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Effects of pitch accents in attachment ambiguity resolution

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Abstract

Previous work has found that listeners prefer to attach ambiguous syntactic constituents to nouns produced with a pitch accent (Schafer et al., 1996). This study examines what factors underlie previously established accent attachment effects by testing whether these effects are driven by a preference to attach syntactic constituents to new or important information (the Syntax Hypothesis) or whether there is a bias to respond to post-sentence probe questions with an accented word (the Saliency Hypothesis). One of the predictions of the Saliency Hypothesis is that selection of accented words should be greater when a sentence is complex and processing resources are limited. The results from the experiments presented here show that the probability of listeners' selecting accented words when asked about the interpretation of a relative clause varies with sentence type: listeners selected accented words more frequently in long sentences than in short sentences, consistent with the predictions of the Saliency Hypothesis. Furthermore, Experiment 4 demonstrates that listeners are more likely to respond to post-sentence questions with accented words than with non-accented words, even when no ambiguity is present, and even when the response results in an incorrect answer. These findings suggest that accent-driven attachment effects found in earlier studies reflect a post-sentence selection process rather than a syntactic processing mechanism.

Keywords

pitch accents; prosody; relative clauses; syntactic processing

Intonational boundaries are perceptual breaks in the speech stream that roughly correlate with lengthening of a pre-boundary word, changes in fundamental frequency (f0) 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. These two prosodic cues constitute two components of prosodic structure. Both contribute to the ultimate interpretation of a sentence, but in different ways. Consider the examples in (1) below (double slashes indicate the location of intonational boundaries, and accents are indicated with capital letters). (1)

- a. The cop saw // the boy with a telescope.
- b. The cop saw the boy // with a telescope.
- c. A. Who likes pizza?
 B. JOHN likes pizza.

In sentences (1a) and (1b), the interpretation of an utterance can be modulated by the placement of intonational boundaries. The most likely interpretation for (1a) is that the prepositional phrase *with a telescope* modifies the preceding direct object *the boy* while in (1b), the prepositional phrase is associated with the verb. On the other hand, sentence (1c) illustrates how the speaker's choice of accent placement has different discourse implications. In (1c), the presence of an accent on *John* signals that *John* is new or focused information in the discourse or given information that is reintroduced as important information. Traditionally, linguists have argued that boundaries are linked to syntactic structure while pitch accents are linked to discourse structure, but there are notable exceptions to this generalization. Schafer, Carter, Clifton, and Frazier (1996) found that pitch accenting can influence relative clause attachment. This paper revisits the nature of the relationship between accenting and syntactic attachment. The findings from a series of experiments suggest that previously established accent driven attachment effects may not be due to a syntactic processing mechanism, but may instead be the result of a post-sentence selection process: listeners are biased towards selecting salient information as the response to a post-sentence query.

A growing body of literature has argued that intonational boundaries and pitch accents interact with different levels of linguistic representation (*e.g.*, Bolinger, 1961; 1972; Chafe, 1974; Halliday, 1967; Schwarzschild, 1999; Selkirk, 1986; Terken, 1984; Truckenbrodt, 1999): prosodic phrasing is linked to syntactic structure¹ while pitch accenting is linked to information structure. Many researchers have suggested rules or constraints that govern the relationship between syntactic and prosodic phrases (Selkirk, 1986; Truckenbrodt, 1999), and a great deal of work from the processing literature suggests that boundaries directly influence syntactic attachment (see Wagner & Watson, 2010 for a review). With respect to the distribution of accents, the information status of entities in a discourse has been considered to be an important factor in determining accent placement (*e.g.*, Bolinger, 1972; Chafe, 1976; Halliday, 1967; Selkirk, 1984; Terken, 1984). Accenting decisions are affected by whether the expression conveys new information (*i.e.*, whether the information is recoverable from the prior discourse) or by whether it conveys contrastive information. Information that is newly introduced to the discourse or contrasts with other salient information tends to be accented. One generalization that can be drawn from these theories is that intonational boundaries are directly linked to syntactic structure, but pitch accents are not.

However, there are exceptions. 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 (2) convey different meanings depending on whether pitch accents are located on *packing* or *cases* (see also Speer et al., 1993). (2)

- a. PACKING cases are always newsworthy.
- b. Packing CASES is always newsworthy.

