more likely to be associated with a relative clause interpretation when unaccented than when accented.

The above work suggests that accents do not directly influence the dependency relationships between lexical heads. Rather, they provide information about discourse structure and grammatical functions, which may have consequences for the ultimate syntactic configuration of the sentence. However, there are some notable exceptions to this generalization. Schafer et al. (1996) has argued for a role for pitch accents in the resolution of relative clause attachment ambiguities. Consider sentence (6).

- (6) *The reporter recently interviewed the SISTER of the senator who was controversial.*

Sentence (6) has more than one interpretation. The relative clause can be attached either high to

the noun phrase, *the sister*, (*i.e.*, It was the sister who was controversial.), which is called high attachment, or low to the noun phrase, *the senator* (*i.e.*, It was the senator who was controversial.), which is called low attachment. In order to examine the role of pitch accents in attachment ambiguity resolution, Schafer et al. (1996) manipulated the presence of a pitch accent on the two potential attachment sites within the complex noun phrase. In the experiment, participants listened to the whole sentence and were asked to answer comprehension questions that probed for high or low attachment (*e.g.*, “*Who was controversial?*”) either in a recall task using open-ended questions (Experiment 1) or in a forced choice two alternative task (Experiment 2). Participants responded to the questions with accented nouns more frequently than with unaccented nouns. The effect was greater for contrastive accents (L+H* in ToBI notation) than new information accents (H*). This finding has been formulated as the Focus Attraction Hypothesis, which states that accented material tends to attract attachment. Focus attraction was found regardless of the kind of pitch accent (new information accent vs. contrastive accent) and of the kind of linking preposition (*e.g.*, *The sun sparkled on the propeller of* (vs. *near*) *the plane that the mechanic was so carefully examining.*).

Recent work by Carlson et al. (2009) also suggests that accenting a word encourages attachment of ambiguous phrases. They manipulated the location of pitch accents so that only one of the possible attachment sites is accented in sentences such as *Jerry kissed the actress that he had recently met at the Oscars ceremony*. In the experiment, participants heard a sentence and were presented with a written questionnaire (*e.g.*, *What happened at the Oscars ceremony?*). They were asked to choose one of the paraphrases of the possible interpretations of the sentence (*e.g.*, *Jerry met the actress.* vs. *Jerry kissed the actress.*). Participants selected the first verb *kissed* as an attachment site more frequently when it was accented than when it was not.

The findings from Schafer et al. (1996) and Carlson et al. (2009) suggest that there may be a more direct relationship between pitch accents and attachment ambiguities, one that is not mediated by pitch accents signaling grammatical functions. The Focus Attraction Hypothesis argues that an accented element is likely to be new or important information in the discourse and

that there is a tendency for ambiguous phrases to attach to new or important information. In this chapter, I examine whether or not accents can directly influence syntactic attachment by exploring the factors that give rise to focus attraction effects.

One possibility is that attachment to accented words that convey new or important information in the discourse is a general heuristic that the processing system uses in parsing as argued by Schafer et al. (1996). Because new or important information tends to be modified, listeners preferentially associate ambiguous phrases with accented words. I call this the Syntax Hypothesis.

A second possibility is somewhat less direct: focused elements attract attachment because focused words are acoustically and pragmatically more salient than non-focused elements. Accenting a word marks it as being focused, and this focusing might make the word stand out as a potential attachment site. Accented words also tend to be lengthened, their segmental content is better articulated, and they tend to be produced with greater intensity. All of these acoustic properties enhance the signal by making it louder or more prominent. I call this the Saliency Hypothesis. Thus, rather than preferring to associate modifiers with accented information because of a tendency for new or important information to be modified, listeners associate modifiers with accented words because the accented words are more prominent. Schafer et al. (1996)'s finding that contrastive accents, which are typically more salient than other accents, are more likely to be associated with focus attraction than new information accents is consistent with this hypothesis.

Under the Saliency Hypothesis, there are two possible explanations of Schafer et al. (1996)'s data. Both explanations assume that the information status of a word does not directly serve as a signal to syntax. However, the two explanations differ from each other in terms of whether accent attachment effects are assumed to be due to a syntactic processing mechanism or not. The first is that focus attraction reflects a syntactic processing mechanism by which listeners attach relative clauses to the most salient referent. The second is that focus attraction is the result of a post-sentence selection process in which the increased saliency of accented attachment sites

leads to increased selection of the accented word. I note that the task used in previous work to examine focus attraction required participants to make judgments about syntactic attachment by either selecting or recalling one of the attachment sites at the end of the sentence. The nature of the task may have encouraged participants to develop a strategy of simply selecting accented words.

One possible way to test the predictions of the Salience and the Syntax hypotheses may be found in the memory literature. A great deal of work has shown that focused words are better remembered than non-focused words (*e.g.*, Birch & Garnsey, 1995; Fraundorf, Watson, & Benjamin, 2008; McAteer, 1992; Sanford, Sanford, Molle, & Emmott, 2006; Singer, 1976) because of their semantic and acoustic salience. If focus improves recall for focused information and if focus attraction results from the salience of the lexical attachment site, effects of salience may be more pronounced when the sentence is complex. When overall resources are limited, the parser might be more likely to rely on factors like salience. Furthermore, when the sentence contains more information and more referents, words marked with a pitch accent may stand out more readily. Note that these predictions are true of both versions of the Salience Hypothesis. More complexity will increase the salience of an accented head, and make attachment to it more likely. Similarly, one might expect a post-sentence selection bias to be amplified by sentence complexity: listeners will rely more on choosing an accented word if they are not fully attending to the task or if they find processing the sentence difficult. In contrast, if accents always attract relative clause attachment because of a structural association between new or important information and modifiers, there should not be an interaction with sentence complexity.

In order to determine which factors give rise to focus attraction effects, I present the results from four different experiments. Experiment 1 replicates the study by Schafer et al. (1996) using the same task as in the original study. Experiments 2 and 3 test the Salience and the Syntax Hypotheses by manipulating the complexity of sentences and the placement of pitch accents. The Salience Hypothesis predicts that the more complex the sentence is, the more listeners should rely on accenting as a means for selection of an attachment site because a referent of accented

material may be the only recoverable referent in the sentence. However, if accent attachment effects reflect a general structural association between new or important information and modifiers, there should not be an interaction with sentence type. Experiment 4 further tests the two possible explanations that the Saliency Hypothesis provides for focus attraction: whether focus attraction reflects a syntactic processing mechanism or a post-sentence selection bias.

Experiment 1

Experiment 1 was designed to replicate Schafer et al. (1996). In order to explore the effect of pitch accents on relative clause attachment decisions, they manipulated the placement of accents on the nouns that serve as potential heads of the relative clause. In experimental sentences, pitch accents occurred either on the high noun or on the low noun as shown in (7) below.

- (7) a. *The sun sparkled on the PROPELLER of the plane that the mechanic was so carefully examining.*
 b. *The sun sparkled on the propeller of the PLANE that the mechanic was so carefully examining.*

In the experiment, the participants' task was to answer a question that probed for high or low attachment after listening to a target sentence. Schafer et al. found that relative clauses were more likely to be associated with accented words than unaccented words. However, since there was no baseline condition in which no accents were produced on the critical word, it is not clear whether focus attraction was driven by the presence of an accent or by its absence across conditions. In Experiment 1, I included a baseline condition and evaluated effects of accents against it.

Method

Participants

Thirty-six undergraduate students from the University of Illinois at Urbana-Champaign participated in Experiment 1. All participants in this and the following experiments were native speakers of English and received course credit for their participation. Participants did not take part in more than one of the presented studies.

Stimuli and Procedure

Thirty-two globally ambiguous sentences were selected from Schafer et al. (1996) to be used as critical items. The critical items all included relative clauses preceded by the complex noun phrase consisting of two nouns both of which could be potentially modified by the relative clause (RC). However, properties of the relative clause like RC extraction type, RC length, the type of RC pronoun, and the length of the matrix clause were not controlled across critical items. The mean RC length was 4.7 words (range: 2-8 words, standard deviation: 1.6). I manipulated the presence of pitch accents on the two noun phrases as in Schafer et al.'s original study, but used a 2 x 2 design, unlike the original study. The possible accent status of the high noun (presence vs. absence) was crossed with the possible accent status of the low noun (presence vs. absence), which resulted in No Accent, Early Accent (accent on the high noun), Late Accent (accent on the low noun), and Both Accents (accents on both nouns) conditions. The four conditions used in the experiment are shown in (8) below.

- (8) a. No Accent (baseline)
The sun sparkled on the propeller of the plane that the mechanic was so carefully examining.
- b. Early Accent
The sun sparkled on the PROPELLER of the plane that the mechanic was so carefully examining.
- c. Late Accent
The sun sparkled on the propeller of the PLANE that the mechanic was so carefully examining.
- d. Both Accents
The sun sparkled on the PROPELLER of the PLANE that the mechanic was so carefully examining.

All sentences were produced by a trained female native speaker of American English. The speaker used a bitonal L+H*¹ pitch accent in the ToBI coding system to mark the first accented noun in a complex noun phrase. For the second accented noun in the Both Accents condition, she produced a down-stepped !H* pitch accent. In the No Accent condition, there were no pitch accents on critical nouns. In the Early Accent condition and the Late Accent condition, pitch accents were produced on the high noun and the low noun, respectively. In the Both Accents condition, both nouns were accented with the down-stepped !H* on the second noun. The speaker produced an intermediate level of juncture (*i.e.*, L-) before the relative clause consistently in all conditions as in Schafer et al.'s original study.

To verify the accent manipulation, acoustic analyses were conducted focusing on the duration of critical nouns and the maximum pitch value at those nouns. In this and the following experiments, pitch perturbations caused by segmental properties were excluded in the measurement of the maximum pitch value. Table 1 presents the results of the acoustic analyses.

¹ Schafer et al. (1996) found that focus attraction effects were greater when critical items were focused with a contrastive accent than with a new information accent. Thus, I used an L+H* pitch accent to mark focused elements in this and the following experiments.

Table 1

Mean durations of and average maximum pitch values at critical nouns by condition (Experiment 1)

		No Accent	Early	Late	Both
Duration (ms)	HN	362	438	364	467
	LN	347	344	431	416
Maximum pitch (Hertz)	HN	194	236	188	237
	LN	191	183	236	225

Note. Boldface indicates that the word was accented. HN: high noun, LN: low noun.

The results showed that there were reliable effects of accents on acoustic measures of the duration and the highest pitch values of the critical words. Critical nouns were both longer in duration and higher in pitch when they were accented than when they were not (Duration: high noun: $t(126)=4.5$, $p<.0001$; low noun: $t(126)=2.4$, $p<.05$); Maximum f_0 : high noun: $t(126)=20.3$, $p<.0001$; low noun: $t(126)=15.0$, $p<.0001$).

Four lists were constructed from 32 critical items produced in four different accent conditions. The lists were counterbalanced so that every item appeared just once in each list. Across lists, each item appeared in every condition, and a participant received only one list. In addition to 32 critical items, each list included 60 distracter items. Twelve distracters with a complex noun phrase followed by *was* or *were* were adopted from Bock, Nicol, and Cutting (1999) and Pearlmutter, Garnsey, and Bock (1999) (e.g., *The janitor said that the names on the billboard were of prominent local politicians.*). Thirty-two distracters, which included either object-extracted (e.g., *The babysitter who the parents liked played with the child.*) or subject extracted relative clauses (e.g., *The woman had hurt the child who talked to the psychologist during the therapy session.*) following a single antecedent noun, were adopted from Gibson, Desmet, Watson, Grodner, and Ko (2005). The other sixteen distracters consisted of conjoined sentences (e.g., *Sam read an article and David wrote a novel.*). No specific instruction was provided for the speaker with respect to the production of pitch accents in the distracter

sentences, but some of them had L+H* pitch accents. The order of the critical and distracter trials was randomized.

In the experimental session, sentences were presented to participants over computer speakers. As soon as the sentence ended, a question that probed for high or low attachment (*e.g.*, *What was the mechanic so carefully examining?*) appeared on the screen along with two choices (*e.g.*, *the propeller* and *the plane*), which represented the high and low attachment interpretations, respectively. In half of the trials, the high noun was located on the left, and in the other half, it was located on the right. Participants were asked to choose one of the two choices by clicking on it. In distracter trials, participants received two noun phrases (*e.g.*, *the babysitter* and *the parents*) in the sentence as alternative choices to the question (*e.g.*, *Who played with the child?*) as in the critical trials.

Results and Discussion

In the experiments I report below, the data set was analyzed using mixed logit models, which as an extension of logistic regression, include simultaneous modeling of participants and items as random effects (Jaeger, 2008). The random effects structure was justified by means of likelihood ratio tests (Baayen, 2008). Random effects parameters that significantly improved the model's goodness of fit were included in the model (all p 's < .05). I used contrast coding for all binary predictor variables in the model.

Table 2 presents the judgment results in terms of the proportion of high attachment responses. Figure 1 presents the results in log-odds space. The results confirmed that both the early and late accents influenced participants' judgments. The presence of a pitch accent reliably increased the likelihood of that noun being selected compared to the baseline condition. I conducted a mixed logit model analysis with the accent variable as a predictor of high attachment responses. The results show that there were more high attachment responses when a pitch accent was present on the high noun than in the baseline condition ($\beta=0.44$, $SE=0.18$, $z=2.4$,

$p < .05$). In contrast, the presence of a pitch accent on the low noun reliably decreased the probability of selecting the high noun compared to the baseline condition ($\beta = -0.60$, $SE = 0.18$, $z = -3.3$, $p < .001$). The Both condition did not reliably differ from the baseline condition ($\beta = -0.21$, $SE = 0.18$, $z = -1.2$, $p > .1$), indicating that the effects of the two accents were additive.

The judgment results demonstrate a clear effect of accents on relative clause attachment: the critical noun was preferred as the head of the relative clause when it was produced with a pitch accent.

Table 2

Proportion of high attachment responses (Experiment 1)

No Accent	Early	Late	Both
.52	.61	.40	.48

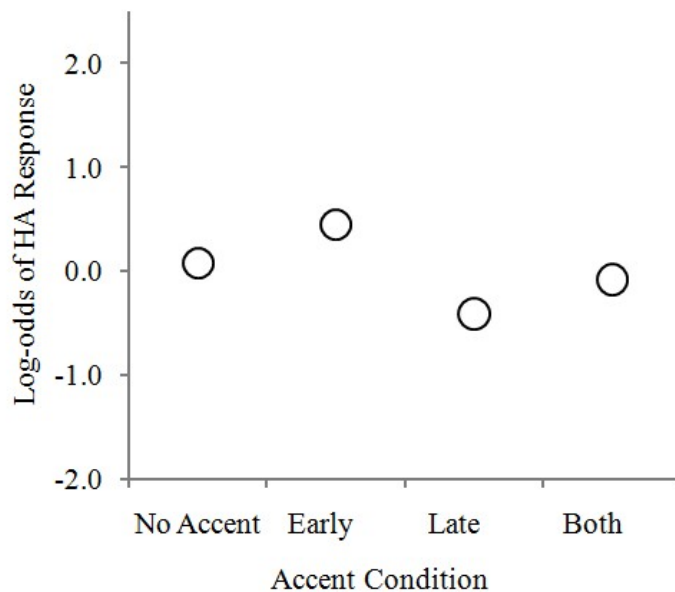


Figure 1. Log-odds of high attachment responses (Experiment 1)

In order to examine what factors underlie this accent attachment effect, I tested the Syntax and the Salience Hypotheses introduced earlier in the introduction in Experiment 2 by manipulating the complexity of the sentence.

Experiment 2

In Experiment 2, I explore whether participants' choices in Experiment 1 reflected a direct structural relationship between accented words and modifiers, or a bias towards salient words by comparing the two hypotheses: the Syntax Hypothesis and the Salience Hypothesis. The Syntax Hypothesis assumes that the information status of a word directly serves as a signal to syntax. A word representing new or important information is more likely to be associated with a modifier than a word conveying given information. In contrast, the Salience Hypothesis assumes that listener responses are due to either attaching modifiers to salient words or choosing salient words in response to the post-sentence question. Thus, the Salience Hypothesis predicts that accent attachment effects should be modulated by the complexity of the sentence: The more complex a sentence is, the less salient unaccented words will become, and the more likely it is that listeners will be biased towards selecting or attaching to the accented word. However, if accented attachment sites always attract relative clauses because they are new or focused, the effect should not be modulated by the complexity of the sentence.

Method

Participants

Forty-eight undergraduate students from the University of Illinois at Urbana-Champaign took part in Experiment 2.

Stimuli and Procedure

In order to test the Syntax and the Salience Hypotheses, sentence complexity was manipulated along with pitch accenting. It has been demonstrated that sentences are more difficult to process when they include object-extracted relative clauses than when they include subject-extracted relative clauses (*e.g.*, King & Just, 1991; Gibson, 1998; Gordon, Hendrick, &

Johnson, 2001; Grodner & Gibson, 2005). I also posit that a greater amount of memory resources are required in the processing of longer sentences than of shorter sentences because of the increased number of words and informational content. Thus, I varied both RC extraction type and RC length to manipulate the complexity of the sentence to create complex RC and simple RC conditions. Other properties of the sentence including the length of the matrix clause and the type of RC pronoun were held constant across conditions. The complex RC condition included long object-extracted relative clauses (mean length: 9.4 words, range: 7-12 words, standard deviation: 1.3), which were longer than the relative clauses used in Schafer et al. (1996) and our earlier experiment, while the simple RC condition included short subject-extracted relative clauses (mean length: 4.4 words, range: 4-5 words, standard deviation: 0.5). The two RC conditions (Complex RC and Simple RC) were crossed with two accent conditions (Early Accent and Late Accent), resulting in the following four conditions. I did not include the No Accent condition as a baseline in this experiment because the presence of the effects of both early and late accents was confirmed in Experiment 1.

- (9) a. Complex RC+ Early Accent
Brandon interviewed the SON of the lady who the man worked with for five years in Germany.
- b. Complex RC+ Late Accent
Brandon interviewed the son of the LADY who the man worked with for five years in Germany.
- c. Simple RC + Early Accent
Brandon interviewed the SON of the lady who worked with the man.
- d. Simple RC+ Late Accent
Brandon interviewed the son of the LADY who worked with the man.

Thirty-two test sentences were recorded by the female speaker who produced the stimuli for Experiment 1. In (9), capitals indicate the location of pitch accents. In the Early Accent conditions ((9a) and (9c)), an L+H* pitch accent was assigned to the high noun (*e.g.*, *son*) and in the Late Accent conditions ((9b) and (9d)), an L+H* pitch accent was assigned to the low noun

(e.g., *lady*). The speaker produced an intermediate level of juncture (L-) after the low noun as in Experiment 1. Schafer et al. (1996) found that the prosody of the relative clause can also modulate the effect of accents on relative clause attachment. In order to prevent any differences in the acoustic properties of the relative clause from interfering with the effects of the accents, I cross-spliced the relative clauses across the same RC conditions. Thus, the relative clauses in (9a) and (9b), and in (9c) and (9d) were acoustically identical. Table 3 presents the results of acoustic analyses of the critical nouns.

Table 3

Mean durations of and average maximum pitch values at critical nouns by condition (Experiment 2)

		Complex RC + Early Accent	Complex RC + Late Accent	Simple RC + Early Accent	Simple RC + Late Accent
Duration (ms)	HN	450	343	457	344
	LN	257	315	260	314
Maximum pitch (Hertz)	HN	242	193	244	194
	LN	181	237	183	238

Note. Boldface indicates that the word was accented. HN: high noun, LN: low noun.

An accent x RC type ANOVA revealed that there was a main effect of accent both on the mean duration and the mean maximum pitch values of critical nouns. The duration of the nouns was longer when they were accented than when they were not (high noun: $F(1,31)=280.8$, $p<.001$; low noun: $F(1,31)=141.1$, $p<.0001$). The maximum pitch values were higher in accented nouns than in their unaccented counterparts (high noun: $F(1,31)=983.9$, $p<.0001$, low noun: $F(1,31)=995.8$, $p<.0001$). There was no main effect of RC type on either measure nor was there a reliable interaction (all F 's < 1), indicating that acoustic properties of the critical nouns did not vary across RC types.

Four lists were constructed using a Latin-square design as in Experiment 1. Each list included 60 distracter trials as well as 32 critical items. The distracter sentences were identical to

those used in Experiment 1. The procedure was also the same as in the earlier experiment.

Results and Discussion

The judgment results are shown below in Table 4. In Figure 2, the results are plotted again as the log-odds of high attachment responses.

Table 4

Proportion of high attachment responses (Experiment 2)

Complex RC + Early Accent	Complex RC + Late Accent	Simple RC + Early Accent	Simple RC + Late Accent
.41	.24	.23	.17

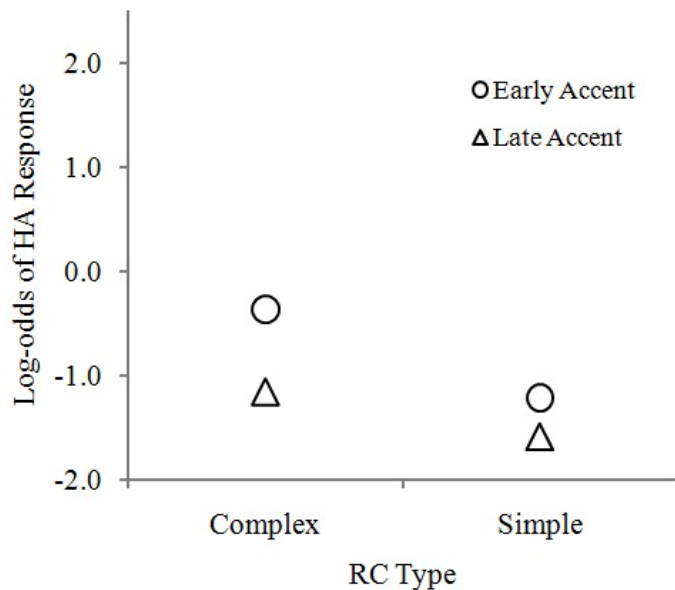


Figure 2. Log-odds of high attachment responses (Experiment 2)

A mixed logit model analysis with accent and RC type as predictors supported the Salience Hypothesis. There was a main effect of RC type with more high attachment responses in the Complex RC condition than in the Simple RC condition ($\beta=0.79$, $SE=0.14$, $z=5.8$, $p<.0001$). There was also a main effect of accent ($\beta=0.81$, $SE=0.20$, $z=4.1$, $p<.0001$), resulting in more high

attachment responses in the Early accent condition than in the Late accent condition. Critically, the interaction between accent and RC type was reliable ($\beta=0.62$, $SE=0.27$, $z=2.3$, $p<.05$)².

