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Accents, not just prosodic boundaries, influence syntactic attachment

Katy Carlson and Joseph C. Tyler

Department of English, Morehead State University, USA

Abstract

Traditionally, pitch accents are understood to relate to the information structure of a sentence and its discourse connections, while prosodic boundaries indicate groupings of words and affect how constituents attach into a syntactic structure. Here, we show that accents also affect syntactic attachment in multiple different syntactic structures. Three auditory questionnaires on ambiguous attachment sentences (such as *Tom reported that Bill was bribed [last May]*) find that accenting the higher or lower verb (*reported* or *bribed*) increases the attachment of the final adverbial phrase as a modifier of the accented verb. A fourth experiment shows that accents on verbs or object nouns (in sentences like *Jenny sketched a child [with crayons]*) also increase the attachment of the final prepositional phrase to the accented head (sketched with crayons vs. a child with crayons). Accent effects were small but consistent across sentences with different levels of bias and did not depend on prosodic boundaries. The results suggest that focused elements are important to the main assertion of the sentence and therefore draw the attachment of upcoming material (though the salience of attachment sites may also be important). The results also demonstrate that both prosodic phrasing and pitch accents can affect basic syntactic structure.

Keywords

pitch accents; prosodic boundaries; attachment; focus; syntactic ambiguity

Introduction

It is increasingly clear that the tune and rhythm of a sentence, i.e. its prosody, matters to many different levels of language processing. The prosody of the sentence can affect everything from the ease of identification of sounds to the integration of a sentence into a larger discourse (see Cutler, Dahan, & van Donselaar 1997 and Wagner & Watson 2010 for reviews). Here, we concentrate on the processing of single sentences with attachment ambiguities, as in (1).

(1) Susie learned that Bill called on Monday.

Corresponding author: Katy Carlson, Department of English, 103 Combs Building, Morehead State University, Morehead, KY 40351, USA. k.carlson@moreheadstate.edu.

Audiences at the Annual CUNY Conference on Human Sentence Processing (2013 and 2015) and AMLaP 2014 have also provided useful suggestions and comments, as have several anonymous reviewers.

- a. high attachment meaning: Susie learned on Monday that Bill called.
- b. low attachment meaning: Susie learned about Bill's Monday call.

The final phrase, *on Monday*, can be syntactically integrated into the sentence (or attached) in two possible ways, corresponding to two different meanings. If the phrase modifies the higher verb, *learned*, then it is attached into the higher verb phrase (VP), creating the meaning in (1a). If the phrase modifies the lower verb, *called*, then it is attached into the lower VP, giving the meaning in (1b). Both prosodic boundaries and pitch accents¹ have been shown to modify attachment preferences in some syntactic structures, but there is a much more extensive literature on the effects of prosodic boundaries on attachment within sentence processing. Because accents have been found to affect attachment only in relative clause ambiguities (Lee & Watson, 2011; Schafer, Carter, Clifton, & Frazier, 1996), this raises the question of whether accents can affect attachment in a wider range of structures, and if such effects are contingent on or interact with prosodic boundaries.

The studies presented here expand our understanding of how accents can influence attachment, exploring several different attachment sites, including verbs in matrix clauses, complement clauses, and relative clauses, as well as object nouns. They help demonstrate the generality of two hypotheses about the role of accents in attachment: the Focus Attraction Hypothesis (Schafer et al., 1996) and the Salience Hypothesis (Lee & Watson, 2011). On the Focus Attraction Hypothesis, accents on the heads of attachment sites draw the attachment of a modifying phrase due to their focus status: focused elements are important to the main assertion of a sentence, and processors prefer to associate ambiguous material with this important information rather than other parts of a sentence. On the Salience Hypothesis, by contrast, accents draw attachment because they make an attachment site more salient or memorable (which may interact with the way that attachment preferences are asked about in experiments). Both predict, though, that accents should affect attachment generally, across a range of structures.

The theory of focus proposes that focusing specific words or phrases leads to the calculation of alternative semantic values for the focused element in addition to the ordinary semantic value of a sentence (Prieto, 2015; Rooth, 1992). A constituent that carries focus, which can be marked in a variety of ways (including pitch accents), is also prominent within the sentence. For example, the statement in (2) conveys the proposition that Mark passed an exam, but the contrastive focus on Mark (shown in CAPS) contrasts him with a contextually relevant set of alternatives to Mark. The resulting implicature is that other people who took the exam did not pass.

(2) I think MARK passed the exam.