¹There are some exceptions to these claims. Boundaries may provide time for processing semantic information (Blodgett, 2004; Schafer, 1997) and tonal movement at edges of intonational phrases may signal information about discourse structure (Pierrehumbert & Hirschberg, 1990).

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. (3)

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

In sentence (3a) 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 (4). (4)

The reporter recently interviewed the SISTER of the senator who was controversial.

Sentence (4) 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, Clifton, and Frazier (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 paper, we 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. We 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. We call this the Salience 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 Salience 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 salience of accented attachment sites leads to increased selection of the accented word. We 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 Saliency 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, 2010; McAteer, 1992; Sanford, Sanford, Molle, & Emmott, 2006; Singer, 1976) because of their semantic and acoustic saliency. If focus improves recall for focused information and if focus attraction results from the saliency of the lexical attachment site, effects of saliency 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 saliency. 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 Saliency Hypothesis. More complexity will increase the saliency 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, we would not expect an interaction with sentence complexity.

In order to determine which factors give rise to focus attraction effects, we 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 Saliency and the Syntax Hypotheses by manipulating the complexity of sentences and the placement of pitch accents. The Saliency 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 (5) below. (5)

- 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, we 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 (RC) preceded by the complex noun phrase consisting of two nouns both of which could be potentially modified by the relative clauses. 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). We manipulated the presence of pitch accents on the two noun phrases as in Schafer et al.'s original study, but used a 2×2 design, unlike the original study. We crossed the possible accent status of the high noun (presence vs. absence) with the possible accent status of the low noun (presence vs. absence), resulting 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 (6) below. (6)

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*² pitch accent in the ToBI coding system (Beckman & Ayers, 1997) 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, we conducted acoustic analyses focusing on the duration of critical nouns and the maximum pitch value at those nouns. Table 1 presents the results of the acoustic analyses. The results showed that there were reliable effects of accents on

²Schafer 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, we used an L+H* pitch accent to mark focused elements in this and the following experiments.

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: HN: $t(126)=4.5$, $p<.0001$; LN: $t(126)=2.4$, $p<.05$); Maximum f0: HN: $t(126)=20.3$, $p<.0001$; LN: $t(126)=15.0$, $p<.0001$).

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 we 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 $<.05$). We 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 early accent and late accent influenced participants’ judgments. The presence of a pitch accent reliably increased the likelihood of that noun being selected compared to the baseline condition. We 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.

In order to examine what factors underlie this accent attachment effect, we 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, we 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, we manipulated two factors: sentence complexity and 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). We 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, we 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. We 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. (7)

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 (7), capitals indicate the location of pitch accents. In the Early Accent conditions ((7a) and (7c)), an L+H* pitch accent was assigned to the high noun (e.g., *son*) and in the Late Accent conditions ((7b) and (7d)), 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, we cross-spliced the relative clauses across the same RC conditions. Thus, the relative clauses in (7a) and (7b), and in (7c) and (7d) were acoustically identical. Table 3 presents the results of acoustic analyses of the critical nouns. An accent $\times$ 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 (HN: $F(1,31)=280.8$, $p<.001$, LN: $F(1,31)=141.1$, $p<.0001$). The maximum pitch values were higher in accented nouns than in their unaccented counterparts (HN: $F(1,31)=983.9$, $p<.0001$, LN: $F(1,31)=995.8$, $p<.0001$). 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.

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 ($\beta=0.62$, $SE=0.27$, $z=2.3$, $p<.05$)³.

³The 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, we report the model that does not include the random slopes for RC Type.

The effect of accents was reliable within each RC type. In both complexity conditions, there were more high attachment responses in the Early Accent condition than in the Late Accent condition (Complex RC: $\beta=0.95$, $SE=0.17$, $z=5.5$, $p<.0001$; Simple RC: $\beta=1.13$, $SE=0.34$, $z=3.3$, $p<.001$).

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, we 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 on-line 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, 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.⁴ 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.

We 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, we 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

⁴We would like to thank an anonymous reviewer for pointing this out.

(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, standard deviation: 1.0). Example sentences are presented in (8) below.

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, we 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 (HN: $t(31)=17.4$, $p<.0001$, LN: $t(31)=9.3$, $p<.0001$) and a higher maximum pitch value (HN: $t(31)=27.6$, $p<.0001$, LN: $t(31)=51.7$, $p<.0001$) than their unaccented counterparts.