The results show that listeners were more likely to be influenced by accenting when the relative clause was long and object-extracted than when it was short and subject-extracted. The presence of a reliable interaction between accent and RC type suggests that listeners' sensitivity to placement of pitch accents may be influenced by the complexity of the structure, supporting the Salience Hypothesis. When listeners were asked to select one of the nouns at the end of the sentence, they were more likely to choose accented words in complex sentences than in simple sentences.

However, because extraction type and length were manipulated simultaneously, it is unclear from the current data whether the presence of an interaction between accent and sentence complexity was due purely to extraction type or length. In order to test this question, I manipulated the length of the relative clause and the extraction type separately in Experiment 3.

Experiment 3

The question of whether length or extraction type influences focus attraction is of particular importance because of the nature of the theories being tested here. Effects of length are incompatible with processing-based explanations of accent attachment effects. While the type of relative clause extraction can be determined fairly early in the relative clause in online processing (immediately after *who*), the length of the relative clause is only apparent to the listener towards the end of the phrase. Given that language processing is highly incremental (*e.g.*, Altman & Kamide, 1999; Altman & Steedman, 1988; Sedivy, Tanenhaus, Chambers, & Carlson,

² The reported fixed effects are based on a model that includes the random by-participant slopes for accent and the random intercepts for both participants and items. The inclusion of random by-participant slopes for RC type was justified in a likelihood ratio test ($p<.05$) (In this model, the interaction between accent and RC type was marginally significant ($p<.07$)). However, it yielded a perfect negative correlation between the random intercepts and random slopes for RC type, indicating that the model overfit the data. Thus, I report the model that does not include the random slopes for RC Type.

1999) and relative clause attachment likely occurs as soon as a reliable cue for a relative clause (*i.e.*, the relative pronoun) is encountered, it is not clear how relative clause length could affect attachment in time to influence on-line processing. Effects of length on the strength of accent attachment is difficult to account for under processing theories, like the Syntax Hypothesis or the processing version of the Salience Hypothesis, in which attachment to accented heads is the result of a processing heuristic. In contrast, effects of length would be consistent with a post-sentence selection bias: listeners are biased to choose the accented word as the response to the post-sentence question, especially when the sentence is long or difficult.

I examined individual contributions of RC extraction type and length by manipulating one factor while controlling for the other. In Experiment 3a, RC extraction type was manipulated while the length of the relative clause was held constant. In Experiment 3b, I compared long and short relative clauses while controlling for extraction type.

Experiment 3a

Method

Participants

The participants were sixty undergraduate students from the University of Illinois at Urbana-Champaign.

Stimuli and Procedure

Thirty-two critical sentences were constructed by modifying the sentences from Experiment 2. Accent (Early Accent vs. Late Accent) and extraction type (Object-extracted vs. Subject-extracted) were crossed, which resulted in 4 different conditions. The length of the relative clause was held constant across conditions (mean: 7.7 words, range: 6-11 words, standard deviation: 1.0). Example sentences are presented in (10) below.

- (10) a. Object-extracted RC + Early Accent
Brandon interviewed the SON of the lady who the man worked with for five years.
 b. Object-extracted RC + Late Accent
Brandon interviewed the son of the LADY who the man worked with for five years.
 c. Subject-extracted RC + Early Accent
Brandon interviewed the SON of the lady who worked with the man for five years.
 d. Subject-extracted RC + Late Accent
Brandon interviewed the son of the LADY who worked with the man for five years.

All critical items were produced by a female speaker of American English. In order to prevent unintended acoustic differences across utterance within an item from interfering with the manipulation, a cross-splicing technique was employed. In Experiment 2, only relative clauses were cross-spliced across conditions. However, in this experiment and experiment 3b, the entire sentence was cross-spliced in order to control for acoustic properties of both the critical nouns and the relative clause within the identical condition. Matrix clauses (before the onset of *who*) with the same accent distribution were cross-spliced, leading each item to share the matrix clause preceding the onset of *who* if it occurred in the same accent condition. In addition, relative clauses of the same extraction type were constructed to be identical across conditions using cross-splicing, so that the accent comparison was not confounded with any acoustic differences in the relative clauses.

In order to ensure that pitch accents were produced in the intended position, I conducted an acoustic analysis on critical nouns, focusing on duration and maximum pitch values. Table 5 presents the results of the acoustic analysis of the cross-spliced stimuli. As in the earlier experiments, accented nouns were realized with a longer duration (high noun: $t(31)=17.4$, $p<.0001$; low noun: $t(31)=9.3$, $p<.0001$) and a higher maximum pitch value (high noun: $t(31)=27.6$, $p<.0001$, low noun: $t(31)=51.7$, $p<.0001$) than their unaccented counterparts.

Table 5

Mean durations of and average maximum pitch values at critical nouns by condition (Experiments 3a)

		Duration (ms)	Maximum pitch (Hertz)
Early Accent	HN	493	259
	LN	283	177
Late Accent	HN	365	189
	LN	357	270

Note. Boldface indicates that the word was accented. Critical nouns were identical across extraction types. HN: high noun, LN: low noun.

The distracter trials were identical to those used in Experiments 1 and 2. The procedure was also the same as in the earlier experiments.

Results and Discussion

Table 6 and Figure 3 present the proportion and the log-odds of high attachment choices, respectively, for 4 different conditions. The results from a mixed logit model analysis with accent and extraction type as predictors showed that there was a main effect of accent ($\beta=0.95$, $SE=0.19$, $z=5.0$, $p<.0001$). The presence of a pitch accent on the high noun reliably increased the probability of selecting high attachment responses compared to the Late Accent condition. However, there was no reliable effect of extraction type ($\beta=0.09$, $SE=0.11$, $z=0.8$, $p>.1$), nor was there an interaction ($\beta =0.29$, $SE=0.22$, $z=1.3$, $p>.1$).

Table 6

Proportion of high attachment responses (Experiment 3a)

Object-extracted + Early Accent	Object-extracted + Late Accent	Subject-extracted + Early Accent	Subject-extracted + Late Accent
.42	.22	.38	.23

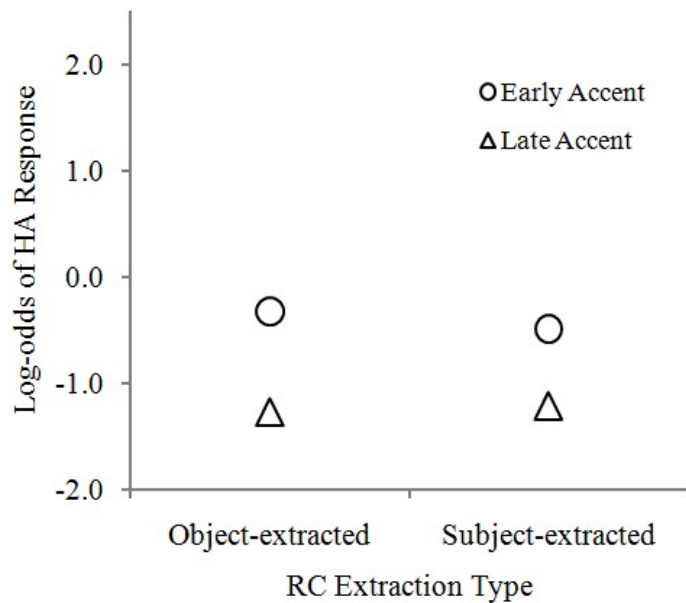


Figure 3. Log-odds of high attachment responses (Experiment 3a)

The data suggest that RC extraction type does not modulate the effects of accent on participants' choice. Experiment 3b examines the effect of the RC length.

Experiment 3b

Method

Participants

Sixty undergraduate students from the University of Illinois at Urbana-Champaign took part in Experiment 3b.

Stimuli and Procedure

In order to explore whether RC length modulates participants' choices, two accent conditions (Early Accent vs. Late Accent) were crossed with two length conditions (Long RC vs.

Short RC), resulting in 4 conditions. The average length of the relative clause was 7.7 words (range: 6-11 words, standard deviation: 1.0) in the Long RC condition and 4.4 words (range: 4-5 words, standard deviation: 0.5) in the Short RC condition. In order to control for RC extraction type, relative clauses were always subject-extracted. Example sentences from each of the four conditions are shown in (11) below.

- (11) a. Long RC + Early Accent
Brandon interviewed the SON of the lady who worked with the man for five years.
 b. Long RC + Late Accent
Brandon interviewed the son of the LADY who worked with the man for five years.
 c. Short RC + Early Accent
Brandon interviewed the SON of the lady who worked with the man.
 d. Short RC + Late Accent
Brandon interviewed the son of the LADY who worked with the man.

Each of thirty-two critical sentences was produced in 4 different versions by the same speaker who recorded the stimuli in the earlier experiments. In order to control for acoustic differences between conditions, I employed the same cross-splicing technique as used in Experiment 3a. The matrix clause up to the onset of *who* was cross-spliced so that it was identical within each accent condition. The relative clause was also cross-spliced so that it was identical within length condition. Table 7 presents the results of an acoustic analysis of the cross-spliced stimuli.

Table 7

Mean durations of and average maximum pitch values at critical nouns by condition (Experiments 3b)

		Duration (ms)	Maximum pitch (Hertz)
Early Accent	HN	489	278
	LN	281	178
Late Accent	HN	365	179
	LN	356	274

Note. Boldface indicates that the word was accented. Critical nouns were identical across extraction types. HN: high noun, LN: low noun.

There were reliable differences in F0 and duration between accented nouns and unaccented nouns. Accented nouns were longer in duration (high noun: $t(31)=16.0$, $p<.0001$, low noun: $t(31)=12.9$, $p<.0001$) and higher in pitch (high noun: $t(31)=20.0$, $p<.0001$, low noun: $t(31)=55.0$, $p<.0001$) than unaccented nouns.

The distracter sentences and procedure were the same as in the earlier experiments.

Results and Discussion

Table 8 presents the proportion of high attachment judgments for the experimental conditions. Figure 4 displays the results in log-odds space.

Table 8

Proportion of high attachment responses (Experiment 3b)

Long RC + Early Accent	Long RC + Late Accent	Short RC + Early Accent	Short RC + Late Accent
.34	.16	.26	.16

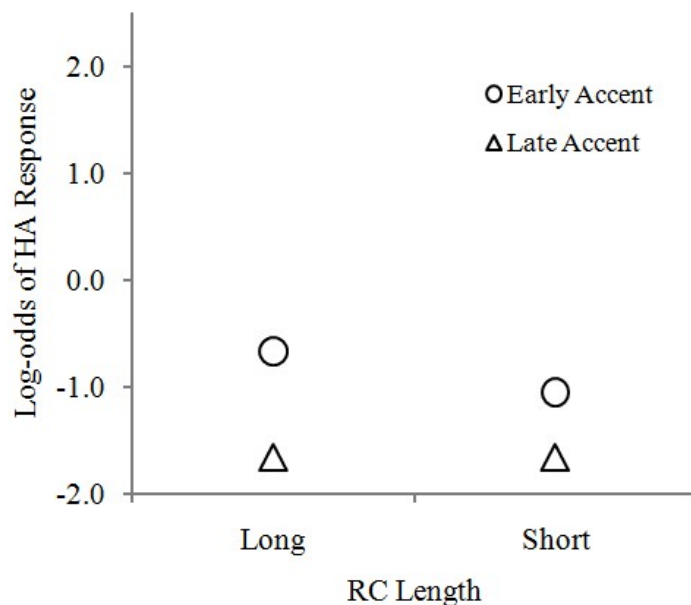


Figure 4. Log-odds of high attachment responses (Experiment 3b)

The results from a mixed logit model analysis with accent and RC length as predictors showed that there was a main effect of accent ($\beta=0.97$, $SE=0.20$, $z=4.8$, $p<.0001$). Participants chose the high noun more frequently in the Early Accent condition than in the Late Accent condition as reflected in the estimate of the coefficient. The effect of RC length was reliable ($\beta=0.27$, $SE=0.12$, $z=2.1$, $p<.05$). Participants selected more high attachment when the relative clause was long than when it was short. There was a reliable interaction between accent and RC length ($\beta=0.50$, $SE=0.25$, $z=2.0$, $p<.05$).

The presence of a reliable interaction between accent and RC length suggests that the effects of complexity found in Experiment 2 were primarily due to sentence length. Effects of length on accent attachment effects are difficult to account for under processing theories like the Syntax Hypothesis or the processing version of the Salience Hypothesis. Because the length of the relative clause can only be detected after the attachment has already been made, it is not clear how length could modulate attachment to accented words in on-line processing.

Note that length effects reflect not just a difference in complexity but also a difference in the amount of time that elapses between the start of the relative clause and the beginning of the question. Both the presence of more content and the passage of more time may lead participants to rely more heavily on salient information in long relative clause sentences than in short relative clause sentences. Effects of length and time are most consistent with the post-sentence selection bias version of the Salience Hypothesis.

There is an alternative hypothesis as to why there were greater effects of accents in long relative clauses than in short relative clauses. It could be the case that longer relative clauses are more likely to contain new information and are therefore more likely to be associated with accented material, which is also likely to be new. Evidence against this claim comes from the literature. In order to determine whether a relative clause that was marked as new was more likely to attach to a new head, Schafer et al. (1996) manipulated the information status of relative clauses by varying the presence of a pitch accent in it (*e.g.*, *The reporter recently interviewed the*

sister of the SENATOR who was so CONTROVERSIAL vs. *The reporter recently interviewed the sister of the SENATOR who was so controversial*). They found a reliable effect of the information status of the modifier on focus attraction. However, the results showed that the effect of accents was greater when the relative clause conveyed given information (i.e., when *controversial* was not accented) than when it conveyed new information (i.e., when *controversial* was accented). This is inconsistent with the alternative hypothesis under consideration, which predicts a greater effect of accent in relative clauses conveying new information than relative clause conveying given information. Given that an accented relative clause is a more direct cue to the relative clause's discourse status than relative clause length, the data from Schafer et al. (1996) suggests that preferences to attach long relative clauses to accented words are not due to interpreting them as being new.

There are at least two other alternative explanations for the interaction between accent and relative clause length in Experiments 2 and 3. As discussed above, Schafer et al. (1996) found that the prosody of the relative clause can influence attachment preferences. It is possible that the prosody of the relative clauses in the short and long conditions differed systematically in ways that modulated the degree of accent attachment. A second explanation for the interaction may be linked to differences in attachment preferences across conditions. In Experiment 2, there were more low attachment responses in the short relative clause condition than in the long relative clause condition. Previous work by Snedeker and Yuan (2008) has shown that effects of prosody are reduced when there are strong structural biases in attachment ambiguities. In Experiments 2 and 3, effects of accenting on attachment may have been reduced in conditions with short relative clauses because these sentences were more strongly biased towards low attachment than those with long relative clauses.

I return to these issues in Experiment 4, but note that all of the alternative hypotheses discussed above are difficult to account for within an incremental sentence processing framework. Information about the prosody, length, and information structure of the relative clause is only available to a listener after an attachment has already been made. The data from

Experiments 2 and 3 are most consistent with a post-sentence selection account of listener responses. In Experiment 4, I examine this question more closely by directly testing the two versions of the Salience Hypothesis.

Experiment 4

In comparing the two versions of the Salience Hypothesis, the processing account is less plausible than the selection account for two reasons. First, in Experiments 2 and 3, there was a greater effect of accents when the relative clause was long than when it was short. According to the processing account, accented words attract relative clause attachment because these words are more salient, and this is especially true when the sentence is long. As discussed above, this is difficult to reconcile with an incremental parser. Second, relative clauses can modify unaccented words as well as accented words. For example, consider (12):

(12) *The reporter recently interviewed the SISTER of the senator who was controversial.*

In (12), the low attachment interpretation sounds as acceptable as the high attachment interpretation, especially if a set of senators had been previously introduced to the discourse. Relative clauses can modify given referents as well as new referents as restrictive and non-restrictive relative clauses, respectively. Thus, it is unclear why the association of accented elements with a relative clause would be a good heuristic for resolving attachment ambiguities.

In Experiment 4, I examine the possibility that previously established accent attachment effects are due to a post-sentence selection bias. In order to test this, I presented participants with sentences like those from Experiment 2 (e.g., *Brandon interviewed the son of the lady who worked with the man.*). I manipulated the post-sentence question such that participants were asked either about relative clause attachment (e.g., *Who worked with the man?*) or about the content of the matrix clause (e.g., *Who did Brandon interview?*). The questions about the matrix

clause were designed to have a correct answer that, critically, was unrelated to the attachment of the relative clause. If the processing version of the Salience Hypothesis is correct, accents on either of the candidate lexical heads should not affect the participants' answer in the matrix clause question condition because there is no syntactic ambiguity present. It should only affect their answer to the question about the relative clause because attachment of the relative clause is ambiguous. However, if there is a bias towards selecting accented words as the answer to any post-sentence question, there should be effects of accents in both question conditions.

In Experiment 4, I also manipulated the length of the relative clause. Experiments 2 and 3 suggest that accented words are more likely to be chosen as the response to the post-sentence question when the relative clause is long than when it is short. If listeners are biased towards producing accented words as the answer to the post-sentence question, this accent effect should be greater for more complex sentences even when the question is not about the relative clause. If, on the other hand, listeners associate the relative clause with salient referents in the discourse as a parsing heuristic and the salience of accented referents grows in difficult contexts, it is expected that this effect would be greater in complex sentences, but only when the question is about relative clause attachment.

Finally, Experiment 4 allows us to address the alternative explanations for the interaction between length and accenting found in Experiments 2 and 3. As discussed above, one possibility is that differences in the prosody of long and short relative clauses modulated attachment preferences. The other possibility is that the strong bias for the short relative clause to attach to the local noun may have reduced the effect of accenting on attachment compared to long relative clauses. In Experiment 4, the matrix question condition is not linked to the relative clause, its prosody, or relative clause attachment preferences. Thus, an effect of accenting on the answer to the matrix question would provide support for the post-sentence selection version of the Salience hypothesis.

Method

Participants

Participants were sixty-four undergraduate students from the University of Illinois at Urbana-Champaign.

Stimuli and Procedure

Critical sentences were identical to those used in Experiment 2. Example sentences shown in (9) are repeated here as (13).

- (13) a. Complex RC+ Early Accent
Brandon interviewed the SON of the lady who the man worked with for five years in Germany.
b. Complex RC+ Late Accent
Brandon interviewed the son of the LADY who the man worked with for five years in Germany.
c. Simple RC + Early Accent
Brandon interviewed the SON of the lady who worked with the man.
d. Simple RC+ Late Accent
Brandon interviewed the son of the LADY who worked with the man.

In Experiment 4, the content of the post-sentence question was also manipulated. In the relative clause question condition, participants were asked about the interpretation of relative clause attachment as in the earlier experiments (*e.g., Who did the man work with?*). In the matrix clause question condition, participants were asked about the object of the matrix clause (*e.g., Who did Brandon interview?*) so that the correct answer was always the high noun phrase (*e.g., the son*).

All three factors (2 RC type x 2 Accent x 2 Question type) were manipulated in a within participant design. Each target sentence was rotated through the experimental conditions across eight lists. The distracter sentences were the same as in the earlier experiments. The order of

critical and distracter trials was randomized.

On each trial, participants listened to a target sentence and then read a question that appeared on the screen. They were asked to produce the answer to the question. Participants' responses were recorded. Note that this task differed from that of the previous experiments, which employed a two-alternative forced choice task. I did this for two reasons. First, in critical sentences, the high noun was always a family term (e.g., son) and the low noun was always a common noun (e.g., lady). Thus, I used a recall task to reduce the probability that participants would develop a strategy in which they simply chose a family term as the answer to the matrix clause question based on the listed choices. Second, Schafer et al. (1996) found attachment effects using both types of tasks, so I wanted to determine whether or not the types of effects I have found in the earlier experiments generalized to this new task.

Results and Discussion

On 12% of trials, participants either recalled nouns other than the two critical nouns (9%) or failed to provide an answer (3%).³ Data from these trials were excluded from the analysis.

Table 9 presents the proportion of high noun choices in 4 different conditions, for each question type. The same results were plotted in log-odds space in Figure 5.

Table 9

Proportion of high noun responses (Experiment 4)

	Complex RC + Early Accent	Complex RC + Late Accent	Simple RC + Early Accent	Simple RC + Late Accent
Matrix Clause Question	.90	.52	.92	.66
Relative Clause Question	.61	.18	.52	.19

³ The percentage of other responses closely matches that from Schafer et al. (1996)'s Experiment 1 (9%), which also used a recall task.