In the rest of the Introduction, we will briefly survey existing work on the effects of prosodic boundaries and accents in sentence processing, showing the types of structures that each

¹We follow the ToBI system for annotating English prosody (Beckman & Elam, 1997), based on the prosodic system of Pierrehumbert (1980). Pitch accents are notated with high (H) or low (L) F0 targets plus an asterisk; there are two levels of prosodic phrasing, intermediate phrases (ip) ending with phrase tones (e.g., L-) and the larger Intonational Phrases (IPh) ending with boundary tones (e.g., H%).

prosodic feature usually affects, and then discuss the details of the two previous papers that found effects of accents on attachment in relative clause ambiguities.

Prosodic phrasing and sentence processing

Much of the earliest work on prosody in sentence processing concentrated on the effects of prosodic phrasing, indicated by prosodic boundaries, on attachment and other syntactic ambiguities (e.g., Cooper & Paccia-Cooper, 1980; Lehiste, 1973; Nespor & Vogel, 1986; Price, Ostendorf, Shattuck-Hufnagel, & Fong, 1991). In some cases, theorists have claimed that unless the placement of syntactic boundaries varied between sentences, the structures could not be disambiguated by prosody (Nespor & Vogel, 1986).

A classic study showing prosodic boundary effects on attachment comes from Speer, Kjølgaard, & Dobroth (1996), who studied the resolution of the early/late closure structure, as in (3).

(3)

- a. Whenever the guard checks the door, it's locked. (late closure)
- b. Whenever the guard checks, the door is locked. (early closure)

A prosodic boundary after *door* facilitates processing of the late closure structure (3a), on which that NP attaches into the VP at the end of the initial subordinate clause, while interfering with the processing of early closure (3b). A prosodic boundary after *checks* does the reverse: it facilitates early closure (on which the NP *the door* attaches into the subject position of the main clause) and interferes with late closure. This ambiguity is not solely about attachment, as it also involves a decision about where a subordinate clause ends and a main clause begins, but the attachment of the NP does differ in the two structures. This work demonstrates the general principle that prosodic boundaries coinciding with major syntactic boundaries aid in the processing of the intended syntactic structure. This principle also extends beyond the sentence level, with larger prosodic boundaries affecting the hierarchical structure of discourse, and by extension the interpretation of ambiguous quantifier phrases (Silverman, 1987) and pronouns (Mayer, Jasinskaja, & Kölsch, 2006).

Most research on prosodic boundaries and attachment has concentrated on a single prosodic boundary location per sentence. When doing so, as Watson & Gibson (2005) note, people prefer not to attach a phrase to the nearest attachment site across a prosodic boundary, and instead become more willing to consider higher, more distant attachment sites. A series of papers on multiple prosodic boundaries (Carlson, Clifton, & Frazier, 2001, 2009; Clifton, Carlson, & Frazier, 2002) also found that the interpretive effect of any single prosodic boundary could be affected by the presence and size of other boundaries in the sentence. For example, consider the structure in (4).

(4) Susie learned (IPh/ip/0) that Bill telephoned (ip) after John visited.

The same ip boundary occurs before the *after*-phrase in all conditions, but the lack of an earlier boundary favors high attachment (interpretation: learned something after John visited) while an IPh early boundary favors low attachment (telephoned after John visited).

The relevant factor is whether the ip before the ambiguous phrase is the largest boundary between the two possible attachment sites or not. A relatively large prosodic boundary at that location favors high attachment, and a relatively small one favors low attachment. Snedeker & Casserly (2010) found evidence of processing effects both of absolute presence or absence of boundaries and of relative size of boundaries in attachment ambiguities. In summary, studies of a range of attachment structures have shown that the prosodic phrasing of the sentence affected attachment decisions.

Pitch accents and sentence processing

Most research on pitch accents in sentence processing so far has not focused on attachment, dealing instead with cross-sentence phenomena like pronoun reference or the fit of a sentence with a given linguistic or visual context (e.g., Carlson, 2001; Ito, & Speer, 2008; Kehler, Kertz, Rohde, & Elman, 2008; Kurumada, Brown, Bibyk, Pontillo, & Tanenhaus, 2014; Pierrehumbert & Hirschberg, 1990). Nevertheless, accents have been shown to affect aspects of sentence interpretation. Studies using the visual world paradigm show clear evidence that listeners use the accentual status of NPs to immediately decide between new, given, and contrastive items in a scene. Dahan, Tanenhaus, & Chambers (2002) presented displays containing both candies and candles. When the candies had already been referred to, instructions to *Look at the CAN-* were taken to refer to the new item, the candle, before the word even finished. People thus expect unaccented elements to be given, and accented items to be new, as also shown in rating studies by Birch & Clifton (1995, 2002), and behave accordingly. Ito & Speer (2008) designed a tree-decorating task with a number of different colored ornaments of various shapes, making it possible to refer to given, new, or contrastive colors and shapes. They found that higher and louder accents (probably L+H*s) were taken as contrastive, i.e. differing from the same element in a previous utterance while holding another part of the phrase constant, as in *blue ball...GREEN ball*. Weber, Braun, & Crocker (2006) similarly found in German that contrastive accents could be used to identify elements in a display which contrasted in some feature, such as *purple scissors/RED scissors*, before the onset of the noun itself.