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 ($\beta=0.29$, $SE=0.22$, $z=1.3$, $p>.1$). This suggests that extraction type does not modulate accent attachment effects.

The effect of accents was reliable within each RC extraction condition (Object-extracted: $\beta=1.20$, $SE=0.22$, $z=5.5$, $p<.0001$; Subject-extracted: $\beta=0.70$, $SE=0.20$, $z=3.5$, $p<.0001$).

These 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 (9) below. (9)

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

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 effect of accents was reliable within each length condition (Long: $\beta=1.16$, $SE=0.17$, $z=6.9$, $p<.0001$; Short: $\beta=0.83$, $SE=0.28$, $z=3.0$, $p<.01$).

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) suggest 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.

We 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, we 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 (10): (10)

The reporter recently interviewed the SISTER of the senator who was controversial.

In (10), 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, we examine the possibility that previously established accent attachment effects are due to a post-sentence selection bias. In order to test this, we presented participants with sentences like those from Experiment 2 (e.g., Brandon interviewed the son of the lady who worked with the man.). We 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, we should find effects of accents in both question conditions.

In Experiment 4, we 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, we would expect this effect to be greater in complex sentences, but only when the question is about relative clause attachment.

Finally, Experiment 4 allows us to address the alternate 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 (7) are repeated here as (11). (11)

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 $\times$ 2 Accent $\times$ 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. We 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, we 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 we wanted to determine whether or not the types of effects we 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%).⁵ 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.

We conducted a mixed logit model analysis 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.

We 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 ($\beta=0.44$, $SE=0.33$, $z=1.3$, $p>.1$).

As in the earlier experiments, for the relative clause question, the effect of accent was reliable within each RC type (Complex: $\beta=2.01$, $SE=0.23$, $z=8.6$, $p<.0001$; Simple: $\beta=1.70$, $SE=0.22$, $z=7.6$, $p<.0001$).

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 ($\beta=0.62$, $SE=0.42$, $z=1.5$, $p>.1$).

The effect of accent was reliable within each RC type for the matrix question (Complex: $\beta=2.61$, $SE=0.30$, $z=8.7$, $p<.0001$; Simple: $\beta=1.96$, $SE=0.29$, $z=6.7$, $p<.0001$), suggesting that 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.

⁵The percentage of other responses closely matches that from Schafer et al. (1996)'s Experiment 1 (9%), which also used a recall task.

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.

General Discussion

The above experiments suggest that accent attachment effects demonstrated in previous work may reflect the increased salience of the accented referent. We 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, we 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 we 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.

Our findings also have 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 examine the effects of prosodic information in on-line processing. Until recently, the tools to do this were not available. However, with the advent of the use of the visual world paradigm (e.g. Dahan, Tanenhaus, & Chambers, 2002; Ito & Speer, 2008; Watson, Gunlogson, & Tanenhaus, 2008, see Watson, Gunlogson, & Tanenhaus, 2006 for a review) and electrophysiological measures (e.g., Hruska, Steinhauer, Alter, & Steube, 2000; Ito & Garnsey, 2004; Li, Hagoort, & Yang, 2008) to study prosody, it has become possible to investigate prosodic processing on-line. 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 above.

Conclusion

Returning to the discussion of the role pitch accents play in syntactic processing, the current findings suggest that unlike intonational 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). 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. However, pitch accents do not directly signal structural dependencies between the elements in an utterance as intonational boundaries do. Apparent exceptions to this view (Schafer et al., 1996; Carlson et al., 2009), which have shown that pitch accents can directly signal syntactic attachment by attracting an ambiguous phrase, may have been the result of a post-sentence selection bias.

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Appendix

A. Experimental Stimuli for Experiment 1 (From Schafer et al. (1996))

1. The reporter recently interviewed the sister of the senator who was so controversial.
2. George questioned the brother of the minister who was divorced.
3. Hank had built the drum machine of the band that disappeared.
4. Larry stared at the arm of the mannequin that needed paint.
5. Lloyd pondered the map of the pyramid that was incomplete.
6. Stacey wanted to invite the friend of the secretary who was German.