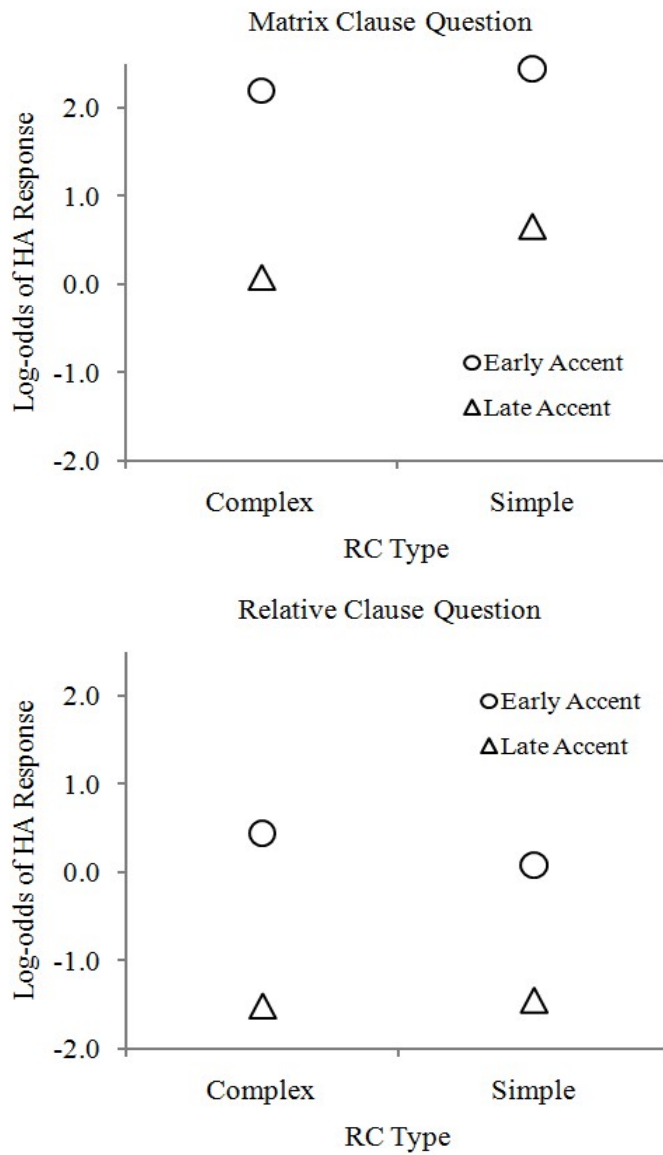


Figure 5. Log-odds of high noun responses (Experiment 4)

A mixed logit model analysis was conducted with accent, question type, and RC type as fixed effects. There were main effects of accent ($\beta=2.12$, $SE=0.20$, $z=10.7$, $p<.0001$) and question type ($\beta=2.30$, $SE=0.23$, $z=10.1$, $p<.0001$). There was a reliable interaction between accent and RC type ($\beta=0.54$, $SE=0.27$, $z=2.1$, $p<.05$), collapsing over question type. Participants were more likely to select the accented noun as the answer to the question when the relative

clause was long, supporting the Salience Hypothesis. The interaction between question type and RC type was also reliable ($\beta=-0.68$, $SE=0.27$, $z=-2.6$, $p<.05$): in the matrix clause condition the likelihood of responding with the high noun was higher when the relative clause was short. In the RC question condition, the likelihood of responding with the high noun was higher when the relative clause was long. There was no reliable interaction between accent, question type, and RC type ($\beta=0.14$, $SE=0.53$, $z=0.3$, $p>.1$) which is inconsistent with the processing version of the Salience Hypothesis.

I also conducted mixed logit model analyses within each question type. In the relative clause question condition, accent was a reliable predictor of high noun responses ($\beta=1.94$, $SE=0.22$, $z=8.9$, $p<.0001$). Participants responded with the high noun more frequently when it was accented than when it was not. There was no main effect of RC type ($\beta=0.19$, $SE=0.17$, $z=1.2$, $p>.1$). The interaction between accent and RC type did not reach significance ($\beta=0.44$, $SE=0.33$, $z=1.3$, $p>.1$).

Critically, the participant's behavior in the matrix clause question condition was also influenced by the location of accents. As in the relative clause question condition, there was a main effect of accent ($\beta=2.41$, $SE=0.22$, $z=11.1$, $p<.0001$). Participants correctly recalled the high noun 91% of the time when the high noun was accented but only 59% of the time when the low noun was accented. There was also a main effect of RC type ($\beta=-0.48$, $SE=0.21$, $z=-2.3$, $p<.05$). Participants recalled the correct high noun more frequently when sentences were simple than when they were complex. The interaction between accent and RC type did not reach significance ($\beta=0.62$, $SE=0.42$, $z=1.5$, $p>.1$). Participants chose the low noun incorrectly more frequently in the Late Accent condition than in the Early Accent condition even when sentences were short.

Notice that unlike in Experiment 2, the interaction between accent and RC type was not reliable for the trials in which participants were asked about relative clause attachment in Experiment 4. The absence of a reliable interaction in this experiment may be due to the difference in task (forced choice two-alternative task vs. recall task). The recall task may have

been more difficult than the forced choice two-alternative task, and participants may have heavily relied on salience across both complexity conditions in Experiment 4.

Although there was not a reliable interaction between accent and RC type within each question condition, there was a reliable interaction when these conditions were collapsed. This suggests that the absence of an interaction within each question condition is the result of a lack of power.

Overall, there was a strong bias to answer the post-sentence question with whatever word in the sentence was accented, even when the answer to the question was unambiguous. This suggests that focus attraction may not be a parsing heuristic that the processing system uses in syntactic ambiguity resolution. Rather, it is the result of a bias towards salient information in responses to the post-sentence question.

These data also rule out the possibility that the results of Experiment 2 and 3 can be explained by structural frequency or the prosody of the relative clause. There is a clear effect of perceptual salience on answers to questions that are not linked to properties of the relative clause.

Conclusion

The above experiments suggest that accent attachment effects demonstrated in previous work may reflect the increased salience of the accented referent. I proposed that listeners' responses to post-sentence questions are influenced by the salience of the accented referent, and because of this, accent effects are likely to be greater in sentences that are complex. Experiments 2 and 3 suggest that the size of the accenting effect is correlated with the length of the relative clause. The presence of a reliable interaction between accent and sentence length is most consistent with the Salience Hypothesis.

In Experiment 4, I tested whether focus attraction is the result of a syntactic processing mechanism that attaches modifiers to salient heads, or whether it is driven by a post-sentence selection bias. The results of Experiment 4 support the post-sentence selection account.

Participants showed a commitment to choosing accented words regardless of the type of question asked. Critically, in the matrix clause question condition, when the low noun was accented, it was incorrectly selected approximately 40% of the time even though the question had nothing to do with the attachment ambiguity. The high error rate in the matrix clause question condition suggests that participants may have developed a strategy in which they selected accented words either because they did not pay attention to the stimuli or because of the difficulty of the task.

One of the concerns that I raised about a processing-based mechanism was that the processor would need to delay attachment of the relative clause until the relative clause's length was apparent and that this violates what we know about the highly incremental nature of sentence processing. However, one might argue that the length effects do not entirely rule out a processing-based account. In a serial parsing system (*e.g.*, Ferreira & Clifton, 1986; Frazier & Rayner, 1982), listeners might make an initial attachment, and then re-analyze the sentence once the length of the relative clause becomes apparent. In a parsing system that computes syntactic structures in parallel (*e.g.*, MacDonald, Pearlmutter, & Seidenberg, 1994; Spivey & Tanenhaus, 1998), the relative ranking of parses might be re-ordered once information about relative clause length is available. Although it will require studies using techniques that measure the online processing of accented information to fully rule out the syntactic processing mechanism account, the data from Experiment 4 suggest that a bias to select accented words as the answer to the post-sentence question most likely underlies the effects demonstrated in previous work and in Experiments 1-3. The similarity in the effect size between matrix and relative clauses questions along with the absence of a three-way interaction between relative clause length, accent position, and question type suggests that these effects are not the results of a syntactic processing mechanism.

Chapter 3

Incremental Interpretation of Intonational Phrase Boundaries

One of the primary questions in the field of spoken language processing is whether speakers use prosody to disambiguate ambiguous structures for listeners (*e.g.*, Allbritton, McKoon, & Ratcliff, 1996; Kraljic & Brennan, 2005; Schafer, Speer, Warren, & White, 2000; Snedeker & Trueswell, 2003) and whether listeners use prosody to resolve ambiguous structures. There have been mixed findings regarding how reliably speakers produce disambiguating prosodic information. Some studies have found that speakers produce reliable disambiguating prosodic information only when they are aware of the ambiguity and when other sources of information (such as syntactic and contextual information) fail to provide disambiguating cues (Allbritton et al., 1996; Snedeker & Trueswell, 2003). However, others have shown that speakers produce reliable prosodic information that resolves syntactic ambiguity regardless of the presence of ambiguity in the context (*e.g.*, Kraljic & Brennan, 2005; Schafer et al., 2000). Despite inconsistencies across studies regarding the speaker's use of prosody, it is universally accepted that listeners use prosodic information reliably to disambiguate syntactic structure when it is present in the spoken input (Allbritton et al., 1996; Beach 1991; Carlson, Clifton, & Frazier, 2001; Clifton, Carlson, & Frazier, 2002; Kjelgaard & Speer 1999; Marslen-Wilson et al., 1992; Price, Ostendorf, Shattuck-Hufnagel, & Fong, 1991; Schafer et al., 2000; Speer et al., 1996; Warren et al., 1995, See Stirling & Wales, 1996; Watt & Murray, 1996 for inconsistent findings).

However, it is still unclear what types of information intonational phrase boundaries provide to the processing system. Consider the sentence in (14):

(14) *The man met the father (a) of the girl (b) who was running.*

Sentence (14) is ambiguous because the relative clause *who was running* can be attached either

to the high noun *father* or to the low noun *girl*. Intuitions suggest that intonational phrase boundaries at (a) and (b) create biases towards low and high attachment, respectively. However, there is little agreement amongst researchers as to why these biases arise.

In this chapter, I present data from three experiments that suggest that intonational phrase boundaries provide information about their local syntactic and semantic context, specifically biasing the processing system towards closing the current constituent. This not only affects attachment preferences but can also lead listeners to rapidly predict upcoming material at the point of the boundary.

Theoretical Approaches

Several hypotheses have been offered to account for how prosodic boundaries influence listener's attachment preferences. One hypothesis is that boundaries are linked to syntactic closure. One example of this type of approach is the Anti-Attachment Hypothesis (Watson & Gibson, 2005). The Anti-Attachment Hypothesis proposes that intonational phrase boundaries provide a cue not to attach incoming lexical items to the preceding syntactic constituent. Intonational phrase boundaries tend to occur at the end of syntactic constituents (*e.g.*, Cooper & Paccia-Cooper, 1980; Selkirk, 1986; Truckenbrodt, 1999; Watson & Gibson, 2004). According to the Anti-Attachment Hypothesis, listeners are sensitive to the distribution of boundaries in production and interpret local boundaries as a cue that the preceding syntactic head is complete. Thus, upcoming elements are less likely to attach to it. Critically, this view assumes that intonational phrase boundaries are a cue to syntactic attachment. Consider the examples in (15).

- (15) a. *The cop saw the spy // with the telescope.*
b. *The cop saw // the spy with the telescope.*

According to the Anti-Attachment Hypothesis, listeners are more likely to interpret the ambiguous prepositional phrase as being associated with the verb *saw* than the object noun *spy* in (15a) because an intonational phrase boundary before the prepositional phrase signals that the

pre-boundary word is unlikely to receive further attachment. This theory also accounts for why an early boundary after the verb biases listeners towards attaching the prepositional phrase to *spy* in (15b). Because the presence of a boundary after a verb signals that the verb is unlikely to receive further attachment, the prepositional phrase is more likely to attach to the other attachment site *spy*. One untested prediction of the Anti-Attachment Hypothesis is that an intonational phrase boundary in a sentence like (15b) should make the sentence more difficult to understand, even as it provides a signal about attachment. The boundary disrupts local attachment between *the spy* and *saw*, which should make the sentence more difficult to process.

While a claim of the Anti-Attachment Hypothesis is that boundaries influence syntactic processing by signaling syntactic closure, a claim of the Interpretive Domain Hypothesis (Schafer, 1997) is that intonational phrase boundaries immediately affect syntactic processing by inducing a semantic wrap-up of the preceding material. Consider (16).

- (16) a. *Although the glasses were ugly, Stacey wore them anyway.*
b. *Although the glasses were ugly, they held a lot of juice.*

Schafer (1997) found that sentence (16a) results in no processing difficulty at the main clause. She argues that this is because its meaning is consistent with the dominant meaning of *glasses* (i.e., spectacles). However, in sentence (16b), the interpretation of the main clause is consistent with the subordinate meaning of *glasses* (i.e., drinking vessel), so listeners are forced to reanalyze from the dominant interpretation of *glasses*, which results in processing difficulty. Schafer (1997) found that when sentences were disambiguated towards the dispreferred meaning, comprehension times were longer when the subordinate clause was followed by an intonational phrase boundary than when it was followed by a weaker intermediate phrase boundary. Schafer (1997) argues that this is evidence that intonational phrase boundaries play a role in semantically consolidating pre-boundary material. Because the preferred meaning of the word *glasses* is consolidated at the boundary, there is a penalty when the sentence is eventually disambiguated towards the dispreferred reading. If the boundary is absent, and no consolidation takes place, it is

easier for listeners to recover.

The idea that boundaries provide information about their local syntactic and semantic context is not universally accepted. For example, the Visibility Hypothesis argues that the interpretation of syntactic structure is not determined by just local boundary information, but by the relative visibility of attachment sites. An attachment site that is in the same prosodic domain as an ambiguously attached constituent is more visible, and therefore more likely to receive attachment, than one that is not. Schafer (1997) defines visibility in terms of the amount of memory resources that need to be expended in making an attachment. Attachment to a node within the same prosodic domain requires fewer memory resources than attachment to a node outside the domain. Frazier and Clifton (1998) defined the same concept in terms of locality, arguing that the presence of intervening boundaries decreases the visibility by increasing the distance between the pre-boundary word and the ambiguously attached constituent. The visibility hypothesis explains the preference for associating the prepositional phrase with the direct object in (15b) by arguing that it is more visible than the verb. Because the verb is separated from the prepositional phrase by a boundary, it is more difficult to attach to it. These theories also predict that the boundary in (15a) should not affect attachment preferences since neither attachment site is in the same prosodic phrase as the prepositional phrase.

The Informative Boundary Hypothesis (Carlson et al., 2001; Clifton et al., 2002) also argues that the interpretation of syntactic structure is not determined by just the position of a local boundary. This theory claims that it is how a local boundary interacts with other boundaries in an utterance that has consequences for attachment preferences. Listeners evaluate the informativeness of a boundary with respect to its size relative to relevant earlier boundaries in an utterance. Consider the sentence in (17).

(17) *Susie learned (a) that Bill telephoned (b) after John visited.*

In sentence (17), a temporal adjunct *after John visited* can be associated either with the matrix

clause (*Susie learned*) or with the subordinate clause (*Bill telephoned*). Carlson et al. (2001) manipulated the size of a boundary at (b) relative to a boundary at (a), and found that a boundary was informative about syntax only when it was larger than a relevant boundary at earlier positions in an utterance. The results showed that a local boundary at (b) created a high attachment bias only when it was larger than a boundary at (a).

Frazier, Carlson, and Clifton (2006) have taken effects described by the Informative Boundary Hypothesis as evidence against boundaries providing any local information about their context. Carlson et al. (2009) explicitly state: “The informative boundary hypothesis denies the simple and attractive explanation that a prosodic boundary is a local cue, signaling a listener not to attach an upcoming phrase to the immediately preceding material...” (p. 1015). Although it is clear that boundaries are not interpreted in isolation and that the global prosodic structure of an utterance is important in influencing attachment, it is still possible that individual boundaries provide information about their local syntactic and semantic context.

I note that theories arguing that boundaries serve as a cue to local syntactic structure are not necessary inconsistent with those arguing that global prosodic information influences syntactic parsing. Rather, those theories account for one aspect of boundary interpretation while leaving the other aspect unarticulated. Theories like the Anti-Attachment Hypothesis provide an account of how local boundaries are interpreted at the moment they are encountered while they do not explain how local boundaries are integrated into global prosodic structure. In contrast, theories like the Visibility Hypothesis and the Informative Boundary Hypothesis provide an explanation of how global prosodic structure influences syntactic representation while they leave unarticulated how each local boundary is interpreted at the moment it is encountered.

In the present study, I examine both questions: whether local boundaries provide a cue that allows listeners to predict upcoming material and 2) whether global prosodic structure has immediate effects on parsing. I use the term “local” in the sense used by Watson & Gibson (2004): that the presence of a boundary can influence the dependency relationships between the words next to which the boundary appears

Empirical Findings: Online Interpretation of Intonational Phrase Boundaries

If boundaries do provide information about their local linguistic context, listeners should be able to use information provided by boundaries to make predictions about what is coming up. A great deal of work has shown that boundaries can have an early effect in syntactic processing. Prior work (*e.g.*, Beach 1991; Kjelgaard & Speer 1999; Marslen-Wilson et al., 1992; Speer et al., 1996; Warren et al., 1995) using cross modal naming (or lexical decision) tasks has focused on whether prosodic information influences initial syntactic analysis during parsing. In this type of task, participants are presented with an ambiguous auditory sentence fragment and are then visually presented with a word that disambiguates the sentence. The participant's task is to name the word. The time it takes to do the naming provides a measure of the extent to which the continuation was expected. Consider sentence (18).

(18) *When Roger leaves the house [it's / is] dark.*

In sentence (18), *the house* can be interpreted either as a direct object of the subordinate verb (late closure) or as a subject of the main clause (early closure). Kjelgaard and Speer (1999) have found that a garden path effect in the early closure baseline condition was eliminated when prosodic boundaries coincided with clausal boundaries (*i.e.*, after the verb), suggesting that prosodic boundaries play a role in initial syntactic interpretation. They observed similar effects for both intonational and intermediate phrase boundaries. When prosodic boundaries coincided with clausal boundaries (*i.e.*, after the verb in early closure sentences and after the noun in late closure sentences), naming of the target word (*it's* or *is*) was faster compared to a prosodically neutral baseline. When boundaries conflicted with the eventual syntactic interpretation, naming times were slower. These types of data have been used to argue for a very early role for boundaries in parsing. However, because the effect of boundaries was measured at or after the disambiguation point, it is not known whether these effects are because boundaries by

themselves signal syntactic structure at the moment they are encountered or whether they are due to an interaction between the presence of a boundary and processing the following lexical items. Thus, when an intonational phrase boundary after *the house* was followed by the target word *is* in (18), it is unclear whether the following lexical items were difficult to process because the boundary serves as a cue to syntactic structure or because those items were not prosodically phrased with the preceding lexical items.

With the advent of the use of a visual world paradigm (e.g. Dahan et al., 2002; Ito & Speer, 2008; Watson et al., 2008, see Watson, Gunlogson, & Tanenhaus, 2006 for a review) and electrophysiological measures (e.g., Hruska et al., 2000; Ito & Garnsey, 2004; Li, Hagoort, & Yang, 2008), it has become possible to investigate on-line processing with a fine-grained temporal resolution and without an unnatural interruption of speech flow. Recent literature has found that eye-tracking combined with the visual-world paradigm can serve as an effective on-line measure of spoken language processing. In the visual world eye-tracking paradigm, participants' eye movements are monitored while they are searching through objects in a visual display. Eye movements are known to be time-locked to referring expressions in the spoken input (Altmann & Kamide 1999; Eberhard, Spivey-Knowlton, Sedivy, & Tanenhaus, 1995; Tanenhaus & Spivey-Knowlton 1996; Tanenhaus, Spivey-Knowlton, Eberhard, & Sedivy, 1995; Sedivy et al., 1999). Prior work has shown that eye-tracking is also sensitive to fine-grained acoustic/phonetic variation (Allopenna et al., 1998; Dahan, Magnuson, & Tanenhaus, 2001a; 2001b; Dahan et al., 2002; Ito & Speer, 2008). Previous studies using a visual world eye-tracking paradigm have provided evidence that listeners continuously make predictions about upcoming structure using a wide array of information sources including verbs (Altmann & Kamide, 1999), prenominal adjectives (Eberhard et al., 1995; Sedivy et al., 1999), prepositions (Chambers, Tanenhaus, Eberhard, Filip, & Carlson, 2002), order-of-mention (Kaiser & Trueswell, 2004), referential contexts (Spivey, Tanenhaus, Eberhard, & Sedivy, 2002; Tanenhaus et al., 1995) and pragmatic factors (Chambers et al., 2002; Chambers, Tanenhaus, & Magnuson, 2004). Although several studies have demonstrated that prosodic prominence, or emphasis, can also be used to

anticipate upcoming referents (Arnold, 2008; Dahan et al., 2002; Ito & Speer, 2008; Watson et al., 2008; Weber et al., 2006), no work has explicitly shown whether boundaries by themselves provide information that allows listeners to predict upcoming syntactic structure.

One exception is work by Snedeker and Trueswell (2003). They used a visual world eye-tracking paradigm to investigate how boundary information influences listeners' initial interpretation of syntactically ambiguous prepositional phrase constructions (*e.g.*, *Tap the frog with the flower*). In these sentences, the prepositional phrase can either modify the preceding direct object or serve as an argument of the verb. A boundary after *tap* creates a bias towards direct object modification while a boundary after *frog* creates a bias towards interpreting the prepositional phrase as an argument of the verb. Snedeker and Trueswell (2003) found that listeners very rapidly used boundary information to determine the role of an upcoming prepositional phrase. Shortly after the onset of the direct object noun but before the prepositional phrase was heard, participants showed more fixations to the object with an attribute (*e.g.*, the frog holding a flower) when the preposition was intended to be a modifier than when it was intended to be an instrument.