Pitch accents have also been found to affect ellipsis processing, likely because ellipsis sentences are focus-sensitive in their resolution (Merchant, 2001; Sag, 1980). For example, consider the sluicing sentence in (5a), where a complete sentence is followed by a wh-phrase. The interpretation of the sentence requires filling in a missing clause derived from the first clause below the wh-phrase, such as “Guess who <t suspected that the hotelkeeper was hiding someone>” or “Guess who <some tourist suspected that the hotelkeeper was hiding t>.” Frazier & Clifton (1998) found that the presence of a pitch accent on the matrix subject (*some tourist*) or the final object (*someone*) increased the likelihood of choosing the structure where *who* referred back to the accented item.

(5)

- a. Some tourist suspected that the hotelkeeper was hiding someone. Guess who?
- b. The captain talked with the co-pilot, but we couldn't tell who else.
- c. It was Lisa who Patty praised at the ceremony, but I don't know who else.

In (5a), an indefinite sluicing example, the possible antecedents for the *wh*- word *who* were the two indefinite NPs. Sluicing sentences can also be definite, as in (5b–c), if the *wh*-phrase includes *else*. In those cases, the *wh*-phrase can have definite antecedents, like the subjects and objects in (5b–c). Carlson, Dickey, Frazier, & Clifton (2009) showed that accent placement on the subject (*captain*) or object (*co-pilot*) in a definite sluicing sentence like (5b) also influenced the interpretation. An additional manipulation focused one argument in the initial clause by clefting it, as seen for *Lisa* in (5c). Clefting behaved like pitch accents in increasing interpretations taking the focused element as the antecedent of the *wh*-word, meaning that (5c) would elicit more responses taking *Lisa* as the contrast with *who else* than the non-clefted version (*Patty praised Lisa at the ceremony...*). This result suggests that focus is the mechanism behind the effects of accent placement. Effects of accents on interpretation have also been found in a range of other ellipsis types, including gapping, comparatives, and VP Ellipsis (Carlson, 2001, 2002; Frazier, Clifton, & Carlson, 2007; Stolterfoht et al. 2007, among others). These results make it clear that ellipsis sentences respond to the placement of pitch accents and focus in the course of determining the antecedent material which is needed to understand the elided portion of a sentence.

It also appears that, at least in some structures, pitch accents can affect sentence interpretation while prosodic boundaries cannot. Carlson, Frazier, & Clifton (2009) explicitly compared the effects of pitch accents and prosodic boundaries on the same sentences in bare argument ellipsis, as in (6):

(6) Jason found out Barbara was in New York, not Edward.

In these sentences, a single negated constituent (*not Edward*) follows a full clause, and the interpretation of the sentence is that this argument contrasts with one of the NPs in the full clause. A range of prosodic boundary placements had no effect on the interpretation or acceptability of the sentences. In particular, changing the relative strength of a prosodic boundary before the remnant phrase (*not Edward*) and a boundary after the first verb (*found out*) did not affect the preferences for which NP to contrast with: the subject of the embedded clause (*Barbara*) was always preferred, because it was closer. Changes in the placement of contrastive accent, however, on the first subject (*Jason*) or the second (*Barbara*), had a strong effect on interpretation, with the remnant (*Edward*) more likely to contrast with the accented noun. Carlson et al. (2009) thus suggested that certain types of sentence structures (e.g., ellipsis sentences, pronoun reference) would respond to accents but not boundaries, and other structures would respond to boundaries but not accents. In summary, pitch accents have been shown to affect the interpretation of the information structure of sentences, and the resolution of ellipsis, but only rarely other aspects of sentence structure.

Pitch accents and syntactic attachment

Two papers form an exception to the generalization that accents do not affect syntactic structure, as they found effects of accents on ambiguous relative clause attachment (Lee & Watson, 2011; Schafer et al., 1996). Schafer et al. (1996) studied prosodic effects on the attachment of relative clauses to an earlier noun (N1) or a later noun (N2) in phrases like *the propeller of the plane that the mechanic was so carefully examining*. A boundary after N2,

plane, increased the proportion of high attachments to N1, *propeller*. Accenting N1 also drew high attachments, and accenting N2 favored low attachments. Further, contrastive (L+H*) accents were more effective in biasing attachment than simple H* accents. Schafer et al. proposed the Focus Attraction Hypothesis to explain their results, on which an upcoming phrase would be drawn to an accented attachment site because the accent conveys focus on that site. This focus makes the attachment site more important to the main assertion of the sentence and likely to undergo more detailed processing, and thus draws attachment of a later constituent.