7. Janice kicked the speaker of the stereo that sometimes didn't work.
8. Susan was dating the cousin of the artist who was a veteran.
9. Alice was listening to the chirping of the bird that was unusually pretty.
10. Phil mended the sleeve of the shirt that was stained.
11. On Saturday, Carol hiked the trail of the park that was crowded.
12. Yesterday Lisa photographed the museum of the city that was in the news.
13. The cops found the hubcap of the car that was stolen.
14. The Board of Health contacted the restaurant of the hotel that was infested.
15. Jennifer was blackmailing the boss of the clerk who was dishonest.
16. Stan waited impatiently in the checkout lane of the supermarket that had just opened up.
17. The sun sparkled on the propeller near the plane that the mechanic was so carefully examining.
18. The squirrels raced through the leaves from the tree that had recently fallen down.
19. The detective eyed the entrance near the house that showed clear sign of damage.
20. The plumber suggested we change the faucet behind the sink that we finally installed last year.
21. Sylvia carefully examined the handle on the pot that she had just finished repairing.
22. We already have to repair the tire for the bicycle that we bought yesterday.
23. In the meeting they showed us the label on the bottle that the artist agreed to design.
24. The insurance inspector photographed the cover for the boat that was covered with graffiti.
25. The tourists admired the museum in the city that they visited again in August.
26. John smashed the car from the rental-agency that his wife hated so much.
27. All the men distrusted the machines in the factory that had accidentally been set on fire.
28. The Japanese were impressed by the investments from the agencies that were making such large profits.
29. The magazine article failed to mention the library near the elementary school that had just recently been built.
30. The local newspaper described the ceremonies in the club that people seemed to find so ridiculous.
31. The architect designed the playground near the park that the children visited frequently.

32. The collector admired the furniture in the dollhouse that had been carefully repainted.

B. Experimental Stimuli for Experiment 2

a. Long object-extracted relative clauses

1. Michael knew the father of the girl who the clerk blamed for breaking the merchandise.
2. Emma liked the mother of the boy who the pilot talked to for a while at the party.
3. Joshua talked to the uncle of the kid who the lady helped on the way to the post office.
4. Natalie admired the aunt of the child who the receptionist greeted with a bright smile.
5. Tyler met the husband of the woman who the secretary saw in the waiting room on the second floor.
6. Ethan hated the nephew of the woman who the physician recognized from the emergency room at the hospital.
7. William visited the niece of the guy who the florist met in Florida last summer.
8. Brandon interviewed the son of the lady who the man worked with for five years in Germany.
9. Jenna loved the daughter of the gentleman who the woman waited for impatiently at the bus stop.
10. Ashley watched the brother of the woman who the dean interviewed in his office for almost two hours.
11. Blake approached the sister of the man who the president accidentally bumped into at the station.
12. Ben questioned the wife of the man who the manager despised for being lazy and irresponsible.
13. Madison helped the grandfather of the girl who the colleague thanked for the invitation last night.
14. Hannah called the grandmother of the boy who the man asked about the street parade yesterday.
15. Anna praised the grandson of the lady who the musician sent a message to about the concert.
16. Grace found the granddaughter of the man who the neighbor welcomed to the Halloween party.
17. Anthony recognized the father of the girl who the boss praised for being responsible and organized.
18. Jordan noticed the mother of the boy who the nurse seems to find very nice and friendly.
19. Justin thanked the uncle of the kid who the dog entertained on the beach of Hawaii.

20. Sofia adored the aunt of the child who the man talked to on the phone on the street.
21. Jasmine contacted the husband of the woman who the chairman joked with about the presenter.
22. Kevin complimented the nephew of the woman who the waiter questioned at the counter in the corner.
23. Nicole glanced at the niece of the guy who the scientist presented the new simulation to at the workshop.
24. Brian saw the son of the lady who the writer invited to his new house last year.
25. Andrea invited the daughter of the gentleman who people expected to join the campaign.
26. Amelia persuaded the brother of the woman who the neighbor called frequently for help.
27. Kyle favored the sister of the man who the copywriter emailed a job offer to yesterday.
28. Adam greeted the wife of the man who the landlord complained to about the other tenants.
29. Megan phoned the grandfather of the girl who the counselor met several times in a week
30. Sean observed the grandmother of the boy who the guide wrote an apologetic letter to last week
31. Andrew believed the grandson of the lady who the girl taught how to use the internet on Tuesday.
32. Liam consulted the granddaughter of the man who coincidentally the doctor stayed with in Chicago.