An analysis of more fine-grained time windows revealed that the effect came about at around the same time as the lexical information of the direct object noun became available. Lexically driven fixations are typically seen around 200ms after word onset (Allopenna et al., 1998). Their results showed that the effects of boundaries were marginally reliable in the time window 300-400ms after the onset of the direct object noun and were reliable in the 400-500ms time window. Because effects of boundaries were seen at around the same time lexical information was made available, it is difficult to know whether boundaries after the verb alone led listeners to anticipate the referents in the display. The authors speculate that the short duration of the direct object noun and a pause after the verb might have jointly provided a cue to the modifier interpretation. Note that these acoustic cues signal boundaries in different positions. A pause after the verb signals the presence of a boundary after the verb, while the short duration of the direct object noun signals that there is no boundary after the direct object noun. Because

there was no explicit examination of the independent contribution of each of these potential boundaries in Snedeker and Trueswell (2003)'s study, it is unclear whether listeners interpret boundaries as soon as they are encountered or whether they wait to integrate prosodic information across multiple words.

Snedeker and Trueswell (2003) argue that the reason they were not able to observe the effect of the boundary before the onset of the direct object noun was because the display contained a distracter animal that could also be described with a modifier (e.g., a giraffe in pajamas). Thus, in this experiment, even with boundary information, listeners had to wait until the relevant lexical information was heard to identify the target referent (e.g., a frog with flowers). Thus, this design cannot tell us whether boundaries by themselves are used predictively.

The Current Study

Although the Anti-Attachment Hypothesis and the Interpretive Domain Hypothesis attribute the effects of boundaries to different levels of processing, both theories predict that intonational phrase boundaries are incrementally interpreted as signaling closure of the processing of the preceding constituent as soon as they are encountered. If a listener knows that the preceding constituent is complete or if the listener has used the boundary to semantically wrap-up the constituent, they may expect upcoming information to be about another referent in the discourse, especially if the discourse (or visual display) is suitably constrained.

In contrast, it is unclear whether the theories like the Visibility Hypothesis and the Informative Hypothesis assume that local boundaries serve as points of closure in processing. Part of the difficulty in knowing it is that much of the recent work on the role of global prosodic structure has used offline meta-linguistic judgments (see Frazier et al., 2006 for a summary) rather than using tasks that tap on-line processing.

Previous studies using on-line measures such as cross-modal naming tasks and eye-tracking have found that prosodic boundaries influence syntactic decisions rapidly. However, for the reasons discussed earlier, it is difficult to know whether individual boundaries provide

information that allows listeners to predict upcoming syntactic structure.

In Experiments 5-7, I use a visual world eye-tracking paradigm to investigate whether intonational phrase boundaries can be used predictively. I overtly manipulate the presence of boundaries in spoken commands and monitor listeners' eye movements to objects in a visual scene while they are listening to auditory instructions. If boundaries can be used to determine what comes next, it would suggest that boundaries are providing information about their local syntactic and semantic context. If boundaries provide information about their local linguistic context, it would suggest that the Visibility Hypothesis should assume that local boundaries signal that preceding material is not packaged with upcoming material. It would also suggest that the Informative Boundary Hypothesis should assume that while global prosodic information is used by listeners to make attachment judgments, each boundary provides local information about syntactic structure.

A second goal of this study is to determine how global prosodic structure is interpreted in on-line processing. To date, the Informative Boundary Hypothesis has only been investigated in off-line studies. The visual world paradigm allows us to explore whether the relative size of boundaries has immediate effects on parsing.

Experiment 5

In Experiment 5, participants were presented with auditory instructions along with a corresponding visual scene on a computer display. Each visual scene included four pictures like those shown in Figure 6. Critical instructions had the form of example (19). In these sentences, the relative clause contained an action verb that modified one of the two preceding noun phrases. Because the relative clause can attach to either the high or low noun phrase, the sentences were locally ambiguous until they were disambiguated by number agreement between the verb in the relative clause and one of the nouns in the complex noun phrase. The presence of an intonational phrase boundary was manipulated at positions (a) and (b) in (19).

- (19) a. *Click on the father (a) of the girls (b) who is running.*
b. *Click on the father (a) of the girls (b) who are riding bicycles.*

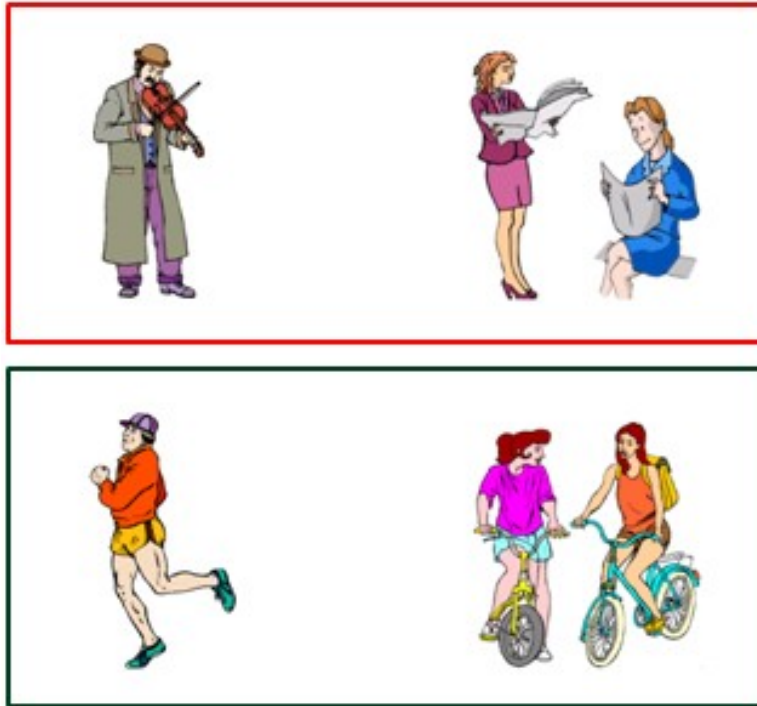


Figure 6. Example visual scene for Experiment 5.

Each visual display contained two pictures depicting the high noun (*i.e.*, potential targets. Hereafter we call them the Targets) and two pictures depicting the low noun (Hereafter, we call them the Relatives). All four referents were involved in different actions so that only the correct interpretation of the auditory instructions would lead participants to find the target in the visual display. Participants were told that boxes around a pair of pictures indicated a family relationship. In order to highlight the salience of the family relationship, different colors were used for each square that enclosed a pair of referents.

To understand the predictions of this experiment, it is important to understand what listeners are likely to look at when hearing an instruction like (19). Upon hearing *Click on the father*, listeners would fixate on the Targets (fathers) until hearing *of the girls*, at which point,

they would fixate on the Relatives (girls). Once the listeners hear the disambiguating information provided by the verb in the relative clause, their fixations should converge on the correct target (*i.e.*, the picture of the father who is running).

According to both the Anti-Attachment Hypothesis and the Interpretive Domain Hypothesis, the presence of an intonational phrase boundary signals closure of the preceding constituent, discouraging local attachment of the forthcoming constituent. For example, in (19), a boundary at (a) should signal that the preceding constituent *the father* is complete and should induce a semantic wrap-up of the material heard thus far. Since a boundary at (a) will be interpreted as signaling that upcoming information is more likely to be about a yet-to-be mentioned entity, fixations are expected to shift away from the Targets and towards the Relatives more rapidly when there is a boundary present than when there is not. Similarly, a boundary at (b) should signal that the preceding constituent *the girls* is complete and drive fixations to the target. Note that at position (a), *of the girls* attaches to the pre-boundary word *father* as its argument in (19) regardless of the presence or absence of a boundary at (a). Thus, it is conceivable that processing difficulty may temporarily increase if *of the girls* is preceded by a boundary, although it is not clear what sort of consequences this type of complexity has for eye movements.

A boundary at position (b) was manipulated for two reasons. First, it allows us to test whether potential effects of the early boundary were driven by the early boundary alone or the combined information at both noun phrases (*i.e.*, the boundary after the high noun and the duration of the low noun) as suggested by Snedeker and Trueswell (2003). If boundaries at (a) are incrementally processed before listeners encounter the next word, there should be an effect on fixations whether or not another boundary is present at (b). Second, it allows us to explore how global prosodic information is used by listeners to predict syntactic structure. The Informative Boundary Hypothesis (Carlson et al., 2001; Clifton et al., 2002) argues that a boundary at (b), which creates a bias towards high attachment, is only informative when it is stronger than a boundary at (a). The Informative Boundary Hypothesis has only been tested using off-line tasks. Thus, one unanswered question in the literature is whether listeners

incorporate global prosodic structure into the interpretation of syntactic structure on-line. This experiment examines how rapidly information about boundary (a) is incorporated into the interpretation of boundary (b). If a boundary at (b) creates a bias towards high attachment on-line, it would lead to an increase in fixations towards potential referents of the high noun (i.e., the Targets). If the Informative Boundary Hypothesis is correct, the effect of a boundary at (b) should be modulated by the presence of a boundary at (a).

Method

Participants

Forty students from the University of Illinois at Urbana-Champaign participated in the experiment for course credit. The participants in this and the following experiments were native speakers of English. They had normal or corrected-to-normal vision and no reported hearing impairment. All participants took part in only one of the experiments I report in this chapter.

Procedure

Participants were seated in front of a computer display wearing a head mounted eye tracker (SR Research EyeLink2). In the experiment, auditory instructions were presented to participants over speakers with a corresponding visual display on the computer screen. The participants' task was to click on pictures in the display. Participants' fixations were recorded from the onset of the auditory instruction until the selection of picture. Two practice items were provided at the beginning of the experimental session.

Materials

There were 24 critical items. Each item began with the phrase *Click on* followed by a complex noun phrase, where the high noun was a term for family (e.g., *father*), and the low noun was a common noun (e.g., *girls*). Example sentence (19) is repeated below as (20).

- (20) a. *Click on the father (a) of the girls (b) who is running.*
b. *Click on the father (a) of the girls (b) who are riding bicycles.*

The two nouns in the complex noun phrase differed in number from each other: one was a singular noun and the other was a plural noun. In half of the critical items, the high noun was singular (*e.g., father of the girls*) and in the other half, it was plural (*e.g., daughters of the gentleman*). We had each item occur in both high and low attachment versions by counterbalancing the auxiliary verb *is* and *are* across lists. Each version occurred with a different action verb (*e.g., running* and *riding bicycles*), but the correct target in the display was identical across both versions (*e.g., the picture of the father who is running*). In the visual display, the location of potential referents of the high noun (the Targets) and those of the low noun (the Relatives) was counterbalanced across items.

Each critical item was produced in four different boundary conditions by a trained male native speaker of English: 1) No Boundary, 2) Early Boundary, 3) Late Boundary, and 4) Both Boundaries. The boundary conditions are shown in (21) with examples (double slashes indicate the location of intonational phrase boundaries).

- (21) a. No Boundary: *Click on the father of the girls who is running.*
b. Early Boundary: *Click on the father // of the girls who is running.*
c. Late Boundary: *Click on the father of the girls // who is running.*
d. Both Boundaries: *Click on the father // of the girls // who is running.*

In the No Boundary condition, there were no intonational phrase boundaries produced within the critical region. The speaker produced an intonational phrase boundary after the high noun in the Early Boundary condition and after the low noun in the Late Boundary condition. In the Both Boundaries condition, the speaker produced intonational phrase boundaries at both positions. Each condition was checked by a trained ToBI coder to ensure that it was produced with the intended prosody. When the intended boundaries were not the perceptual equivalent of a “4” in

the ToBI coding scheme, which roughly reflects the percept of intonational phrase boundaries, the sentences were re-recorded. The boundaries were produced with an L-L% boundary tone. Critical nouns were produced with a presentational pitch accent (H*). In order to control for acoustic differences in the region before the word of interest, the phrase preceding the first boundary in each condition (*e.g.*, *Click on the* in the Early Boundary and Both Boundaries conditions, *Click on the father of the* in the Late Boundary condition) was replaced with the corresponding phrase in the No Boundary condition. An acoustic analysis of the stimuli was conducted to ensure that the presence of intonational phrase boundaries was cued by the lengthening of pre-boundary words, the presence of post-boundary pauses, and the degree of pitch reset at the onset of the following phrase. Table 10 presents the means for acoustic measures of duration and pitch reset for high nouns and low nouns.

Table 10

Mean durations of the high noun and the low noun and mean values of pitch reset at the words following the critical nouns, by condition (Experiment 5)

		NB	Early	Late	Both
Duration (ms) (including pause)	high noun	441 (16.2)	564 (16.8)	441 (16.2)	569 (17.6)
	low noun	375 (14.7)	365 (16.3)	471 (13.2)	475 (16.9)
Pitch reset (Hertz)	high noun	5.2 (.76)	24.2 (.99)	5.9 (.88)	20.1 (.98)
	low noun	5.4 (.39)	7.4 (.53)	24.6 (.73)	24.9 (.96)

Note. Standard errors are presented in parentheses.

The mean durations of the critical nouns were reliably longer when they were followed by intonational phrase boundaries than when they were not (high noun: $t(23)=15.0$, $p<.0001$; Low noun: $t(23)=13.2$, $p<.0001$). The mean duration of pauses was 278ms (standard error: 4.0) after the high noun and 261ms (standard error: 3.3) after the low noun. The speaker did not show much variation in pitch range overall, but there was a relatively greater pitch reset when there were boundaries (after high noun: $t(23)=22.3$, $p<.0001$; after low noun: $t(23)=23.4$, $p<.0001$)

than when there were not.

There were 8 different lists (4 boundary conditions x 2 auxiliary verbs) in total. Each participant received only one of them. Each list included 6 critical items per condition and 46 distracters. 14 of the distracters contained a single noun modified by a relative clause (*e.g., Click on the boy who is feeding the dog*), 14 distracters included a common noun followed by a prepositional phrase (*e.g., Click on the man on the boat*), 15 distracters included a reduced relative clause modifying the preceding noun (*e.g., Click on the woman wrapping a gift*), and 3 distracters included a present participle modifying the following noun (*e.g., Click on the smiling girls*). The critical and distracter items were presented in a randomized order.

Results and Discussion

Target Selection

Participants reached the intended readings most of the time (97%). The trials on which participants selected incorrect targets were excluded from the analysis of eye fixation patterns.

Fixation Data

The proportion of fixations to each of the four pictures was calculated out of the fixations to all four pictures. In order to reduce the number of samples discarded, any fixations reaching the area within up to 100 pixels from the borders of each picture were counted as fixations to the given picture (McMurray, Tanenhaus, & Aslin, 2002). Samples were taken every 25ms. The proportion of fixations to the Targets was obtained by combining the proportions of fixations to possible referents of the high noun.

A challenge in using fixations to investigate the online processing of intonational phrase boundaries is the inherent confound between boundaries and timing. Conditions in which boundaries are present are inherently longer than conditions in which they are not, and this creates a difference across conditions in the timing of the lexical input.

To illustrate this problem, we present the proportion of fixations to the Targets in Figure 7 aligned at the onset of the high noun (*father*). There are more looks to the Targets when a boundary is present than when it is absent starting at a little over 800ms after the onset of the pre-boundary word (in the region 800-1600ms: $F1(1,39)=49.7$, $p<.0001$, $F2(1,23)=26.3$, $p<.0001$). But, listeners hear the post-boundary phrase *of the girls* around 441ms after the onset of *father* in the conditions without intonational phrase boundaries (No Boundary and Late Boundary conditions), but do not hear *of the girls* until 845ms in the conditions with intonational phrase boundaries (Early Boundary and Both Boundaries conditions). In these latter conditions, the pre-boundary word (*father*) is lengthened and followed by a pause. This makes it difficult to determine whether differences across conditions are due to the presence of the boundary or simply due to when listeners hear critical words.

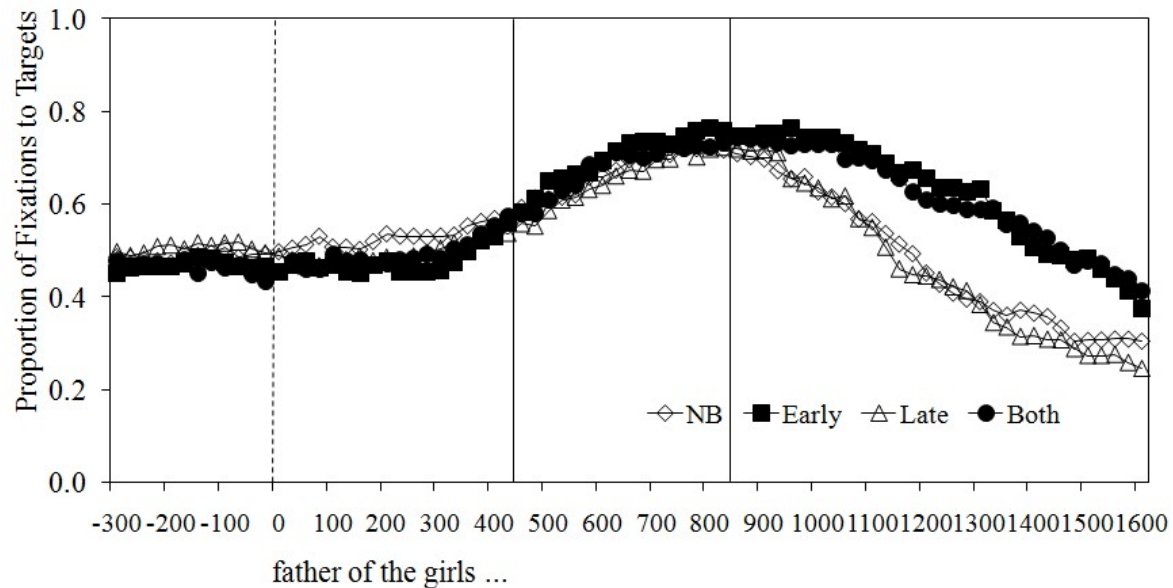


Figure 7. Fixation proportions over time to the Targets with the utterances synchronized at the onset of *father* (i.e., 0 ms corresponds to the onset of *father*). The shaded symbols indicate the conditions with early boundaries (Early Boundary and Both Boundaries conditions) while unshaded symbols indicate the conditions with no early boundaries (No Boundary and Late Boundary conditions). The solid vertical lines represent the average onset of *of* in the conditions with early boundaries (right) and that of the conditions without (left).

Because of this problem, the analyses I present in this and the following experiments are from fixations aligned at the onset of the words immediately following the boundaries (*i.e.*, the offset of post-boundary pauses). This includes the onset of the preposition *of*, and the onset of the relative pronoun *who*. Boundaries are signaled by changes in F0, duration on the pre-boundary word, and post-boundary pauses. Thus, listeners have information about the boundary by the offset of the pauses following pre-boundary words. The advantage of aligning fixations at the onsets of the next words is that at these points in the sentence, the only difference across conditions is whether or not a boundary has been heard: the lexical contents at these points are identical.

Onset of “of”

At this and the following critical points, effects of boundaries were evaluated based on the proportion of fixations to the Targets (fathers) because listeners were not provided with sufficient information to disambiguate potential targets until they heard a main verb (*running*) in the relative clause. Figure 8 presents the proportions of fixations over time to the Targets (fathers) after the onset of *of*, for each boundary condition. As illustrated in Figure 8, there were large differences between conditions in the proportion of fixations to the Targets before the alignment point. In the time window -300-0ms, there were more fixations to the target pictures when an intonational phrase boundary was present than when it was not, and this difference was reliable ($F(1,39)=83.0, p<.0001$; $F(1,23)=18.0, p<.0001$). There was no effect of the late boundary and no interactions (F 's <2). Note that the presence of a boundary is signaled prior to the alignment point by means of segmental lengthening, a change in F0 and pausing. Thus, this early divergence in fixations may reflect the listeners' perception of boundaries. The increase in fixations to the Targets as a function of the boundary before the alignment point may reflect semantic consolidation as predicted by the Interpretive Domain Hypothesis (Schafer, 1997).

In the 0-200ms time window where eye movements responding to the auditory input of *of* could not yet have been initiated, the effect of the early boundary was also reliable both by

participants ($F(1,39)=18.8$, $p<.0001$) and by items ($F(1,23)=5.9$, $p<.05$).

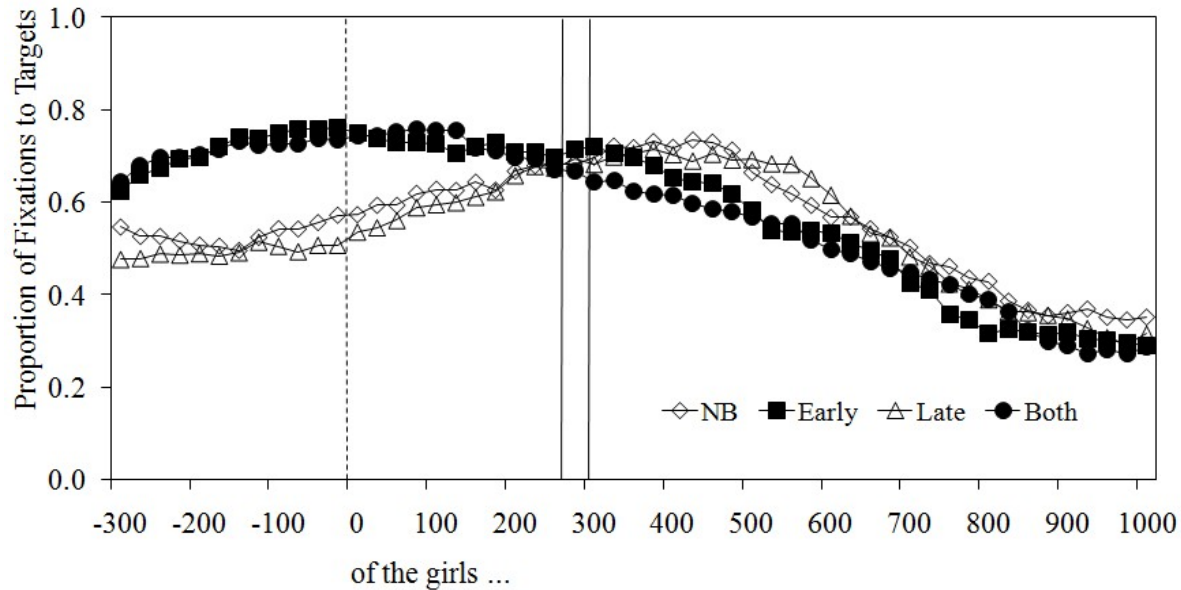


Figure 8. Fixation proportions over time to the Targets with the utterances synchronized at the onset of *of* (*i.e.*, 0 ms corresponds to the onset of *of*). The shaded symbols indicate the conditions with early boundaries (Early Boundary and Both Boundaries conditions) while un-shaded symbols indicate the conditions with no early boundaries (No Boundary and Late Boundary conditions). The solid vertical lines represent the average onset of the next lexical input (girls) in the conditions with early boundaries (right) and that of the conditions without (left).