Lee & Watson (2011) also studied relative clause attachment and accents using auditory questionnaires. They began by replicating one of the Schafer et al. experiments, and then manipulated the length and complexity of the relative clauses. They also found that accents drew attachment, but that shorter relative clauses were less likely to shift to high attachment in the presence of the earlier (N1) accent. They interpreted this to mean that long relative clauses heighten the effect of the salience of an accented noun due to declining memory, though it is also possible that short relative clauses have a stronger bias to attach to the lower noun (N2) for reasons of prosodic balance (Fodor, 1998). In a final experiment, they included questions about the content of the matrix clause (along with those about relative clause attachment), for which only the higher noun (N1) was the correct answer. The accuracy of participants on the unambiguous matrix questions varied with the position of accent, with almost 40% incorrect N2 answers when N2 was accented. This led Lee & Watson to conclude that apparent accent effects may involve a bias in the post-sentence task rather than any true effect on attachment, with participants tending to choose answers corresponding to accented elements because of their perceptual salience. Their Salience Hypothesis thus includes the possibility that the accent effect is an extra-grammatical one having to do with simple prominence and the design of question-and-answer tasks, rather than one based on the grammatical and syntactic consequences of pitch accent placement. The alternative version of the Salience Hypothesis is that accented words, being more salient than others, draw attachment of phrases.

Finally, Carlson, Clifton, & Frazier (2009) have shown a limited effect of accent on attachment of adverbial phrases, along with a range of boundary effects. Specifically, in sentences like (7), recordings were manipulated in Praat to have more accent on the first verb, *comforted*, or the later verb, *insulted*.

(7) Jimmy comforted the girl that he had insulted after the party.

This led to a small but significant effect of accent placement (7%), with the more prominent accent on the first verb increasing the proportion of answers attaching the final phrase, *after the party*, to that verb. The same sentences also showed much larger effects of prosodic boundaries, with up to 50% differences in interpretation between certain patterns.

The previous studies show limited evidence that accents can affect syntactic attachment, raising the question of how broadly the effect can be found. Having primarily found evidence of accent effects on the attachment of relative clauses to nouns, it is unclear whether accents can influence attachment across a wider range of structures or with accents

on different syntactic categories. The current studies therefore examine attachment of different types of ambiguous phrases (adverbial phrases or PPs) and different attachment sites, including verbs in matrix clauses (Experiments 1–4), verbs in complement clauses (Experiments 1, 4), verbs in relative clauses (Experiment 2), and even object nouns (Experiment 3). These experiments are intended to test whether, as predicted by the Focus Attraction Hypothesis and the Salience Hypothesis, accents on the heads of attachment sites in all of these structures will draw the attachment of an ambiguous phrase.

These studies also explore whether pitch accent effects on attachment are contingent on or interact with prosodic boundaries. It would be reasonable if the grouping of words, as indicated by prosodic phrasing, were more important to syntactic grouping than accents. Attachment sites within the same prosodic phrase as an ambiguously-attached constituent might be more accessible than those outside, for example, regardless of their accentual status (cf. Schafer (1997)). We suggest the Boundary-Dependent Hypothesis, which predicts that accents could affect attachment only when prosodic boundaries already favor an interpretation, as an alternative to the Focus and Salience Hypotheses. For example, an accent on a higher attachment site would be irrelevant if the prosodic boundaries are most consistent with low attachment, but could increase high attachments if prosodic boundaries also favor high attachment.

If accent effects on attachment turn out to be independent of the prosodic phrasing, though, this would show that accents influence the syntactic parse independent of prosodic boundaries. This would be consistent with the Focus Attraction Hypothesis of Schafer et al. (1996), which presents focus as an independent factor that could influence attachment regardless of the prosodic phrasing of the sentence, and with one version of Lee & Watson's (2011) Salience Hypothesis. The studies below vary both accent positions and the location of prosodic boundaries in different sentence types in order to isolate and compare the effects of the two types of prosodic features, accents and boundaries. And finally, another version of the Salience Hypothesis (Lee & Watson, 2011), the question-answering strategy, was tested directly in Experiment 4.

Experiment 1

This experiment uses sentences with a complement clause and a final adverbial phrase that could attach to the matrix or complement clause, as in (8). In previous work on sentences like this, Carlson et al. (2001) studied the effects of prosodic boundaries, finding that prosodic boundaries before the adverbial and after the first verb (at the #s in (8)) influenced each other's interpretation.