b. Short subject-extracted relative clauses

1. Michael knew the father of the girl who blamed the clerk.
2. Emma liked the mother of the boy who talked to the pilot.
3. Joshua talked to the uncle of the kid who helped the lady
4. Natalie admired the aunt of the child who greeted the receptionist.
5. Tyler met the husband of the woman who saw the secretary
6. Ethan hated the nephew of the woman who recognized the physician.
7. William visited the niece of the guy who met the florist.
8. Brandon interviewed the son of the lady who worked with the man.
9. Jenna loved the daughter of the gentleman who waited for the woman.

10. Ashley watched the brother of the woman who interviewed the dean.
11. Blake approached the sister of the man who bumped into the president.
12. Ben questioned the wife of the man who despised the manager.
13. Madison helped the grandfather of the girl who thanked the guest.
14. Hannah called the grandmother of the boy who asked a question.
15. Anna praised the grandson of the lady who wrote to the musician
16. Grace found the granddaughter of the man who welcomed the neighbor.
17. Anthony recognized the father of the girl who praised the boss.
18. Jordan noticed the mother of the boy who found the nurse friendly.
19. Justin thanked the uncle of the kid who played with the dog.
20. Sofia adored the aunt of the child who phoned the man.
21. Jasmine contacted the husband of the woman who joked with the chairman.
22. Kevin complimented the nephew of the woman who questioned the waiter.
23. Nicole glanced at the niece of the guy who saw the new simulation.
24. Brian saw the son of the lady who invited the writer.
25. Andrea invited the daughter of the gentleman who joined the campaign.
26. Amelia persuaded the brother of the woman who called the neighbor.
27. Kyle favored the sister of the man who emailed the copywriter.
28. Adam greeted the wife of the man who complained to the landlord.
29. Megan phoned the grandfather of the girl who met the counselor.
30. Sean observed the grandmother of the boy who apologized to the guide.
31. Andrew believed the grandson of the lady who informed the girl.

32. Liam consulted the granddaughter of the man who stayed with the doctor.

C. Experimental Stimuli for Experiment 3a

1. Michael knew the father of the girl who the clerk blamed/blamed the clerk for breaking the merchandise.
2. Emma liked the mother of the boy who the pilot talked to/talked to the pilot at the party.
3. Joshua talked to the uncle of the kid who the lady helped/helped the lady on the way to the post office.
4. Natalie admired the aunt of the child who the receptionist greeted/greeted the receptionist with a bright smile.
5. Tyler met the husband of the woman who the secretary saw/saw the secretary in the waiting room.
6. Ethan hated the nephew of the woman who the physician recognized/recognized the physician from the emergency room.
7. William visited the niece of the guy who the florist met/met the florist in Florida.
8. Brandon interviewed the son of the lady who the man worked with/ worked with the man for five years.
9. Jenna loved the daughter of the gentleman who the woman waited for/ waited for the woman at the bus stop.
10. Ashley watched the brother of the woman who the dean interviewed/ interviewed the dean in the office.
11. Blake approached the sister of the man who the president bumped into/ bumped into the president at the station.
12. Ben questioned the wife of the man who the manager despised/despised the manager for being lazy.
13. Madison helped the grandfather of the girl who the colleague thanked/ thanked the colleague for the invitation.
14. Hannah called the grandmother of the boy who the man asked/asked the man about the street parade.
15. Anna praised the grandson of the lady who the musician sent a message to/sent a message to the musician yesterday.
16. Grace found the granddaughter of the man who the neighbor welcomed/ welcomed the neighbor to the Halloween party.
17. Anthony recognized the father of the girl who the boss praised/praised the boss for being responsible.
18. Jordan noticed the mother of the boy who the nurse found/found the nurse to be very friendly.
19. Justin thanked the uncle of the kid who the dog entertained/entertained the dog on the beach.