I also compared the proportion of fixations to the Targets over the 200-800ms time window. Given that it takes roughly 200ms to program an eye-movement (Allopenna et al., 1998), boundary-driven fixations are expected to occur about 200ms after the offset of the boundary. The 800ms time point was chosen as an endpoint of the analysis window because the average duration between the onset of *of* and the onset of the next critical point (*i.e.*, the onset of relative clause) was 653 ms in the conditions with no late boundaries. Critically, starting from about 200ms after the onset of *of*, the pattern of fixations was reversed. There were more fixations away from the Targets (*i.e.*, towards the Relatives) when there was an intonational phrase boundary than its absence (Early Boundary and Both Boundaries conditions vs. No Boundary and Late Boundary conditions) ($F(1,39)=6.1$, $p<.05$, $F(1,23)=6.0$, $p<.05$). No other

effects were reliable ($F's < 1$). This suggests that listeners interpreted early boundaries as signaling that the preceding head (*father*) is complete.

It is difficult to know, however, whether the effect of boundaries after the onset of the alignment point is independent of the effect from the earlier time window. Over the time window before the alignment point, there were more fixations to the Targets when there was a boundary than when there was not, indicating that intonational phrase boundaries provided extra time to look at the referents of a pre-boundary word. Thus, an alternative explanation is that the effect of boundaries shifting participants' fixations away from the referents of a pre-boundary word was simply a side effect of timing. We return to this question later in the section.

Onset of "girls"

I also examined whether fixations were driven by early boundaries alone. In order to explore this question, I resynchronized the utterances at the onset of the next lexical word (*girls*) and examined whether early boundaries had an effect before the next referential information was presented. Figure 9 presents the proportions of fixations to the Targets after realigning the data at the onset of the low noun.

The proportion of fixations to the Targets was examined over the 0-200ms time window, a region in which eye movements could not yet have been initiated on the basis of auditory information about the low noun. There were more fixations away from the Targets when there were early boundaries than when there were not and this difference was reliable ($F(1,39)=8.7$, $p < .01$, $F(1,23)=7.9$, $p = .01$). There was no main effect of late boundary ($F's < 2$), nor was there a reliable interaction ($F's < 2.5$). The acoustic properties of the low noun convey information about whether a late boundary is actually present. Because these effects occur before this information is available, it suggests that the early boundary is interpreted locally.

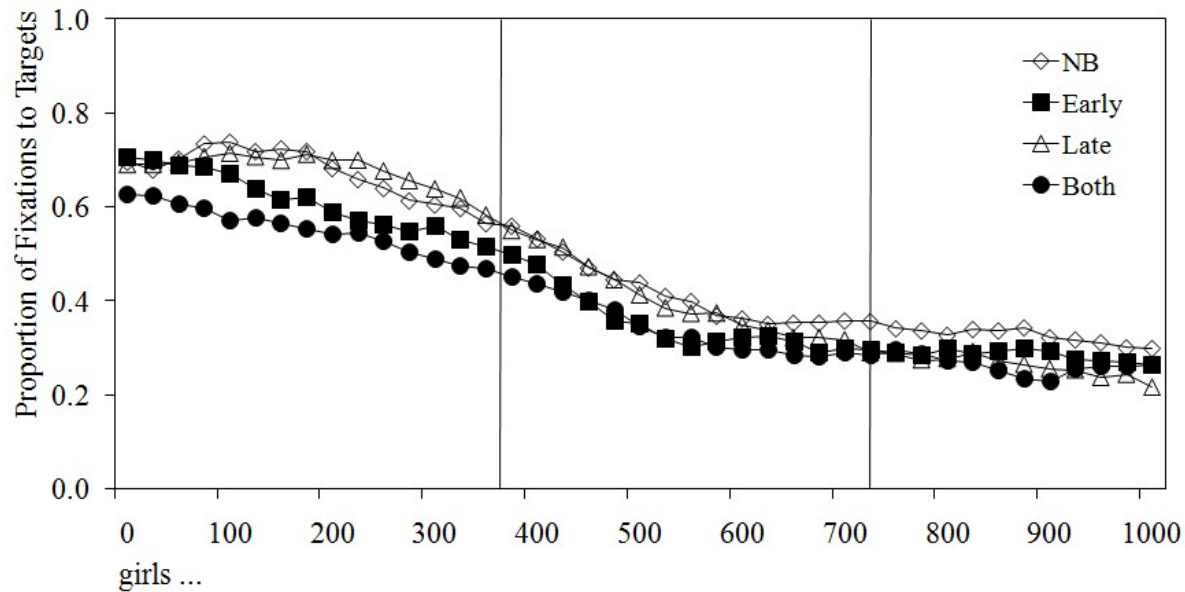


Figure 9. Fixation proportions over time to the Targets with the utterances re-synchronized at the onset of the low noun (*girls*)(*i.e.*, 0 ms corresponds to the onset of *girls*). The shaded symbols indicate the conditions with early boundaries (Early Boundary and Both Boundaries conditions) while un-shaded symbols indicate the conditions with no early boundaries (No Boundary and Late Boundary conditions). The vertical lines represent the offset of the low noun (*girls*), including pauses, in the conditions with early boundaries (right) and that of the conditions without (left).

Onset of “who”

Figure 10 presents the proportion of fixations over time to the Targets after the onset of the relative clause. As in the earlier analysis, there were reliable differences before the alignment point. In the -300-0ms time window, there were more looks to the referents of the pre-boundary word (*i.e.*, fewer looks to the Targets) in the conditions with late boundaries than in the conditions without, and this difference was reliable ($F(1,39)=81.3$, $p<.0001$, $F(1,23)=36.7$, $p<.0001$). There was also a sustained effect of the early boundary that was reliable by items ($F(1,23)=6.0$, $p<.05$) and marginally reliable by participants ($F(1, 39) = 3.9$, $p<.06$). Within each late boundary condition, there were more looks away from the Targets when there was an early boundary than when there was not (*i.e.*, No vs. Early; Late vs. Both). The interaction between early boundary and late boundary was not reliable ($F's < 1$). In the 0-200ms time window,

the effect of late boundary was reliable ($F(1,39)=44.4$, $p<.0001$, $F(1,23)=11.5$, $p<.01$). Yet the effect of early boundary disappeared (F 's <1). There was no reliable interaction (F 's <1.5).

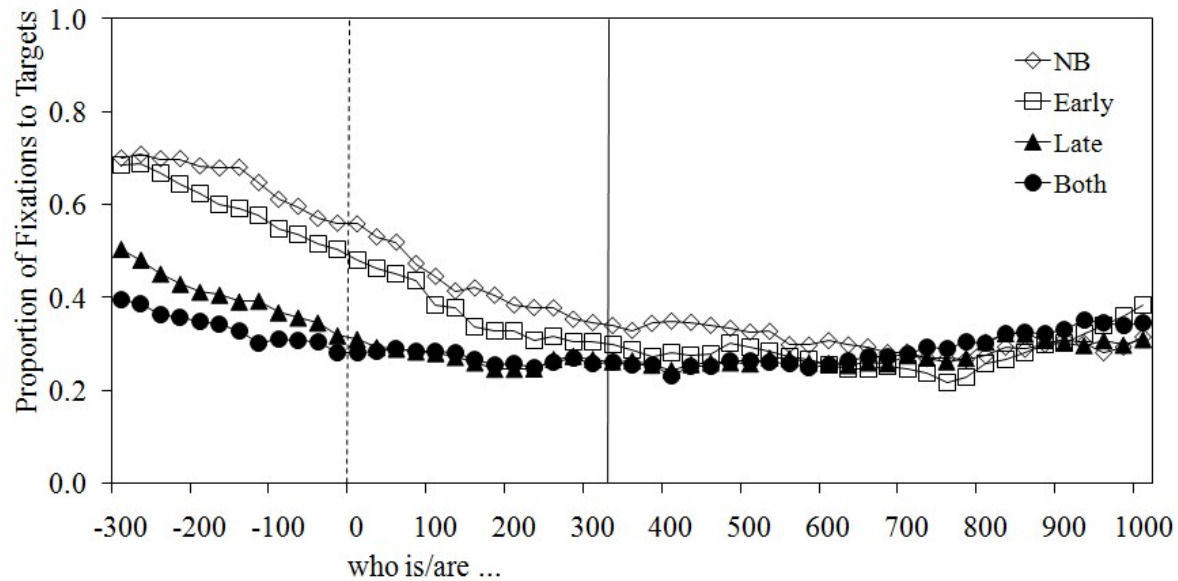


Figure 10. Fixation proportions over time to the Targets with the utterances re-synchronized at the onset of “who”. The shaded symbols indicate the conditions with late boundaries (Late Boundary and Both Boundaries conditions) while un-shaded symbols indicate the conditions with no late boundaries (No Boundary and Early Boundary conditions). The vertical line represents the average onset of the action verb (*e.g.*, *running*) across all conditions.

I also compared the proportion of fixations over the 200-500ms time window where eye movements responding to the auditory input of the relative clause had been initiated. The 500ms was chosen as an end point of the analysis window because the average duration between the beginning of the relative pronoun and the onset of the verb that disambiguates the target (*e.g.*, *running*) was 326ms across conditions. Unlike the early boundary, the presence of a late boundary did not increase the proportion of eye fixations away from the referents of a pre-boundary word. As in the previous region (*i.e.*, -300-200ms), there were more fixations towards the Relatives when there was a late boundary than when there was not. This difference was reliable by participants ($F(1,39)=7.8$, $p<.01$), but not by items ($F(1,23)=2.8$, $p=.11$). There was

no main effect of early boundary ($F's < 1$), nor was there a reliable interaction ($F's < 2$).

Note that after the onset of *of*, the presence of a boundary led to an increase in looks to the referents of a pre-boundary word initially and then it led to an increase in fixations towards the other referents. After the onset of *who*, the first effect was replicated with the presence of a late boundary inducing more fixations towards the Relatives. Unexpectedly, however, there was no effect of late boundaries shifting participants' attention away from the Relatives (*i.e.*, towards the Targets). I discuss a possible reason for the asymmetry between the effects of the early and late boundaries later in the section.

Boundary effects or timing effects?

The results suggest that early boundaries are interpreted by listeners as a cue that discourages attachment to pre-boundary words at the moment they are encountered. Listeners initially shifted fixations to the referents of the pre-boundary word more rapidly when a boundary was present than when it was not, which is consistent with the Interpretative Domain Hypothesis. Listeners then shifted their attention away from the referents of the pre-boundary word more quickly when there was a boundary after the high noun than when there was not, which is consistent with the Anti-Attachment Hypothesis.

However, an alternative account of these findings is that this pattern of fixations simply reflects extra processing time provided by pre-boundary lengthening and post-boundary pauses that accompany intonational phrase boundaries. Because the presence of these cues provided extra time for listeners to look at the referents of a pre-boundary word, they could have shifted their attention to the other pictures in the display more quickly. In conditions in which there is no boundary, listeners have less time to fixate on the critical word, and therefore, may be slower in shifting to the Relatives when they hear the prepositional phrase. There were reliably more fixations to the Targets in the -300-200ms time window when a boundary was present, which is consistent with a timing-based hypothesis.

One way to test this possibility is to examine whether the effect of the boundary leading

to more fixations away from the referents of a pre-boundary word correlated with the amount of extra time provided by intonational phrase boundaries. In order to test this question, I divided 24 critical items into three different groups of equal size based on the amount of pre-boundary lengthening and the duration of post-boundary pauses: Large, Medium, and Small difference groups.

Figure 11 plots the effect of early boundaries calculated as differences in the proportion of fixations to the Targets between the conditions with early boundaries and without, for each item group. Negative values here indicate that there were more fixations away from the Targets in the conditions with boundaries than in the conditions without. If a timing-based account is correct, the effect of the boundary shifting fixations away from the referents of a preceding word is expected to be greater in the order of the item group Large > Medium > Small.

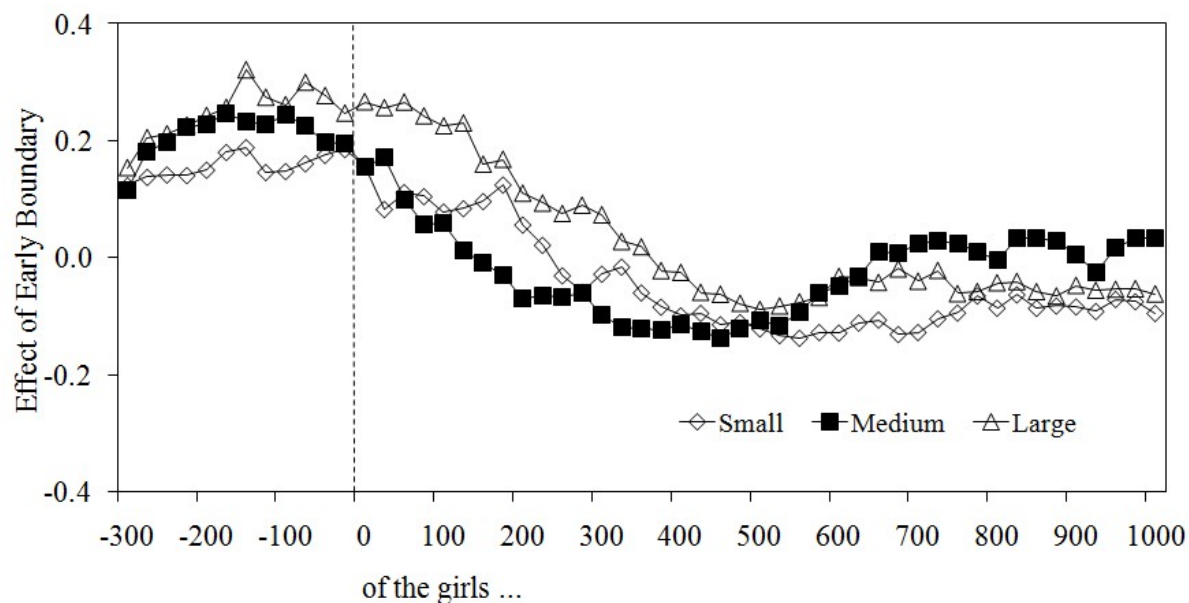


Figure 11. Differences in fixation proportions over time to the Targets between the conditions with early boundaries and without, with the utterances re-synchronized at the onset of “of”. The data were split by Type of Item: Small, Medium, and Large (where the difference in the duration of the high noun and the following pause between the conditions with early boundaries and without was greater in the order of Large > Medium > Small).

Figure 11 illustrates that having more time to process the referents of a pre-boundary word did not necessarily lead participants to shift their attention towards the other referents in the display more quickly. In the -300-0ms time window, there were more fixations towards the Targets when there was a boundary than when there was not and this effect was the greatest in the Large difference group. However, in the later region, the effect of the early boundary was shown in the unexpected direction: the speed with which participants shift their attention towards the other pictures was the slowest in the Large difference group. It was the fastest in the Medium group over the 0-500ms time window and in the Small difference group over 500-800ms. In neither of the regions did the interaction between the effect of early boundary and Item Type reach reliability ($F's < 1$).

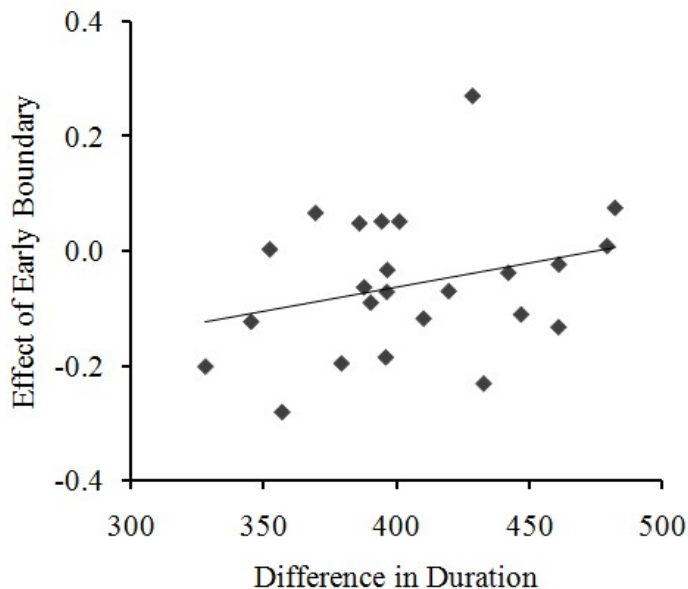


Figure 12. No significant correlation between the amount of extra timing (independent variable) and the effect of the early boundary (dependent variable) over 200-800ms after the onset of *of*.

If the timing-based account is correct, the effect of early boundaries observed over the 200-800ms time window after the onset of *of* should be negatively correlated with the amount of extra timing provided by a boundary. Figure 12 shows that there is no reliable correlation

between these two variables. We also note that the correlation was not in the direction predicted by the timing-based account.

These data suggest that the effects of early boundaries cannot simply be reduced to timing. The effects of boundaries shifting listeners' attention away from the referents of a pre-boundary word reflected the listeners' perception of the boundary, not just side effects of timing. However, because this claim is based on null effects and the post hoc analysis was conducted without controlling potential confounds such as the intrinsic length of the pre-boundary word or the salience of a potential referent in the visual display, we should be cautious about drawing a strong conclusion from the reported data. In future work, I hope to manipulate intonational phrase boundaries and the temporal distance to pit against each other to obtain more solid evidence that there is an effect of boundaries independent of time.

Why no effects of late boundaries?

The data suggests that consistent with the hypothesis of incremental processing, both early and late boundaries are interpreted as signaling a semantic wrap-up, increasing looks to the referents of a pre-boundary word at the moment they are encountered. Early boundaries led listeners to shift their attention away from those referents more quickly when a boundary was present, suggesting that those boundaries provide syntactic information to the processor. Late boundaries, however, did not result in such effects.

One possible explanation is that the sentences were lexically disambiguated soon after the presentation of the late boundary. In this experiment, auditory instructions were constructed to be temporarily ambiguous between high and low attachment until they were disambiguated by auxiliary verbs in the relative clause. The target was disambiguated once the main verb in the relative clause was heard because there was only one picture in the visual display that was involved in the action described by the verb. The action was associated with the target when the sentences were disambiguated towards high attachment while it was associated with the picture that was paired with the target when the sentences were disambiguated towards low attachment.

Thus, prosodic information conveyed by late boundaries could have been overridden by the lexically presented information that reliably disambiguated the sentences. In Experiment 6, I tested this possibility using globally ambiguous sentences. If any information that late boundaries conveyed about syntax was veiled by the presence of the disambiguating lexical information in Experiment 5, effects of late boundaries should be observed when sentences are globally ambiguous and contain no lexically presented disambiguating information.

Use of global prosodic structure

In Experiment 5, there was no evidence that global prosodic information influenced attachment decisions. According to the Informative Boundary Hypothesis, effects of the late boundary should be reduced if there is an early boundary that is present that is greater than or equal in size to the late boundary. There was no hint of this type of interaction in the data. In fact, the Both Boundaries condition, which contained boundaries at both locations, induced more fixations to the pre-boundary word than the Late boundary condition. It is possible that the lack of interaction was due to the overall weak effects of the late boundary, possibly caused by the presence of disambiguating lexical information so soon after the boundary. Thus, in Experiment 6, a further goal was to explore whether and how global prosodic structure is used in resolving attachment ambiguities.

Experiment 6

In Experiment 5, we failed to observe an effect of late boundaries on syntactic processing in the fixation data. It is conceivable that the absence of the effect of late boundaries was due to the presence of lexically disambiguating information, which was available shortly after the boundary. The disambiguating information provided by the following lexical item might have obscured effects of the late boundary. Experiment 6 examines this possibility using globally ambiguous relative clause sentences such as (22) below.

(22) *Click on the candle (a) below the triangle (b) that's in the blue circle.*

The sentence in (22) is ambiguous because the relative clause *that's in the blue circle* can modify either the high noun (*the candle*) (high attachment) or the low noun (*the triangle*) phrase (low attachment). If local boundaries are interpreted as signaling closure as soon as they are encountered, boundaries at both (a) and (b) should bias listeners to look away from the referents of the pre-boundary word more quickly when a boundary is present than when it is not. Critically, a boundary at (b) should increase the probability of listeners' anticipating high attachment.

Another goal of the current experiment is to explore whether global prosodic information has immediate effects on parsing. The Informative Boundary Hypothesis (Carlson et al., 2001; Clifton et al., 2002) argues that a boundary at (b), which creates a bias towards high attachment, is only informative when it is stronger than a boundary at (a). This experiment examines how rapidly information about boundary (a) is incorporated into the interpretation of boundary (b).

To examine these questions, I varied the size of boundaries at (a) and (b) between the intonational phrase boundary (IP) and the intermediate phrase boundary (ip), which enabled to test the Informative Boundary Hypothesis using the types of prosodic boundary comparable to those used in previous work (Carlson et al., 2001; Clifton et al., 2002). An intermediate phrase boundary is a weaker juncture than an intonational phrase boundary and it is the perceptual equivalent of a "3" in the ToBI coding schemes. Each critical sentence was produced in 4 different conditions as shown in (23).