(8) Susie learned # that Bill telephoned # after John visited.

A larger early boundary (after *learned*) favored the local (low) attachment of the adverbial, and a larger late boundary (after *telephoned*) favored high attachment of the adverbial clause (after *John visited*). Overall, Carlson et al. found that the sentences had a strong bias toward low attachment, with most conditions showing less than 30% high attachment.

In Experiment 1, we explore whether accents on the heads of the two possible attachment sites, the higher and lower verbs, influence attachment of the adverbial. The presence of prosodic boundaries before the final phrase was also varied, in order to examine whether any accent attachment effect depends on the presence of a prosodic boundary or not.

Method

Materials—Twenty sentences like (9) were constructed, each with a short adverbial or prepositional phrase (PP) at the end referring to a time. A full list of items appears in Appendix A.

(9)

- a. John CLAIMED that Mary arrived IPh last week.
- b. John claimed that Mary ARRIVED IPh last week.
- c. John CLAIMED that Mary arrived last week.
- d. John claimed that Mary ARRIVED last week.

The sentences were produced in four prosodic conditions. Conditions (a–b) had an Intonational Phrase (IPh) boundary after the second verb, expressed as a continuation rise (L–H%) and a short pause. Conditions (c–d) were produced without any prosodic boundaries above the word level, so no pause or boundary tones before the adverbial. Conditions (a,c) had contrastive L+H* pitch accents on the first verb, *claimed*, while conditions (b,d) had similar accents on the second verb, *arrived*.

In order to ensure that the recordings had the intended prosodic features, their pitch tracks were examined and acoustic measurements were taken. Any disfluent productions or recordings with incorrect prosody were re-recorded and re-analyzed. Table 1 shows the F0 averages for the conditions, with the accented verb peaks in bold.

The F0 measurements show that the sentences started with modest H* accents on the subjects, followed by very high accents on Verb1 in conditions (a,c) and Verb2 in conditions (b,d). Unaccented verbs averaged at least 60 Hz lower than their accented counterparts (a significant difference: $F(1,19) = 471$, $p < 0.001$ for Verb1; $F(1,19) = 1411$, $p < 0.001$ for Verb2). In conditions (a–b), a continuation rise pattern (L–H%) of a very low F0 target followed by a high target occurred at the end of Verb2. Conditions (c–d) did not reach such a low target at the end of Verb2 (significant difference between Verb2 final pitches, $F(1,19) = 13$, $p = 0.002$), instead showing normal declination in pitch from the end of the contrastive accent and no final rises. All conditions had another H* accent on the head noun in the adverbial phrase.

The durational averages in Table 2 support the intended prosodic structure as well. Both the first and second verbs were longer when they were accented than when they were not accented (accent effect on Verb1: $F(1,19) = 43$, $p < 0.001$; on Verb2: $F(1,19) = 154$, $p < 0.001$). The second verbs were also much longer in conditions (a–b), when they preceded a major IPh boundary along with the following pause, than in conditions (c–d) without the

boundary (Verb2 boundary effect: $F(1,19) = 513$, $p < 0.001$). The pitch tracks in Figure 1 show a visual plot of the F0 contours of the conditions for one example sentence.

In order to establish a baseline for the interpretation of these sentences, a written norming questionnaire was carried out. A separate group of 30 participants read the 20 items and chose between written paraphrases of them, as in (10) without the parenthetical labels:

(10) John claimed that Mary arrived last week.

- a. John claimed something last week. (high attachment)
- b. Mary arrived last week. (low attachment)

The sentences received an average of 10% high attachment, showing a very strong low bias. This is understandable given that the adverbials were quite short, ranging from 2 to 6 syllables; Clifton et al. (2006) found that sentences of this type with short adverbials were interpreted as low attachment more often than those with longer adverbials of 11 to 13 syllables.

The Boundary-Dependent Hypothesis predicts that accents would affect the interpretation of these sentences only in conditions (a–b), where a prosodic boundary separates the final phrase from the local attachment site. This sets up a prosodic phrasing consistent with high attachment, and an accent on the first verb could then attract more attachments to the higher site. Without a boundary separating the ambiguous phrase from the local attachment site, though, the accents should not overcome the strong low bias. The Focus Attraction and Salience Hypotheses, by contrast, predict that accents on the verbs could draw attachment regardless of the presence of prosodic boundaries favoring any particular attachment.