20. Sofia adored the aunt of the child who the man phoned/phoned the man on the street.
21. Jasmine contacted the husband of the woman who the chairman joked with/joked with the chairman about the presenter.
22. Kevin complimented the nephew of the woman who the waiter questioned/questioned the waiter at the counter.
23. Nicole glanced at the niece of the guy who the scientist chatted with/chatted with the scientist at the workshop.
24. Brian saw the son of the lady who the writer invited/invited the writer for dinner.
25. Andrea invited the daughter of the gentleman who the professor walked with/walked with the professor for two hours.
26. Amelia persuaded the brother of the woman who the neighbor called/called the neighbor for help.
27. Kyle favored the sister of the man who the copywriter emailed a job offer to/emailed a job offer to the copywriter.
28. Adam greeted the wife of the man who the landlord complained to/complained to the landlord about the other tenants.
29. Megan phoned the grandfather of the girl who the counselor spoke to/spoke to the counselor several times a week.
30. Sean observed the grandmother of the boy who the guide apologized to/apologized to the guide last week.
31. Andrew believed the grandson of the lady who the girl waved at/waved at the girl from a distance.
32. Liam consulted the granddaughter of the man who the doctor stayed with/stayed with the doctor in Chicago.

D. Experimental Stimuli for Experiment 3b

1. Michael knew the father of the girl who blamed the clerk (for breaking the merchandise).
2. Emma liked the mother of the boy who talked to the pilot (at the party).
3. Joshua talked to the uncle of the kid who helped the lady (on the way to the post office).
4. Natalie admired the aunt of the child who greeted the receptionist (with a bright smile).
5. Tyler met the husband of the woman who saw the secretary (in the waiting room).
6. Ethan hated the nephew of the woman who recognized the physician (from the emergency room).
7. William visited the niece of the guy who met the florist (in Florida).
8. Brandon interviewed the son of the lady who worked with the man (for five years).

9. Jenna loved the daughter of the gentleman who waited for the woman (at the bus stop).
10. Ashley watched the brother of the woman who interviewed the dean (in the office).
11. Blake approached the sister of the man who bumped into the president (at the station).
12. Ben questioned the wife of the man who despised the manager (for being lazy).
13. Madison helped the grandfather of the girl who thanked the colleague (for the invitation).
14. Hannah called the grandmother of the boy who asked the man (about the street parade).
15. Anna praised the grandson of the lady who sent a message to the musician yesterday/emailed the musician.
16. Grace found the granddaughter of the man who welcomed the neighbor (to the Halloween party).
17. Anthony recognized the father of the girl who praised the boss (for being responsible).
18. Jordan noticed the mother of the boy who found the nurse (to be very friendly).
19. Justin thanked the uncle of the kid who entertained the dog (on the beach).
20. Sofia adored the aunt of the child who phoned the man (on the street).
21. Jasmine contacted the husband of the woman who joked with the chairman (about the presenter).
22. Kevin complimented the nephew of the woman who questioned the waiter (at the counter).
23. Nicole glanced at the niece of the guy who chatted with the scientist (at the workshop).
24. Brian saw the son of the lady who invited the writer (for dinner).
25. Andrea invited the daughter of the gentleman who walked with the professor (for two hours).
26. Amelia persuaded the brother of the woman who called the neighbor (for help).
27. Kyle favored the sister of the man who emailed a job offer to/wrote to the copywriter.
28. Adam greeted the wife of the man who complained to the landlord (about the other tenants).
29. Megan phoned the grandfather of the girl who spoke to the counselor (several times a week).
30. Sean observed the grandmother of the boy who apologized to the guide (last week).

31. Andrew believed the grandson of the lady who waved at the girl (from a distance).
32. Liam consulted the granddaughter of the man who stayed with the doctor (in Chicago).

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Figure 1.
Log-odds of high attachment responses, Experiment 1

Figure 2.
Log-odds of high attachment responses, Experiment 2

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

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

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

Table 1

Mean durations of and average maximum pitch values at critical nouns (HN: high noun, LN: low noun) by condition, Experiment 1

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

Note. Boldface indicates that the word was accented.

Table 2

Proportion of high attachment responses, Experiment 1

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

Mean durations of and average maximum pitch values at critical nouns (HN: high noun, LN: low noun) by condition, Experiment 2

Table 3

		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.

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

Table 5

Mean durations of and average maximum pitch values at critical nouns (HN: high noun, LN: low noun) 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.

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

Table 7

Mean durations of and average maximum pitch values at critical nouns (HN: high noun, LN: low noun) 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.

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

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