- (23) a. *Click on the candle **ip** below the triangle **ip** that's in the blue circle.*
b. *Click on the candle **ip** below the triangle **IP** that's in the blue circle.*
c. *Click on the candle **IP** below the triangle **ip** that's in the blue circle.*
d. *Click on the candle **IP** below the triangle **IP** that's in the blue circle.*

The conditions differed from each other in terms of relative boundary size. In (23a) and (23d), the strength of the late boundary was equal to that of the early boundary. In (23b), the late

boundary was stronger than the earlier boundary while in (23c), the late boundary was weaker than the earlier boundary. According to the Informative Boundary Hypothesis, condition (23b) should result in more high attachment than (23c). Conditions (23a) and (23d) should lie somewhere in between. If the relative size of boundaries has immediate effects on parsing, the effect of the late boundary triggering fixations away from the referents of the pre-boundary word should be modulated by whether it is preceded by an intonational phrase boundary or by an intermediate phrase boundary.

In this experiment, each critical instruction was presented with a visual scene consisting of four objects that were potential referents of the high noun (*i.e.*, the Targets) and four shapes that were potential referents of the low noun. For example, the sentences in (23) were presented with the visual scene illustrated in Figure 13.

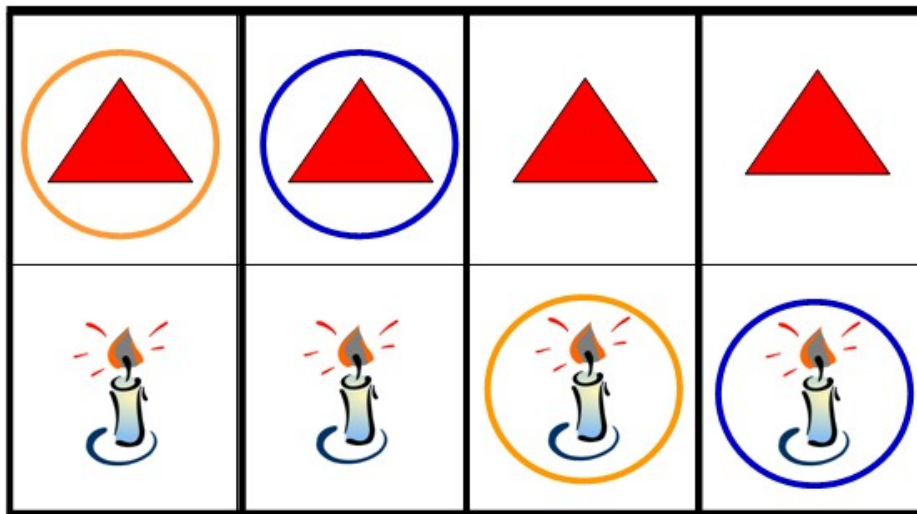


Figure 13. Example visual scene for Experiment 6.

The participants' task was to click on one of the pictures in the visual display according to the instructions. Participants' eye movements during visual search were monitored. In Figure 13, in the high attachment interpretation, the correct target is the candle in a blue circle. In the low attachment interpretation, the correct target is the candle that is paired with the triangle

surrounded by a blue circle.

Method

Participants & Procedure

Participants were sixty-four undergraduate students from the University of Illinois at Urbana-Champaign. They received course credit in compensation for their participation. The procedure was the same as in Experiment 5.

Materials

There were thirty-two critical sentences, each consisting of a complex noun phrase followed by a relative clause headed by *that*, as shown in (23). The two nouns in the complex noun phrase were linked to each other by locative prepositions. In half of the critical instructions, the locative preposition was *below*, and in the other half, it was *above*. The experimental sentences were produced by a trained female native speaker of English. The intermediate phrase boundary was produced with a low phrase accent (L-), and the intonational phrase boundary with an L-H% boundary tone. Critical nouns were produced with a presentational pitch accent (H*) when it was followed by an intermediate phrase boundary and with a contrastive pitch accent (L+H*) when it was followed by an intonational phrase boundary.

Note that although the sentences were ambiguous, overall preferences for low attachment are expected for two reasons. The first is that listeners largely preferred low attachment in Experiment 5, most likely because of the frequency of this construction in English. The second reason is pragmatic: in the high attachment reading, the referring expression *the candle below the triangle* is less felicitous than in the low attachment reading because the definite determiner *the* is used before the word *triangle* even though there is not a unique triangle in the display. The use of the definite determiner in combination with the display might lead listeners to expect post-nominal modification of *triangle*. The use of indefinites was also problematic because their

pragmatic requirements are not satisfied by the display under either reading. The use of the definite determiner before the low noun with this display, however, provides a strong test of whether late boundaries serve as a cue to closure. If a late boundary induces high attachment even when syntactic and pragmatic properties create biases towards low attachment, then this would be strong evidence for boundaries as serving as cues to closure.

As in Experiment 5, the stimuli were cross-spliced in order to prevent the results from being influenced by any unintended acoustic differences in the speech stream. First, the words preceding the first prosodically manipulated word (*i.e.*, *Click on the*) in the sentence were cross-spliced so that they were identical across conditions. I also cross-spliced the high noun and the following words before the onset of the other critical noun (*i.e.*, *candle below the*) within the same early boundary condition ((23a) and (23b), (23c) and (23d)) so that there were no acoustic differences between conditions that had the same boundary status. For the same reason, the low noun and the following words (*i.e.*, *triangle that's in the blue circle*) were cross-spliced within the same late boundary condition ((23a) and (23c), (23b) and (23d)). This process ensured that the critical nouns across conditions were identical for each experimental item, if they were followed by the same kind of boundary.

Table 11 presents the mean durations of the critical nouns and the post-boundary pauses for each boundary type.

Table 11

Mean durations of high nouns, low nouns, and post-boundary pauses (in ms)(Experiment 6)

	high noun	pause after high noun	low noun	pause after low noun
ip	461 (11.7)	34 (2.4)	472 (10.6)	33 (1.4)
IP	624 (10.7)	215 (2.2)	646 (14.1)	215 (2.6)

Note. Standard errors are presented in parentheses.

The mean durations of the pre-boundary words were longer when they were followed by intonational phrase boundaries than by intermediate phrase boundaries and the differences were

reliable (HN: $t(31)=25.7$, $p<.0001$, LN: $t(31)=24.9$, $p<.0001$). The post-boundary pauses were also longer after intonational phrase boundaries than after intermediate phrase boundaries (pause after HN: $t(31)=56.5$, $p<.0001$, LN: $t(31)=56.4$, $p<.0001$). Table 12 presents the mean values of the low f0 target (L-) and of the high f0 target (H%) at the end of the critical nouns.

Table 12

Mean F0 values at L- and H% (in Hertz) (Experiment 6)

	high noun		low noun	
	L-	H%	L-	H%
ip	184 (2.8)		163 (2.7)	
IP	167 (2.7)	207 (2.0)	156 (2.3)	202 (1.8)

Note. Standard errors are presented in parentheses.

The comparison within each critical noun showed that the mean f0 minimum of intonational phrase boundaries was reliably lower than that of intermediate phrase boundaries (high noun: $t(31)=4.6$, $p<.0001$, low noun: $t(31)=2.3$, $p<.05$).

Eight lists were constructed out of 256 sentences (32 sentences x 4 boundary conditions x 2 types of locative prepositions). Critical items were rotated through 4 boundary conditions across lists. Each item occurred only once in one of the 4 conditions within the list, but occurred in all conditions across lists. The type of locative prepositions was also counterbalanced across lists. Each item occurred with *below* in half of the lists and with *above* in the other half. Each list contained 32 critical items (8 items per condition) and 96 distracter items. As in the test sentences, the distracter sentences included locative prepositions, requiring participants to figure out the spatial relationship between objects and shapes in the visual display to find target pictures. Sixty out of 96 distracters were simpler in structure than the test sentences in that they contained only one word indicating the spatial relationship: Each of the prepositions *above*, *below* and *in* occurred in sixteen distracters each (e.g., *Click on the alarm clock [that's] above the gray triangle*, *Click on the car [that's] below the orange cube*, *Click on the triangle [that's] in the*

purple circle.). Twelve distracters included *next to* (e.g., *Click on the cage [that's] next to the blue arrow.*). In another twelve distracters, the spatial relationship was expressed in two dimensions (e.g., *Click on the coffee maker above the pink heart and next to the blue square.*). The other twenty-four distracters were potentially ambiguous like the test items, but the ambiguity was resolved by the visual display that conveyed only one reading (e.g., *Click on the plate in the green circle [that's] next to the triangle. Click on the harp [that's] next to the arrow in the gray circle.*). Half of the distracter sentences contained the same relative pronoun as appeared in the critical sentences. When prosodic boundaries were produced in the distracter sentences, they were always intermediate phrase boundaries. The experimental and distracter sentences were presented in a randomized order.

Results and Discussion

Selection data

Table 13 presents the proportion of high attachment responses by condition. Participants clicked on the high attachment target only 13% of the time on average, showing an overall preference for low attachment.

Table 13

Proportion of high attachment responses (Experiment 6)

(ip, ip)	(ip, IP)	(IP, ip)	(IP, IP)
.13	.16	.11	.14

As shown in Table 13, there were more high attachment responses in the conditions where the late boundary was an intonational phrase boundary ((ip, IP) and (IP, IP)) than the conditions with an intermediate phrase boundary ((ip, ip) and (IP, ip)). A 2-way ANOVA with early boundary (ip vs. IP) and late boundary (ip vs. IP) as within-subjects factors revealed that there was a main effect of late boundary ($F(1,63)=6.3$, $p<.05$, $F(1,31)=5.8$, $p<.05$). The effect of the early

boundary was not reliable ($F(1,63)=2.1$, $p>.1$, $F(1,31)=2.3$, $p>.1$). There was no reliable interaction ($F's<1$). Although the statistical results suggest that listeners interpreted the late boundary just locally, note that the mean proportions are in the direction predicted by the Informative Boundary Hypothesis. I discuss this later in the section.

Fixation data

As in Experiment 5, in order to control for effects of the timing of the lexical input, I compared the proportions of fixations across conditions after resynchronizing the data at the onset of the words following the post-boundary pause: 1) at the onset of the preposition (*below/above*) and 2) at the onset of the relative clause (*that*).

Onset of “below/above”

Figure 14 presents the proportions of fixations to the Targets (candles) after the onset of *below/above*. As in Experiment 5, there was an early divergence in fixation before the alignment point (*i.e.*, -300-0ms) between the conditions with distinctive early boundaries. There were more fixations towards the referents of the pre-boundary word (candles) when early boundaries were intonational phrase boundaries than when they were intermediate phrase boundaries. The difference was reliable ($F(1,63)=16.5$, $p<.0001$, $F(1,31)=31.5$, $p<.0001$). There was no main effect of late boundary, nor was a reliable interaction ($F's<1$). In the following region 0-200ms, there were no main effects and no interaction ($F's<3$).

As in the earlier experiment, the effect of early boundaries was examined over the 200-800ms time window after the onset of *below/above*. In this region, there were more fixations away from the Targets (candles) when the high noun (*candle*) was followed by intonational phrase boundaries than by intermediate phrase boundaries. The effect of early boundary was reliable by participants ($F(1,63)=4.6$, $p<.05$), but not by items ($F(1,31)<1$). There was no effect of late boundary, nor was there a reliable interaction ($F's<2$). However, over the 200-400ms time window shortly after the onset of “below/above”, the effect of early boundary was reliable by

participants ($F(1,63)=4.5$, $p<.05$) and marginally reliable by items ($F(1,31)=3.4$, $p<.08$) Although this is weak evidence, it suggests that early boundaries were interpreted as signaling that the preceding constituent is complete, replicating the findings from Experiment 5.

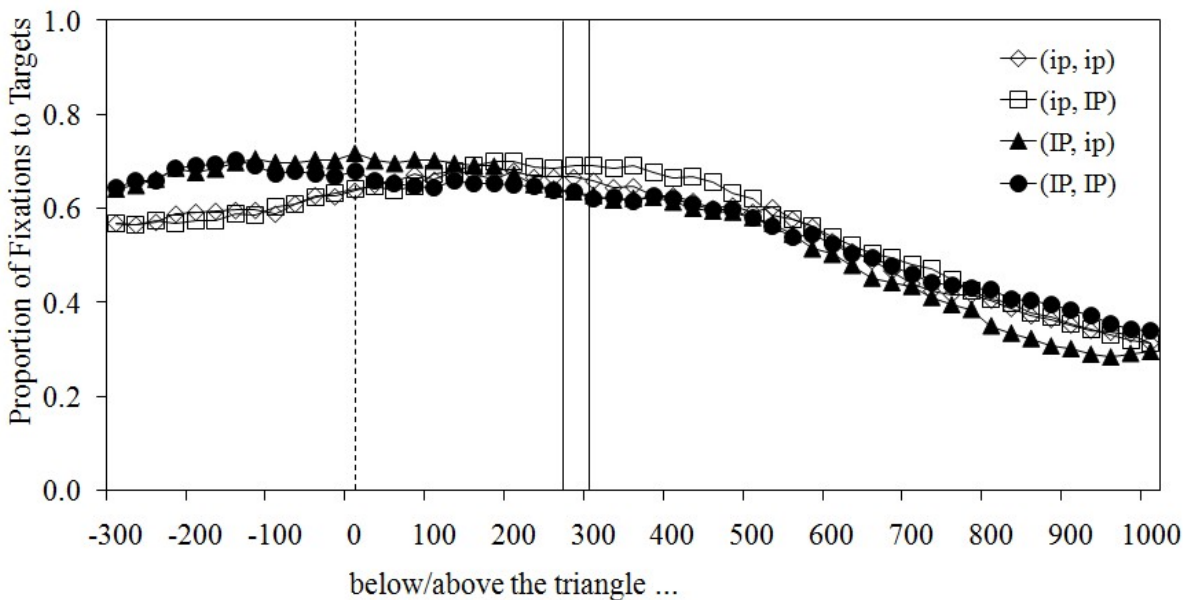


Figure 14. Fixation proportions over time to the Targets with the utterances synchronized at the onset of *below/above* (i.e., 0 ms corresponds to the onset of *below/above*). The shaded symbols indicate the conditions in which the early boundary was an intonational phrase boundary ((IP, ip) and (IP, IP)) while un-shaded symbols indicate the conditions in which the early boundary was an intermediate phrase boundary ((ip, ip) and (ip, IP)). The vertical lines represent the average onset of the low noun (triangle) in the early ip conditions (right) and that of the early IP conditions (left).

Onset of “that’s”

Figure 15 presents a time course of the proportions of fixations to the Targets (candles) at the onset of the relative clause. As in the earlier analysis, the data before the alignment point (i.e., -300-0ms) shows that participants’ fixations stayed longer on the referents of the pre-boundary word (triangles) (i.e., less looks towards candles) when the low noun (*triangle*) was followed by intonational phrase boundaries than by intermediate phrase boundaries, and this difference was reliable ($F(1,63)=12.2$, $p<.01$, $F(1,31)=10.7$, $p<.01$).

This pattern of fixations was reversed in the 0-200ms time window after the onset of the relative clause, revealing fewer fixations to the referents of the pre-boundary word (triangles) (*i.e.*, more fixations towards the Targets (candles)) when the late boundary was an intonational phrase boundary than when it was an intermediate phrase boundary. This indicates that the effect of the late boundary came about even before the onset of the relative clause. A 2-way ANOVA showed that there was a main effect of late boundary ($F(1,63)=4.7$, $p<.05$, $F(1,31)=5.1$, $p<.05$). There was no main effect of early boundary and no interaction.

The same pattern of fixations was sustained over the 200-500ms time window, which was the same analysis window used in Experiment 5. There was a reliable difference between the conditions with late boundaries and without ($F(1,63)=5.9$, $p<.05$, $F(1,31)=9.4$, $p<.01$). There was no main effect of early boundary, nor was there a reliable interaction ($F's<1$).

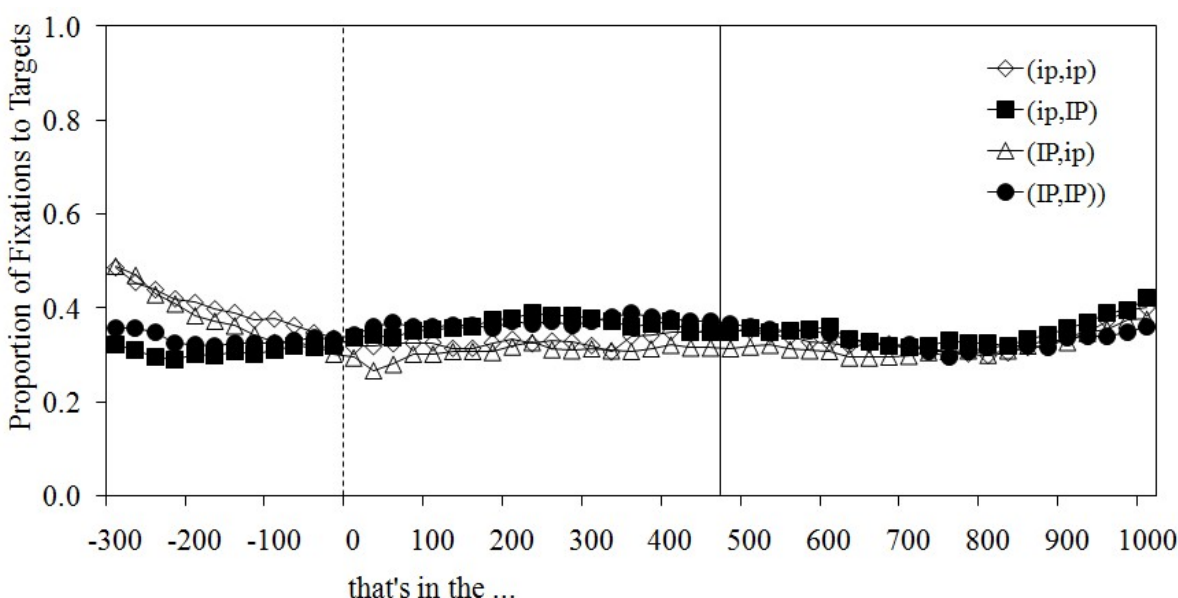


Figure 15. Fixation proportions over time to the Targets with the utterances synchronized at the onset of the relative clause (*i.e.*, 0 ms corresponds to the onset of *that's*). The shaded symbols indicate the conditions in which the late boundary was an intonational phrase boundary ((ip, IP) and (IP, IP)) while un-shaded symbols indicate the conditions in which the late boundary was an intermediate phrase boundary ((ip, ip) and (IP, ip)). The solid vertical line indicates the average onset of the color adjective in the relative clause (*blue*) across conditions.

The results replicate the findings from Experiment 5. The presence of an each boundary was interpreted as signaling closure at the moment it was encountered. Furthermore, we extended the findings from Experiment 5 by observing reliable effects of the late boundary in both the fixation data and listener selections. The late boundary as well as the early boundary reliably drove fixations away from the pre-boundary word, suggesting that the lack of an effect of the late boundary in Experiment 5 was due to the immediacy of the disambiguating lexical cue.

Do global prosodic structure influence parsing?

In Experiment 6, there were reliable effects of both the early and late boundaries in the fixation data while there was a reliable effect of just the late boundary in the selection data. In both the fixation and selection data, there was no reliable interaction between the early and late boundaries. The statistical data appear to be inconsistent with the predictions of the Informative Boundary Hypothesis. However, note that the numeric pattern of the means in the selection data is in the direction predicted by the Informative Boundary Hypothesis. The (ip, IP) condition elicited a higher proportion of high attachment responses than the (IP, ip) condition with the conditions with two boundaries of equal size located in between.

The lack of statistical support for the Informative Boundary Hypothesis may, of course, be due to a lack of power, but it might also be due to a floor effect given that there were strong low attachment preferences in the current data. In Clifton et al. (2002), several different syntactic constructions were examined to test the Informative Boundary Hypothesis. They manipulated the size of the early boundary (0, ip, and IP) while maintaining the size of the late boundary across conditions (ip). The results from their Experiment 2 showed that the difference between the condition in which the early boundary was absent (0) and the condition in which it was present (IP) was reliable across syntactic constructions regardless of varying overall attachment preferences. In contrast, the difference between the intermediate phrase boundary and the intonational phrase boundary was not reliable in the constructions in which there were overall low attachment preferences, such as the relative clause structure ($p's > .06$). It is possible that

listeners' sensitivity to global prosodic structure might interact with default syntactic preferences. In the current data, early boundaries may have been uninformative in interpreting the late boundary because it provided redundant information given that low attachment was structurally preferred.

Other issues

In Experiments 5 and 6, two different effects were triggered by intonational phrase boundaries. There were more fixations to the referents of a preceding word when there was a boundary than when there was not in the region before the alignment point (i.e., where acoustic information that signals the intonational phrase boundary was available), possibly reflecting a semantic wrap-up process. Immediately after this effect, there was a tendency to look less at those referents when the boundary was present than when it was not, immediately after the offset of a post-boundary pause.

There are two potential problems, however, in concluding that the effects we observed in Experiments 5 and 6 are due to semantic and syntactic processing. First, the effect of boundaries was evaluated based on the proportion of looks to more than one referent (*e.g.*, fathers and candles) in the visual display because information that disambiguated the potential targets was not available at the point of the boundary. A potential problem with this measure is that it is not straightforwardly linked to the interpretation of the relative clause. Thus, there is no way to be certain that the effect of intonational phrase boundaries in the fixation data is mediated by a syntactic or semantic process. This effect could reflect a side effect of intonational phrase boundaries on lexical processing: pre-boundary words are longer and provide more robust information for phonological analysis. The early effect of eliciting more looks to referents of a pre-boundary word could reflect more robust lexical processing. The subsequent fixations away from those referents could reflect the end of this process. These effects might also reflect effects of processing that are related to focus, as words preceding intonational phrase boundaries tend to be accented (*e.g.* Carlson et al., 2009). The accent on the pre-boundary word may have driven

increased fixations to the pre-boundary word. Thus, there is no way to be sure that these effects are due specifically to a syntactic or semantic process as predicted by the closure theory.