Participants—The participants were 48 native English-speaking members of the Morehead State University community, who participated in exchange for \$10.² An additional 6 participants participated, but their data were eliminated, either due to errors in the running condition or because their accuracy in answering comprehension questions about the unambiguous fillers was under 90%. These fillers were easy to understand, suggesting that any participant who missed multiple items was not paying enough attention to the task.

Procedure—The experiment was conducted using E-Prime software on a PC with speakers and a monitor inside a sound-attenuated booth. Each item involved an auditory file which was played through the speakers, after which a comprehension question and two answers appeared on the monitor. Answers were labeled a and b, and participants pressed the corresponding key on the keyboard to select an answer. For the experimental items, the question was *What happened?* and the two answer choices were as shown in (10) for the norming questionnaire. The high attachment answer choice appeared first half of the time.

²We ran a total of eighty participants in the experiment due to enthusiastic signups. The direction of results and pattern of significance were identical when analyses were conducted on the full set of 72 participants (with data from 8 people excluded for accuracy issues or to balance conditions).

Participants were seated in the booth and asked first to complete a short practice session. In the practice, they listened to six unrelated sentences and answered a comprehension question after each one. After the practice session, the experimenter asked if the volume was appropriate and whether they had any questions. Then they completed the experiment, which contained 116 items. Stimuli included 18 sentences with other attachment ambiguities (e.g., *Alfie threatened a thug with a weapon*), ellipsis sentences of two types (20 antecedent-contained deletion sentences, such as *Susie bought every song that I had enjoyed listening to because Paula did*, and 20 comparatives in double object sentences, e.g. *He gave more books to Mark than you*), and 38 unrelated filler sentences with a variety of structures (e.g., *Brice thought the way they sang the song was really funny*). The items were counterbalanced so that each participant heard only one prosodic version of each item and heard an equal number of items in each condition over the experiment. The items appeared in one of 12 pseudo-randomized lists such that no consecutive items were of the same type.

Results

The results are expressed as the percentage of high attachment interpretations, as shown in Figure 2.

The sentences show a strong low attachment bias, with all conditions receiving under 30% high attachments. The data for the experimental items were analyzed in R (R Development Core Team, 2015) with a linear mixed-effects regression using the `glmer` function from the `lme4` package (Bates et al., 2015), as the data were binomial. Fixed effects of accent position (Verb1 vs. Verb2) and prosodic boundary presence (none vs. IPh) and their interaction were entered into the model. Both fixed effects were within participants and items, and dummy (treatment) coding was used.³ The model was fitted first with a maximal random effects structure with random slopes and intercepts for both items and participants, as recommended by Barr et al. (2013). Random slopes were then removed stepwise until convergence was achieved. The best-fitting model, with two fixed effects (Vcond and Bnd) and two random intercepts for participant and sentence number ($dv \sim Vcond + Bnd + (1|Subject) + (1|SentNum)$), is shown in Table 4.

The conditions represented in the intercept are V1 for Vcond (accent position on Verb1) and boundary for Bnd (presence of boundary). Models with random slopes and with an interaction between the two factors did not converge or did not have AIC and BIC values that would be considered a significant improvement.

We find that both matrix verb accent and a prosodic boundary before the ambiguous phrase significantly increased high attachment compared to the other conditions. As expected, a major prosodic boundary between the nearest attachment site and the ambiguous phrase resulted in more high attachment answers. Contrastive accent on the first verb also led to more high attachments than when the second verb was accented.

³All statistical analyses in this paper excluded participants as discussed in Participants sections and excluded all filler sentences from the analysis, rather than putting either group in dummy variables.

Discussion

The prosodic boundary effect replicates much previous work on boundaries and attachment, and thus is not surprising, but confirms that listeners were attending to the prosodic features of the sentences. The accent effect, though, is more novel. Previous work on accent effects on attachment has mostly explored the attachment of relative clauses to nouns. Nouns that could be modified by a descriptive relative clause may be more natural elements to contrastively accent than verbs which could have adverbial time phrases modify them, as it is more common for nouns to be focused in a sentence (Selkirk, 1984). But here, just as in relative clause attachment structures (Schafer et al., 1996), accenting the head of the intended attachment site did draw attachment. Further, the accent effect did not interact with the presence of the prosodic boundary, as would be expected on the Boundary-Dependent Hypothesis. Instead, the results support the Focus Attraction Hypothesis or the Salience Hypothesis, with a consistent effect of accent placement across boundary conditions.

The accent effect is, it must be noted, not a very large effect. But the well-established prosodic boundary effect is not particularly large in most syntactic structures either. So any theory of sentence processing that includes prosodic boundary effects on attachment needs to also account for accent effects.

Experiment 2a

Having shown effects of accent on attachment to verbs in matrix vs. complement clauses in Experiment 1, this experiment explores accent effects on attachment to verbs in matrix vs. relative clauses, in order to establish how general this effect is. So while the matrix verbs in Experiment 1 took complement clauses, in Experiments 2a–b the matrix verbs were simple transitives with their object NPs modified by relative clauses, as in (11).

(11) Allan avoided the banker that he had borrowed from # long before the deadline.

The final prepositional phrase starting with *long* could attach to the matrix verb *avoided* or the near verb inside the relative clause, *borrowed from*.

Carlson, Clifton, & Frazier (2009) tested the effects of different patterns of prosodic boundaries on similar sentences. They varied in their interpretation quite a bit, with almost 80% high attachment responses for the condition with the largest boundary before the ambiguous phrase and under 30% high attachment for the condition with only an early boundary (following the first verb). There was also some evidence for a verb accent effect in a final experiment in Carlson, Clifton, & Frazier (2009), where resynthesized prosody placing the largest accent on the first or second verb resulted in a small effect on interpretations. The sentences sounded somewhat unnatural due to the prosodic resynthesis, however, and the effect was elusive.

Method

Materials—The stimuli were 24 sentences, including the 16 from Carlson, Clifton, & Frazier (2009) plus 8 more sentences with similar structures. A full list of items appears in Appendix B. They were produced in the four prosodic conditions shown in (12).

(12)

- a. Allan AVOIDED the banker that he had borrowed from ip long before the deadline.
- b. Allan avoided the banker that he had BORROWED from ip long before the deadline.
- c. Allan AVOIDED the banker that he had borrowed from IPh long before the deadline.
- d. Allan avoided the banker that he had BORROWED from IPh long before the deadline.

Conditions (a) and (c) had contrastive accent on the first verb, and conditions (b) and (d) accented the second verb. All conditions had prosodic boundaries after the second verb. In conditions (c–d), this boundary was a full IPh boundary, with a L–H% continuation rise; conditions (a–b) had small ip boundaries, with just a L– phrase accent ending each one. In all conditions, this prosodic boundary was the largest one in the relevant area, so we would expect all of them to encourage high attachment. In order to make the stimuli more uniform, the same recording of the final adverbial was spliced onto the end of each version of each sentence. This splicing was unlikely to be detectable because the final adverbial was always isolated in its own prosodic phrase following a pause.

To ensure that the recordings had the intended prosodic features, their pitch tracks were examined and acoustic measurements were taken. Any disfluent productions or recordings with incorrect prosody were re-recorded and re-analyzed. Table 1 shows the F0 averages for the conditions, with the accented verb peaks in bold, and Table 2 shows the duration averages. The F0 measurements show that verbs with contrastive accents averaged 60–100 Hz higher than the same verbs in unaccented conditions (significant accent effects: Verb1, $F(1,23) = 938$, $p < 0.001$; Verb2, $F(1,23) = 1042$, $p < 0.001$). The durational measurements show that accented verbs were also 40–70 ms longer when accented (significant accent effects: Verb1, $F(1,23) = 162$, $p < 0.001$; Verb2, $F(1,23) = 142$, $p < 0.001$). The IPh boundaries in conditions (c–d) show a very low F0 dip for the L– (significantly lower in (c–d) than (a–b), $F(1,23) = 52$, $p < 0.001$) and a following H% target, plus longer pauses than in (a–b) with ip boundaries ($F(1,23) = 33$, $p < 0.001$).

Participants—The participants were 48 native English-speaking members of the Morehead State University community who participated in exchange for experiment credit for a psychology class. An additional two participants participated, but their data were removed because their accuracy on comprehension questions after unambiguous filler trials was below 90%. The remaining participants all had over 90% correct answers for the filler sentences.

Procedure—The experiment was conducted using E-Prime software on a PC with speakers and a monitor inside a sound-attenuated booth. Each item involved an auditory file which was played through the speakers, after which a comprehension question and two answers appeared on the monitor. Answers were labeled a and b, and participants pressed the

corresponding key on the keyboard to select an answer. The high attachment answer choice appeared first half of the time. The questions and answers for experimental items were as shown in (13) for item (12), with explanatory labels added here for clarity.

(13) What happened long before the deadline?

- a. Allan avoided the banker. (high attachment)
- b. Allan borrowed from the banker. (low attachment)

Participants were seated in the booth and first completed a short practice session. In the practice, they listened to six unrelated sentences and answered a comprehension question after each one. After the practice session, the experimenter asked if the volume was appropriate and whether they had any questions about the procedure. Then they completed the experiment, which contained 116 items. Stimuli included 20 sentences with other attachment ambiguities (e.g., *Amy tripped a tourist with a cane*), ellipsis sentences of two types (16 complex gapping sentences, such as *The clown assumes the lawyers work from home and the tailor in an office*, and 18 comparative ellipsis sentences, *Mika wanted to bake more muffins than Leah*), and 38 unrelated filler sentences with a variety of structures (e.g., *Reed didn't understand why the flowers wilted*). The items were counterbalanced so that each participant heard only one prosodic version of each item and heard an equal number of items in each condition over the experiment. The items appeared in one of 12 pseudo-randomized lists such that no consecutive items were of the same type.