Second, while there was no reliable effect of boundaries signaling syntactic closure at the late boundary in Experiment 5, it was reliable in Experiment 6. Note that the discrepancy in the presence of this effect between the experiments was confounded with the type of boundary tone that marked intonational phrase boundaries (L% in Experiment 5 and H% in Experiment 6) and the type of non-intonational phrase boundary (No phrase boundary in Experiment 5 vs. intermediate phrase boundary in Experiment 6) against which the effect of intonational phrase boundaries was evaluated. The stimuli used in the two experiments also differed in terms of the type of pitch accent that occurred on the pre-boundary word. Pre-boundary words were produced with presentational pitch accents in Experiment 5 but were produced with contrastive pitch accents in Experiment 6. Thus, it is not clear whether the absence of an effect of the late boundary leading to a gaze shift was due to the immediacy of the disambiguating information or due to differences in the properties of the stimuli.

In order to address the first problem, in Experiment 7, I provide a more transparent measure of whether boundaries constrain syntactic analysis by using displays in which participants' fixations converge on a single target, a target that is linked to the interpretation of the relative clause at the point of the boundary. In order to address the second problem, Experiment 7 uses the same types of boundary tone and pitch accent as used in Experiment 5. The effect of intonational phrase boundaries is evaluated against a condition in which there is no boundary.

Experiment 7

In Experiment 7, the stimuli were designed such that effects of boundaries were measured based on the fixations to a single referent that is linked to the interpretation of upcoming syntactic structure. An example sentence is presented in (24) below.

(24) *Click on the boy and the girl holding flowers.*

Sentence (24) is ambiguous because the modifier *holding flowers* can attach low to the second noun phrase (*i.e.*, the girl), which we call low attachment, or high to the entire conjoined noun phrase (*i.e.*, the boy and the girl), which we call high attachment. Each target instruction was presented with the visual display that contained two pairs of individual pictures that corresponded to the high and low attachment interpretations, respectively. An example visual display is shown in Figure 16.

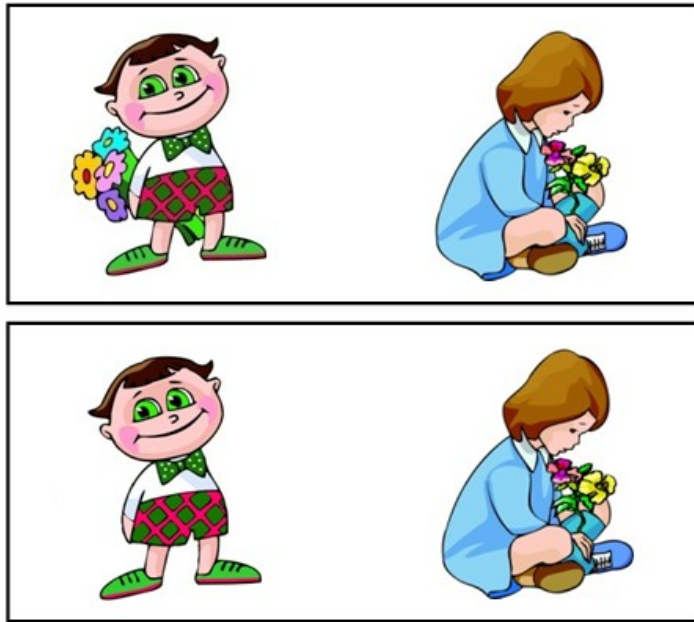


Figure 16. Example visual scene for Experiment 7

The participants' task was to click on one of the squares that contained a pair of individual pictures that matched their initial interpretation of the auditory instructions. For the low attachment interpretation, a correct response would be for the listener to click on the box in which the girl is holding flowers but the boy is holding nothing. For the high attachment

interpretation, the correct response would be for the listener to click on the box in which both the boy and the girl are holding flowers.

The stimuli for this experiment differed from those used in earlier experiments in two respects. First, in critical sentences, ambiguous modifiers were preceded by the conjoined noun phrase. The use of the conjunction *and* was motivated by an attempt to make it easy to process the relationship between the two noun phrases with respect to the visual display. In Experiment 5, a design in which the possessive preposition *of* was used, participants were required to be explicitly aware of the fact that the referents within a square were in a family relationship. In Experiment 6, a design in which locative prepositions were used, processing complex noun phrases required keeping track of the relative positions of objects and shapes. In the current study, the word *and* (along with the visual display) unambiguously conveys the grouping of the pictures.

Second, in Experiment 7, the visual display was highly constrained so participants could potentially anticipate the target at the point of the boundary and well before the end of auditory instructions, which was not possible in the previous experiments. In the latter, the information that disambiguated potential target referents was not available until later in the ambiguous phrase (*i.e.*, action verbs in Experiment 5, color adjectives in Experiment 6).

In Experiment 7, the ambiguity involved whether a critical attribute was considered to be associated with the referents of both nouns or with only a referent of the second noun. Thus, looks to the referents of the first noun should reflect the listeners' expectation of how the upcoming ambiguous phrase is to be structured. In (24), if there is an increase in looks to the boy with flowers when the boundary is present (hereafter, we call this type of referent the high attachment target), it would suggest that the boundary is interpreted as a signal to high attachment.

Method

Participants & Procedure

Thirty-six undergraduate students from the University of Illinois at Urbana-Champaign participated in this experiment for course credit. The procedure was the same as in the earlier experiments.

Materials

There were sixteen critical sentences. Each sentence comprised a conjoined noun phrase followed by a reduced relative clause as shown above. The two nouns in the conjoined noun phrase were linked to each other by the conjunction *and*. Each sentence was produced by a trained female native speaker of English in two different conditions as shown below (double slashes indicate the location of intonational phrase boundaries).

- (25) a. No Boundary: *Click on the boy and the girl holding flowers.*
b. Late Boundary: *Click on the boy and the girl // holding flowers.*

As in Experiment 5, intonational phrase boundaries were produced with an L-L% boundary tone. Critical nouns conveyed a presentational pitch accent (H*). As in the earlier experiments, the stimuli were cross-spliced such that there were no acoustic differences between conditions in the words preceding the second noun subject to the boundary manipulation (*i.e.*, *Click on the boy and the*).

Table 14 presents the mean durations of the critical noun (*i.e.*, *girl*) and the mean values of pitch reset at the word following it. The mean duration of the critical noun was longer when it was preceded by an intonational phrase boundary than when it was not ($t(15)=13.8$, $p<.0001$). There was a greater pitch reset after the critical noun in the boundary condition than in the no boundary condition ($t(15)=13.4$, $p<.0001$). The mean duration of pauses in the boundary condition was 200ms (standard error: 6.23).

Table 14

Mean durations of the second noun and mean values of pitch reset at the word following the second noun (Experiment 7)

	No Boundary	Late Boundary
Duration (ms)	386 (24.3)	580 (28.1)
Pitch reset (Hertz)	3.1 (1.19)	27.1 (1.72)

Note. Standard errors are presented in parentheses.

Critical items were rotated through two boundary conditions, resulting in two different experimental lists. Each list contained thirty distracter trials in addition to sixteen critical trials. Seven distracter trials included conjoined noun phrases without any post-nominal modifiers (*e.g.*, *Click on the ballerina and the diver.*). In another seven distracters, only the first noun was modified (*e.g.*, *Click on the woman holding a cup and the man.*). There were sixteen distracters that consisted of the same structure as that of critical trials (*e.g.*, *Click on the dog and the cow wearing earrings.*). These trials differed from critical trials in that they were disambiguated by the visual display: the display supported only one interpretation (8 trials: high attachment, 8 trials: low attachment). Half of the distracters were produced with intonational phrase boundaries.

Using a structure similar to the ones used here, Clifton et al. (2002) found that there is a bias to attach modifiers to the entire conjoined noun phrase (*e.g.*, *old men and women with very large houses*). In order to prevent participants from being biased towards one interpretation, all participants were provided with the eight distracter trials that shared the structure with the critical trials but included unambiguous visual displays at the beginning of the test session. This was meant to remind participants that the dispreferred interpretation was possible before encountering the critical trials. The order of the rest of the distracter and experimental trials was randomized.

Results and Discussion

Selection data

Consistent with the findings from Clifton et al. (2002), there were overall high attachment preferences, which were not reduced by the attempt to train participants to be exposed to both interpretations at the beginning of the test session. Participants clicked on the high attachment pair 85% of the time on average. The results demonstrate that there was no effect of the late boundary promoting high attachment responses. The two boundary conditions showed differences in the unexpected direction with more high attachment responses in the No Boundary condition (87%) than in the Late Boundary condition (83%). However, this difference was reliable by items ($t(15)=2.6$, $p<.05$), but not by participants ($t(35)=1.5$, $p>.1$).

Fixation data

In order to provide a more sensitive measure of whether intonational phrase boundaries have a predictive effect on the interpretation of upcoming structure, the proportion of fixations to the high attachment target (e.g., the boy who is holding flowers) was used as a dependent measure of on-line effects of boundaries.

Figure 17 presents the proportions of fixations to the high attachment target after the onset of the modifier phrase (*i.e.*, the offset of a post-boundary pause). As illustrated in Figure 17, there were more looks to the high attachment target over the region -100-700ms when there was an intonational phrase boundary than when there was not. Of interest, as in Experiment 6, this effect came about even before the alignment point, indicating that it was driven by boundary information that was available on the pre-boundary word (*i.e.*, segmental lengthening, a change in F0 and pausing). Over the -100-700ms region, the difference between the No Boundary and the Late Boundary conditions was reliable ($t_1(35)=2.2$, $p<.01$, $t_2(15)=2.7$, $p<.05$). This suggests that listeners used an intonational phrase boundary to predict upcoming syntactic structure upon hearing reliable cues to the boundary.

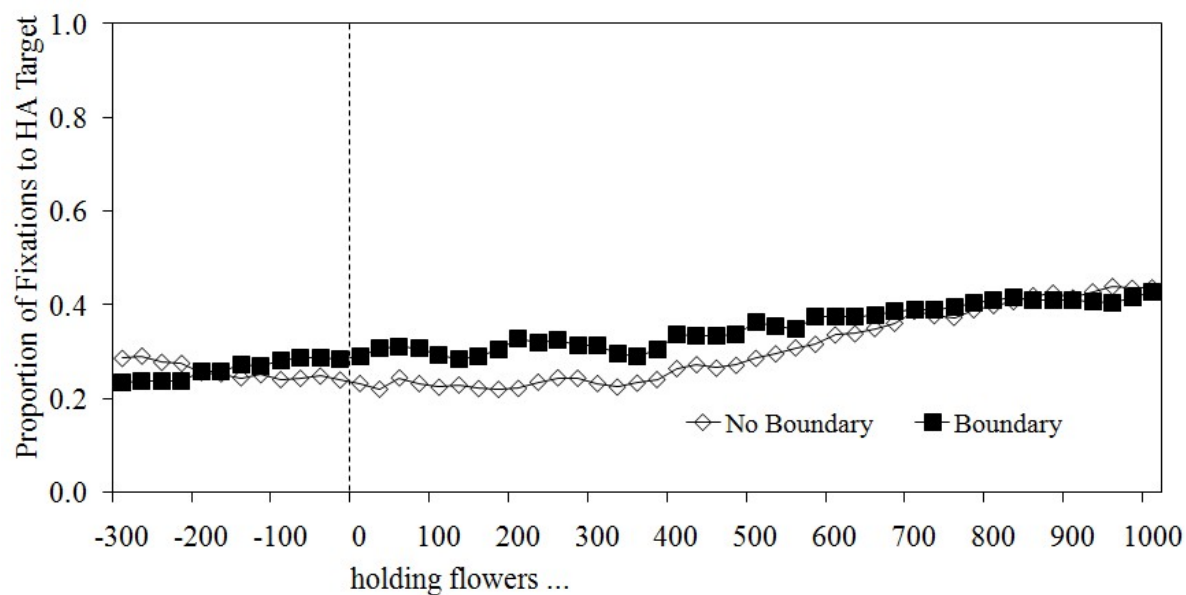


Figure 17. Fixation proportions over time to the high attachment target with the utterances synchronized at the onset of the modifier (*i.e.*, 0 ms corresponds to the onset of *holding*). The shaded symbol represents the condition with an intonational phrase boundary and the un-shaded symbol represents the condition with no boundary.

In Experiment 7, I used a more constrained display that allowed participant fixations to converge on a single target that was directly linked to the interpretation of the upcoming ambiguous phrase at the point of the boundary. There were more anticipatory looks to the high attachment target at the onset of the modifier phrase when there was an intonational phrase boundary than when there was not. This suggests that the effect of boundaries in the fixation data reflects syntactic processing.

The presence of an effect of the late boundary signaling syntactic closure suggests that the discrepancy in the presence of this effect between Experiments 5 and 6 was not due to the types of boundary tone and pitch accent that accompanied the intonational phrase boundary. Identical data patterns were observed in Experiment 6 and in this experiment despite the fact that intonational phrase boundaries were associated with different types of boundary tone (Experiment 6: L-H%, this experiment: L-L%) and the pre-boundary words were produced with

different types of pitch accent (Experiment 6: L+H*, this experiment: H*). The findings from Experiment 6 and this experiment also suggest that listeners interpret the presence and absence of an intonational phrase boundary differently, independent of whether the latter is an intermediate boundary or no boundary at all.

Why no effects of boundaries in the selection data?

There was no reliable effect of the late boundary in the selection data. While the late boundary promoted high attachment in final responses in Experiment 6, it did not so in Experiment 7. One possible explanation may be that boundary cues interact with attachment preferences: boundaries are ignored if they are redundant with structural preferences. This view could reconcile the seemingly disparate results from Experiments 6 and 7. In Experiment 6, there was a reliable effect of the late boundary, but no effect of the early boundary. Given the strong low attachment bias associated with relative clause attachment in this study, the late boundary might have been weighted less heavily because it provided redundant information. Similarly, the lack of a late boundary effect in the coordinate structures used in Experiment 7 may have been due to the late boundary signaling the already preferred high attachment interpretation. Of course, this claim needs to be tested empirically, and although there is some work that suggests that there is an interaction between boundary use and structural frequency (Snedeker & Yuan, 2008), it is not clear whether specific boundaries are interpreted differently in different structural contexts.

Conclusion

The goals of this chapter were to determine 1) whether the presence of an intonational phrase boundary provides syntactic and semantic information to the processing system, and 2) whether the relative size of boundaries has immediate effects on attachment decisions. It is not universally accepted that boundaries provide information about their local syntactic and semantic context, other than by increasing or decreasing the relative accessibility of attachment sites (e.g.

Carlson et al., 2009; Frazier et al., 2006). These data demonstrate that intonational phrase boundaries serve as a cue to closure, which allows listeners to predict upcoming material at the point of the boundary.

Although there was no statistical support for the Informative Boundary Hypothesis, the numeric patterns of the selection data from Experiment 6 suggest that global prosodic information does have effects on parsing. As a sentence unfolds, listeners could potentially integrate multiple prosodic boundaries in a sentence while they use information that each local boundary provides about the probability of attaching upcoming materials to the pre-boundary word. However, there was no evidence in the fixation data showing that the relative size of boundaries has immediate effects on parsing.

The data suggest that theories like the Visibility Hypothesis and the Informative Boundary Hypothesis should incorporate a local interpretation component in their models. For example, in the Visibility Hypothesis, local boundaries might provide information about how upcoming material is grouped. A boundary would signal that preceding material does not belong to the same prosodic domain as upcoming words and that it is invisible as an attachment site. In the Informative Boundary Hypothesis, local boundaries provide a cue to not attach upcoming elements to a pre-boundary word. The relative size of boundaries comes into play in parsing because a cue provided by an earlier boundary to syntactic and semantic closure may be overridden by a cue from a stronger boundary later in an utterance.

In Experiments 6 and 7, there was a dissociation between the fixation data and final selection data. On-line fixation data reflects that intonational phrase boundaries provide local information about the likelihood of attachment to the word that precedes it at the moment they are encountered. The discrepancy between the on-line and offline measures may be attributable to the fact that while on-line measures reflect information prosodic boundaries provide about local syntactic context, off-line measures reflect participants' syntactic decisions that are affected not just by a local boundary, but also by lexical information that becomes available later in the sentence, structural biases, and meta-linguistic consideration.

Although it has been known for quite some time that boundaries can disambiguate surface structure (*e.g.*, Shattuck-Hufnagel & Turk, 1996), the data from Experiments 5-7 provide a step towards understanding how incremental the processing of boundaries is, the role boundaries play in parsing, and how rapidly boundaries are used by listeners as a cue to predict upcoming linguistic structure.

Chapter 4

Individual Differences in the Use of Intonational Phrase Boundaries in Syntactic Processing

Research on syntactic processing has focused primarily on whether and how different linguistic and non-linguistic constraints influence interpretation of syntactic structure. A relatively recent emerging line of research has shown that the parsing of syntactic structure can vary across individuals, with some individuals being more affected by constraints available in the linguistic input than others (*e.g.*, Just & Carpenter, 1992; King & Just, 1991; Long & Prat, 2008; Pearlmuter & MacDonald, 1995). One source of individual variability in syntactic processing stems from differences in abilities to perform working memory tasks (*e.g.*, Felser, Marinis, & Clahsen, 2003; Just & Carpenter, 1992; King & Just, 1991; Long & Prat, 2008; MacDonald, Just, & Carpenter, 1992; Pearlmuter & MacDonald, 1995; Swets, Desmet, Hambrick, & Ferreira, 2007; Traxler, 2007). People who perform well on these tasks⁴ are more likely to employ probabilistic constraints such as plausibility (*e.g.*, Long & Prat, 2008; Pearlmuter & MacDonald, 1995) or animacy (Just & Carpenter, 1992) in resolving local syntactic ambiguity than people who do not perform well on these tasks.

Differences in performance on working memory tasks are also correlated with how globally ambiguous sentences are resolved. Consider (26).

(26) *Someone shot the servant of the actress who was on the balcony.*

Sentence (26) is globally ambiguous because the relative clause can be interpreted as modifying

⁴ Although there is a great deal of controversy surrounding what working memory span tasks measure (*e.g.*, Caplan & Waters, 1999; Engle, 2002; Just & Carpenter, 1992; MacDonald & Christiansen, 2002), I assume that these tasks are sensitive to individual differences in a cognitive process that underlies efficient language use. Although I am agnostic as to whether this process is actually linked to memory capacity per se, I use memory capacity as a shorthand to refer to this aspect of the processing system.

either the high noun phrase *the servant* (high attachment) or the low noun phrase *the actress* (low attachment). Several studies have shown that there are individual differences in resolving attachment ambiguities like (26) (Felser et al., 2003; Mendelsohn & Pearlmutter, 1999; Swets et al., 2007; Traxler, 2007). Studies using tasks that measure online processing have found that both children and adults with high working memory capacity are more likely to attach the relative clause to the high noun than those with low working memory capacity (e.g., Felser et al., 2003; Traxler, 2007) while studies using offline tasks have shown that high attachment is preferred by individuals with low working memory capacity to a greater extent than those with high working memory capacity (e.g., Mendelsohn & Pearlmutter, 1999; Swets et al., 2007).

One constraint that has not been investigated with respect to ambiguity resolution and memory span is prosodic structure. In (26), an intonational phrase boundary after the high noun (*i.e.*, *servant*) creates a bias towards low attachment while a boundary after the low noun (*i.e.*, *actress*) creates a bias towards high attachment.

In this chapter, I investigate the relationship between the use of intonational phrase boundaries and working memory span. This question is of theoretical interest for two reasons. The first is that, despite inconsistencies in the patterns of results between online and offline studies, prosody has been proposed to be the factor that underlies the working memory and attachment preference interaction in (26). Felser et al. (2003) speculate that children with high working memory capacity may have been more sensitive to a pause before the presentation of the relative clause in their self-paced listening task compared to those with low working memory capacity. On the other hand, Swets et al. (2007) argue that readers with low working memory capacity are more likely to use an implicit prosodic break before the relative clause as a consequence of segmenting the complex noun phrase from the relative clause. Thus, both researchers have appealed to prosody to explain results that are contradictory. However, because neither of the studies discussed above manipulated prosody explicitly, it is unclear whether individuals indeed vary in their use of prosodic boundaries. The present study explores this question by explicitly manipulating intonational phrase boundaries.

The second reason for investigating prosody's interaction with working memory is because it differs from other linguistic constraints. While probabilistic constraints known to interact with working memory capacity (*e.g.*, plausibility and animacy) all require computing and integrating real world knowledge into a linguistic representation as the sentence is processed, the use of prosody only requires a timely detection of acoustic/phonetic information followed by integration with syntactic structure. Thus, it may potentially provide greater benefit to low span comprehenders given that it may be easier to detect and can convey useful syntactic information. This possibility underlies the claim of Swets et al. (2007). They argue that low span comprehenders may be more sensitive to prosodic phrasing because it can potentially help them structure the input. In contrast, as Felser et al. (2003) suggested, high span comprehenders may be more sensitive to prosodic constraints. High working memory capacity may allow for the use of multiple sources of information in syntactic processing, regardless of whether they require the online computation of real world knowledge.

Thus, investigating whether working memory modulates listeners' sensitivity to prosodic information can provide insight into whether prosody helps structure the input for low-span comprehenders or whether it is one of many constraints that are more available to high span comprehenders. If the latter is true, it would suggest that individual differences in working memory capacity do not only constrain the use of resource intensive constraints like animacy and plausibility, but rather, they also have extensive influence over the use of probabilistic constraints in language processing more generally.

Experiment 8

Method

Participants

Fifty-six undergraduate students from the University of Illinois at Urbana-Champaign

participated in exchange for course credit. Participants were all native speakers of English. They had normal or corrected-to-normal vision and no reported hearing impairment.

Working Memory capacity test

Participants' working memory capacity was estimated from the mean score of four different working memory measures⁵: reading span, listening span, alphabet span, and digit span. I employed this composite measure because using multiple tasks provides higher test-retest reliability and greater classificatory stability than using a single measure (Waters & Caplan, 2003). In the reading span test, participants were presented with a set of a varying number of sentences. Participants were asked to make a true/false judgment after reading each sentence out loud. When all of the sentences in each trial were presented, participants were asked to recall the last word of each sentence. The listening span test was an auditory variant of the reading span test. The only difference in procedure from the reading span test is that participants were asked to listen to each sentence instead of reading it out loud. In the alphabet span test, after reading a set of a varying number of words aloud, participants were asked to recall them in alphabetical order. In the digit span test, participants read a set of a varying number of digits out loud. At the end of each trial, they were asked to recall the results of subtracting 2 from each digit in order. In all tests, the number of target sentences, words, and digits in each trial varied from two to eight (*i.e.* level 2 to level 8). There were two trials at each level. If participants successfully recalled all the items in one of the two trials, they moved on to the next level. The score of each test was calculated based on the highest level successfully completed. The number of correctly recalled items at the partially completed level was reflected in the score as a fraction.

Materials and Procedure

The same materials as used in Experiment 6 were used. Example sentences and an

⁵ The materials used in the listening and reading span tasks were adopted from Stine and Hindman (1994).

example visual scene are repeated as (27) and Figure 18, respectively, below.

- (27) a. Click on the candle **ip** below the triangle **ip** that's in the blue circle.
b. Click on the candle **ip** below the triangle **IP** that's in the blue circle.
c. Click on the candle **IP** below the triangle **ip** that's in the blue circle.
d. Click on the candle **IP** below the triangle **IP** that's in the blue circle.

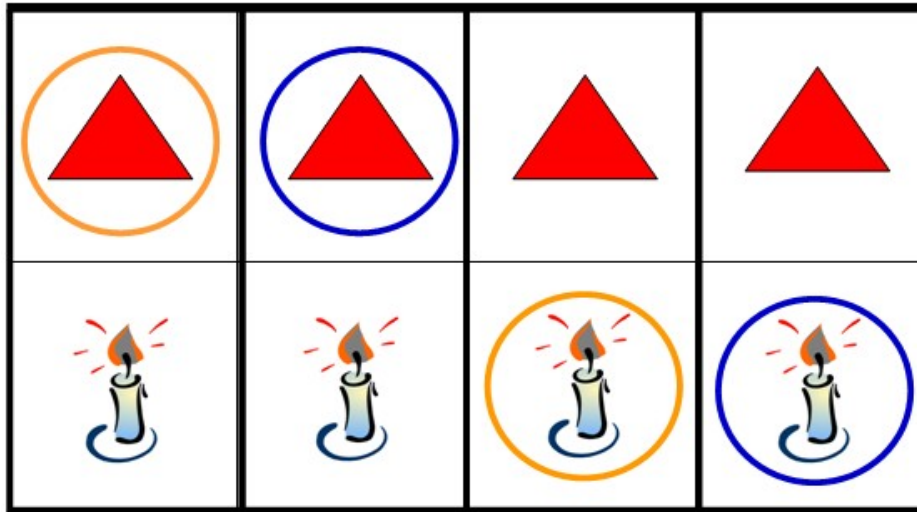


Figure 18. Example visual scene for Experiment 8

On each trial, participants listened to a target sentence. As soon as it ended, they were presented with a visual scene that included 8 different pictures as in Figure 18. The participants' task was to click on one of the pictures in the visual display according to their initial interpretation. Participants' eye movements were not monitored.

Results and Discussion

The data set was analyzed using mixed logit models with participant and item as random effects. The random effects structure in the model was determined based on model comparisons using likelihood ratio tests as in Experiments 1-4.

Effect of intonational phrase boundaries

As in Experiment 6, there was a strong bias towards low attachment in interpreting the relative clause, across conditions (Table 15). There was a clear effect of intonational phrase boundaries in the late position, which replicates the findings from Experiment 6. Participants selected the high attachment target more frequently when there was an intonational phrase boundary after the low noun than when there was an intermediate phrase boundary (25% vs. 17.5%).

Table 15.

Proportion of high attachment responses (Experiment 8)

(ip, ip)	(ip, IP)	(IP, ip)	(IP, IP)
.18	.25	.17	.25

The results from a mixed logit model analysis with early boundary and late boundary as predictors of high attachment responses showed that there was a main effect of late boundary ($\beta=0.40$, $SE=0.17$, $z=2.3$, $p<.05$). There was no main effect of early boundary ($\beta=-0.03$, $SE=0.13$, $z=-0.2$, $p>.1$), nor was there a reliable interaction between early boundary and late boundary ($\beta=0.08$, $SE=0.26$, $z=0.3$, $p>.1$).

Working memory capacity and prosody

In order to examine whether working memory capacity had an impact on the extent to which listeners use prosody in syntactic ambiguity resolution, working memory was included in the model as a predictor along with early boundary and late boundary. The average of the scores from the four working memory tests was centered and included as a continuous variable in the model. Overall, listeners with low working memory capacity showed more high attachment responses than those with high working memory capacity, but this difference was not reliable ($\beta=-0.45$, $SE=0.33$, $z=-1.4$, $p>.1$). The interaction between late boundary and working memory was reliable ($\beta=0.72$, $SE=0.27$, $z=2.7$, $p<.01$), indicating that listeners' sensitivity to the late

boundary varied with their working memory capacity (Figure 19). The interaction between early boundary and working memory was not reliable ($\beta=-0.17$, $SE=0.22$, $z=-0.8$, $p>.1$), nor was the 3-way interaction ($\beta=0.15$, $SE=0.45$, $z=0.3$, $p>.1$).

Figure 19 illustrates that the effect of intonational phrase boundaries increased as a function of working memory capacity, which indicates that listeners with higher working memory capacity were more sensitive to prosodic information than those with low working memory capacity.

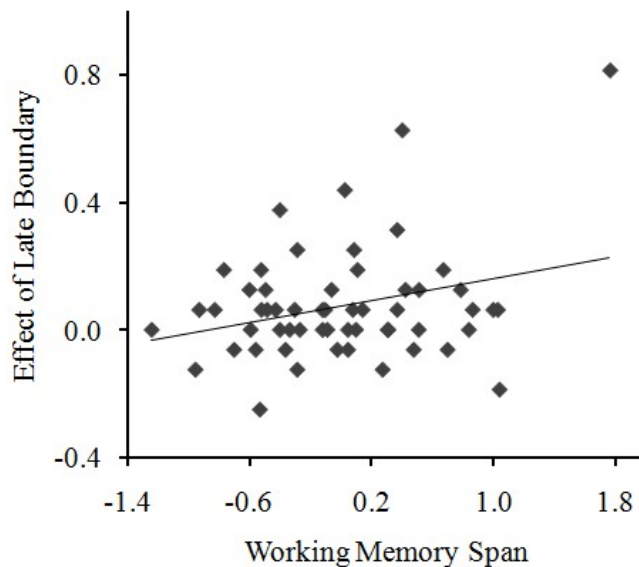


Figure 19. Significant positive correlation between the boundary effect (dependent variable) and working memory span (independent variable) where the boundary effect represents the difference in the proportion of high attachment responses between the conditions in which the late boundary was an intonational phase boundary and those in which the late boundary was an intermediate phrase boundary. Working memory scores were centered.

The data suggest that working memory span influences not only the ability to utilize constraints that require complex computations but also the use of low-level acoustic/phonetic information like prosody.

Conclusion

In Experiment 8, listeners with high working memory capacity were affected by prosodic cues to a greater extent than those with low working memory capacity. When there was an intonational phrase boundary between the complex noun phrase and the relative clause, high span listeners showed a greater increase in the probability of associating the relative clause with the high noun than low span listeners.

Although the data suggest that working memory is correlated with the use of prosodic information in spoken language processing, it is still unclear whether prosody can account for the effects in reading. The data here are inconsistent with previous claims that readers with low working memory capacity are more sensitive to an implicit prosodic break between the complex noun phrase and the relative clause than those with high working memory capacity (Swets et al., 2007; Traxler, 2009). The results show that it was high span listeners who were most successful at utilizing boundary information. Successful use of prosody requires detecting relevant acoustic/phonetic information in time and integrating it into a syntactic analysis while it is held in memory. Individual differences may occur because comprehenders with high working memory capacity may have more resources to perform this operation.

The findings suggest that prosodic information is one of the probabilistic constraints whose use is correlated with working memory capacity. Individual differences in working memory capacity have consequences for various aspects of language processing, which range from the use of the constraints that involve the integration of real world knowledge to the use of the constraints that require the detection of low level acoustic/phonetic information available within the linguistic input.

Chapter 5

General Discussion

The primary goal of this dissertation has been to explore one of the theoretical debates in the literature: What aspects of prosody are reliably used in syntactic processing? I examined this question by focusing on the roles intonational phrase boundaries and pitch accents play in attachment ambiguity resolution. The traditional view (*e.g.*, Bolinger, 1961; 1972; Chafe, 1974; Halliday, 1967; Lehiste, 1973; Price et al., 1991; Schwarzschild, 1999; Selkirk, 1984; 1986; Terken, 1984; Truckenbrodt, 1999) is that while intonational phrase boundaries play a primary role in syntactic processing, the role pitch accents play in processing is mostly limited to the discourse level. Pitch accents play only a supporting role in syntactic processing. An exception to this view is work by Schafer et al. (1996) that suggests that pitch accents can also play a primary role in relative clause attachment. The view proposed by Schafer et al. (1996) differs from the traditional view in that it assumes that there is a direct relationship between pitch accenting and syntactic representation.

In this dissertation, I attempted to resolve these two conflicting views. In Chapter 2 (Experiments 1-4), I examined what factors give rise to the effects of pitch accents on attachment decisions. The data showed that the accent attachment effects were driven by the acoustic and perceptual properties of accented words, not by a syntactic processing mechanism, supporting the traditional view. The perceptual salience of accented words biased listeners towards selecting those words as the answer to the post-sentence question.

Another goal was to investigate two issues that have remained unaddressed in the literature on prosodic boundaries and syntax: 1) what types of information intonational phrase boundaries provide to the parser and 2) whether individual differences exist in the use of intonational phrase boundaries in syntactic processing. The data from Chapter 3 (Experiments 5-7) demonstrate that intonational phrase boundaries provide a signal to semantic and syntactic

closure that allows listeners to predict upcoming linguistic structure. The data from Chapter 4 (Experiment 8) suggest that sensitivity to intonational phrase boundaries in interpreting syntactic structure may vary across individuals. In what follows, I summarize the findings from each of the experiments reported in this dissertation.

In Experiments 1-4, I revisited the issue of whether pitch accents play a primary role in syntactic processing as intonational phrase boundaries do. Schafer et al. (1996) manipulated the presence of pitch accents on potential attachment heads so a pitch accent occurs on the high noun in one condition and on the low noun in the other condition (*e.g.*, *Brandon interviewed with the son of the lady who worked with the man.*). The effect of accents on relative clause attachment was evaluated based on participants' responses to post-sentence comprehension questions that probed for high or low attachment (*e.g.*, *Who worked with the man?*). Schafer et al. found that listeners' preference to attach the relative clause high was greater when a pitch accent was produced on the high noun than on the low noun.

In Schafer et al. (1996)'s study, accent attachment effects were examined based on the comparison between the Early Accent and the Late Accent conditions. In Experiment 1, a condition in which none of the potential attachment heads were accented was included as a baseline. The presence of a pitch accent on a noun reliably increased the probability of selecting that noun as the answer to the post-sentence comprehension question compared to its absence, replicating the previous finding.

In Experiments 2-4, I investigated the factors that give rise to this effect. The literature on memory suggests that accented words are better remembered than unaccented words because of their semantic and acoustic salience. One possibility is that accented words were selected as the answer to the post-sentence question more frequently than unaccented words because of their perceptual salience (the Salience Hypothesis). This view predicts that listeners would be more likely to select perceptually salient accented words in complex sentences in which a referent of accented material could be the only recoverable referent. Alternatively, however, if the effect was driven by a preference for attaching modifiers to new or important information in the

discourse (the Syntax Hypothesis), there should be no interaction between accent and sentence complexity. I manipulated sentence complexity by varying the extraction site and length of the relative clause (long object-extracted RC vs. short subject-extracted RC). The results supported the Saliency Hypothesis. The effect of pitch accents was modulated by sentence complexity with a greater effect in long object-extracted relative clauses than in short subject-extracted relative clauses.

In Experiment 3, I explored whether the preference for selecting salient information as the answer to the post-sentence question is driven by an on-line syntactic processing mechanism or by a post-sentence selection bias. Given that language processing is highly incremental (*e.g.*, Altman & Kamide, 1999; Altman & Steedman, 1988; Sedivy et al., 1999), the syntactic processing mechanism version of the Saliency Hypothesis predicts that accent effects should not be affected by the length of the relative clause because information about the relative clause length is not available at the moment listeners are provided with the cue for the relative clause (*i.e.*, the relative pronoun). In order to test this question, the extraction site (Experiment 3a) and length (Experiment 3b) of the relative clause were manipulated separately. The results were consistent with the post-sentence selection bias version of the Saliency hypothesis. Accent effects interacted with the length of the relative clause with a greater effect in long relative clauses than in short relative clauses. However, there was no such interaction found between accent and RC extraction site.

More solid evidence against a processing-based account comes from Experiment 4. In this experiment, the type of question was manipulated so participants were asked either about the interpretation of the relative clause (*e.g.*, *Who worked with the man?*) or about the contents of the matrix clause (*e.g.*, *Who did Brandon interview?*). If the accent attachment effects were the result of a syntactic processing mechanism, the effects should be observed only when the question asks about relative clause attachment. Consistent with the post-selection bias account, there was a bias to select accented words as the answer to the post-sentence query regardless of what the question was about.

Although future research that employs on-line techniques is required to completely rule out a processing-based account, the data from Experiments 2-4 suggest that the previously established accent attachment effects may have been due to a post-sentence bias to select salient information. This implicates that the findings from Schafer et al. (1996) should not be taken as evidence that pitch accents play the same role as that of intonational phrase boundaries in syntactic processing.

Experiments 5-8 used a visual world eye-tracking paradigm to investigate how intonational phrase boundaries are interpreted by listeners in on-line processing. One of the unanswered questions to date is whether intonational phrase boundaries themselves are sufficient for signaling local syntactic structure. In Experiment 5, I used temporarily ambiguous relative clause sentences such as *Click on the father (a) of the girls (b) who is running/are riding bicycles*. The presence of an intonational phrase boundary led to more fixations to the referents of the pre-boundary word, possibly reflecting a semantic wrap-up process. Shortly after the offset of a post-boundary pause, there was a more rapid gaze shift from those referents when there was an intonational phrase boundary than when there was not. However, the latter effect was observed only for the early boundary at (a).

Experiment 6 tested whether the absence of an effect of the late boundary on syntactic processing was due to the disambiguation by lexical information soon after the late boundary. To this end, I used globally ambiguous structures such as *Click on the candle (a) below the triangle (b) that's in the blue circle*. The data showed that when there was no lexical disambiguation information, intonational phrase boundaries in both positions had immediate effects on gaze shifts. Another goal of Experiment 6 was to examine how global boundary information is interpreted on-line. The on-line data did not provide evidence for an immediate effect of global prosodic structure, but the numeric pattern of the offline data was consistent with the prediction by the Informative Boundary Hypothesis.

Experiment 7 used a more constrained visual display in which participants' fixations converge on a single target that is linked to the interpretation of the relative clause at the point of

the boundary. The presence of the late boundary was manipulated in sentences like *Click on the boy and the girl (a) holding flowers*. There were more anticipatory looks to the high attachment target (i.e., the boy with flowers) when there was an intonational phrase boundary at (a) than when there was not, even before the modifier was heard. This suggests that the effect of boundaries in the fixation data was mediated by a syntactic process.

Taken together, the findings from Experiments 5-7 demonstrate that intonational phrase boundaries provide information about their local syntactic and semantic context that allows listeners to predict upcoming syntactic structure at the point of the boundary.

I should point out, however, that I am not making the claim that listeners only interpret boundaries locally with respect to the previous word. Although the interaction between early boundary and late boundary was not reliable in Experiment 6, the numeric pattern of the selection data suggested that listeners are capable of integrating global prosodic information in the interpretation of ambiguous sentences. And, as has been shown in previous work (Carlson et al., 2001), listeners integrate current boundary information with previous occurrences of prosodic boundaries in making inferences about syntactic structure. Individual boundaries may simply serve as guideposts to the upcoming structure of the sentence as the sentence is processed online. Compatible with this view is the finding by Snedeker and Casserly (2010) that attachment decisions are influenced by global prosodic structure as well as local boundary information.

With respect to the absence of effects of early and late boundaries in offline measures of Experiments 6 and 7, we speculated that it might be due to an interaction with attachment preferences. In Experiment 6, there were no effects of early boundaries that created a bias that matched the structural preferences of the relative clause construction. Similarly, in Experiment 7, there were no effects of late boundaries that created a bias that matched a high attachment preference of the conjoined noun phrase construction. Thus, early and late boundaries might have been interpreted as providing redundant information in Experiments 6 and 7, respectively, which listeners may have weighted less strongly in processing the sentence. Future work will need to explore this possibility.

Experiment 8 explored whether there are individual differences in the use of intonational phrase boundaries in attachment processing, which is another question that has remained unanswered in the literature on prosody and syntactic processing. The results showed that working memory capacity and the use of prosody were positively correlated. Listeners with higher working memory capacity were more likely to utilize boundary information in syntactic processing than those with low working memory capacity.

Alternatively, the correlation between working memory and the use of prosody may reflect the dependence of both measures to a third variable such as processing speed, linguistic experience, or inhibitory control. Future research will need to investigate this question, using a battery of psychometric measures that tap various aspects of cognitive abilities as well as linguistic experience.

The first major contribution of this dissertation is theoretical. Returning to the discussion of the role pitch accents play in syntactic processing, the current findings suggest that unlike intonational phrase boundaries, pitch accents do not have a direct influence on syntactic attachment. Previous work suggests that pitch accents may influence syntactic interpretation, but only in so far as they signal discourse status or grammatical functions (*e.g.*, Nivedita, 2004; Schafer et al., 2000). For example, pitch accents play a role in the resolution of the embedded question vs. relative clause ambiguity associated with *who* in the sentence *I asked the pretty little girl who's cold* (Schafer et al., 2000). When there is a pitch accent on *who*, the sentence is preferentially disambiguated towards an embedded question interpretation. This type of disambiguation, however, is only achieved as a consequence of pitch accents resolving the lexical ambiguity associated with two meanings of *who*, not as a consequence of pitch accents directly signaling structural dependencies between the elements in an utterance as intonational phrase boundaries do. Thus, pitch accents function to signal information about discourse status or to disambiguate the grammatical functions of words, which can have consequences for how sentences are interpreted. This is also consistent with the claim by Lehiste (1973) and Price et al. (1991) that pitch accents play a role in syntactic processing only when different interpretations

are associated with different underlying structures. The results from Experiments 1-4 show that apparent exceptions to this view, in which pitch accents appeared to have directly signaled syntactic attachment by attracting an ambiguous phrase (Carlson et al., 2009; Schafer et al., 1996), may have been the result of a post-sentence selection bias. Furthermore, this study is the first to show that intonational phrase boundaries are sufficient for allowing listeners to predict upcoming syntactic structure and that individual differences may exist in the extent to which boundary information is used in syntactic processing.

Why are intonational phrase boundaries and pitch accents used differently in processing? Intonational phrase boundaries are used as a reliable cue to recover syntactic structure because the grammar requires them to match major syntactic boundaries and the parser is sensitive to that relationship. In contrast, the parser may not interpret pitch accents as signaling how the sentence is structured because the distribution of pitch accents is not associated with where syntactic boundaries are located. However, this raises a possibility that there might be cross-linguistic differences in terms of what aspects of prosody influence syntactic processing. Pitch accents may play a primary role in attachment ambiguity resolution in any languages in which the distribution of prosodic prominence may be constrained by syntactic factors.

The second major contribution is methodological. The findings from Experiments 1-4 provide implications for how experiments on prosody in language processing are designed. Previous work (Carlson et al., 2009; Schafer et al., 1996) that investigated the effect of pitch accents on syntactic attachment used paradigms such as recall tasks, two-alternative forced choice, and paraphrase selection. The effect of pitch accents was assessed based on the participants' overt selection of one of the potential attachment sites. A problem with this type of approach is that participants' responses may be influenced by the perceptual properties of the signal. This may give rise to effects that may not reflect processes that are engaged in typical syntactic processing. There are two potential solutions to this problem. One is to use on-line techniques such as visual world eye-tracking paradigm (e.g. Dahan et al., 2002; Ito & Speer, 2008; Watson et al., 2008, Watson et al., 2006) and electrophysiological measures (e.g., Hruska

et al., 2000; Ito & Garnsey, 2004; Li et al., 2008) to study prosody. The second possibility is to use offline measures in which the response variable is unlikely to be biased by the acoustic-phonetic properties of the stimulus. Any task in which the response matches the prosodically manipulated element of the test sentence is likely to be susceptible to the biases demonstrated in the present study.

In Experiments 5-7, the visual world eye-tracking paradigm was employed in order to explore how intonational phrase boundaries are interpreted at the moment they are encountered. The findings demonstrate that this methodology is promising for the investigation of the on-line interpretation of boundary information. This paradigm can be extended in future research to examine what aspects of intonational phrase boundaries drive the effects found here. The paradigm can also be applied to directly test the effect of global prosodic structure in on-line processing, perhaps by using structures with more balanced ambiguities.

This dissertation provides empirical evidence for the claim that there is an asymmetry between intonational phrase boundaries and pitch accents in guiding the interpretation of ambiguous structures. In addition to the directions for future research mentioned above, another direction that needs to be taken is to extend this line of work to explore whether there is a corresponding asymmetry in the use of prosody in production. Empirical work on whether intonational phrase boundaries and pitch accents are used differently in production will provide a better understanding of how distinct aspects of prosody contribute to different levels of language processing.

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