Results

The results are expressed as the percentage of high attachment interpretations and are shown in Figure 3.

The data for the experimental items were analyzed in R with a linear mixed-effects regression using the glmer function. Fixed effects of accent position (on Verb1 vs. Verb2) and prosodic boundary size (ip vs. IPh) and their interaction were entered into the model using dummy (treatment) coding; both fixed effects were within participants and items. Model specification and selection was carried out as for Experiment 1. The best-fitting and most parsimonious model had two fixed effects (Vcond and Bnd) and random intercepts for participants and items ($dv \sim Vcond + Bnd + (1|Subject) + (1|SentNum)$), with results shown in Table 5, but no interaction.

The conditions represented in the intercept are V1 for Vcond (accent on Verb1) and large for Bnd (a large prosodic boundary).

We find that the position of accent on the first verb significantly increased high attachment compared to accent on the second verb. There was a numerical trend toward increased high attachment with a larger prosodic boundary but the effect was not significant. The two factors did not interact in the best model. As in the complement clause structure in Experiment 1, then, contrastive accent on the first verb led to more high attachments (into the VP headed by that verb) than when the second verb was accented.

Experiment 2b

In Experiment 2a, there were two issues of potential concern. First, the experiment included other sentences with attachment ambiguities, though of a different type, which could potentially affect the processing of the experimental sentences. Second, the prosodic boundary conditions were not ideal, since all stimuli had the largest boundary at the same position, predicting a null effect of boundaries. Experiment 2b was conducted in order to address both issues. The experiment contained no other sentences with attachment ambiguities, and a different set of boundary conditions was used.

Method

Materials—This experiment used the same set of 24 items as Experiment 2a, shown in Appendix B. They were produced in the four conditions shown in (14), with the first or second verb accented and with either an IPh boundary or no boundary before the final phrase.

(14)

- a. Allan AVOIDED the banker that he had borrowed from long before the deadline.
- b. Allan avoided the banker that he had BORROWED from long before the deadline.
- c. Allan AVOIDED the banker that he had borrowed from IPh long before the deadline.
- d. Allan avoided the banker that he had BORROWED from IPh long before the deadline.

Conditions (a) and (c) had contrastive accent on the first verb, and conditions (b) and (d) accented the second verb. Conditions (c–d) had full IPh prosodic boundaries after the second verb with L–H% continuation rises. Conditions (a–b) had no pause after the second verb and a word-level boundary in most cases.

To ensure that the recordings had the intended prosodic features, their pitch tracks were examined and acoustic measurements were taken. Any disfluent productions or recordings with incorrect prosody were re-recorded and re-analyzed. Table 1 shows the F0 averages for the conditions, with the accented verb peaks in bold, and Table 2 shows the duration averages. The F0 measurements show that verbs with contrastive accents averaged more than 70 Hz higher than the same verbs in unaccented conditions (significant accent effects on Verb1: $F(1,23) = 1421$, $p < 0.001$; on Verb2: $F(1,23) = 1085$, $p < 0.001$). The durational measurements show that accented verbs were also over 40 ms longer when accented (significant accent effects on Verb1: $F(1,23) = 178$, $p < 0.001$; on Verb2: $F(1,23) = 69$, $p < 0.001$). The IPh boundaries in conditions (c–d) show a very low F0 dip for the L– and a following H% target (lower Verb2-final F0s in (c–d) than in (a–b): $F(1,23) = 95$, $p < 0.001$) plus noticeable pauses averaging at least 180 ms. The second verbs in conditions (c–d) were also over 100 ms. longer than the ones in (a–b), due to being at the end of a prosodic phrase (Verb2 boundary effect: $F(1,23) = 320$, $p < 0.001$).

Participants—The participants were 48 people recruited and paid through Amazon Mechanical Turk. They self-reported as native English speakers after completing the study and being assured that they would be paid regardless of their native language. Any non-native English speakers were removed from the data set, and the data from eight additional participants were removed because their accuracy on comprehension questions after unambiguous filler trials was below 90%. All participants were paid \$4 for their participation.

Procedure—Participants on Amazon Mechanical Turk clicked through to a Qualtrics survey. This began with a page of instructions, including one directing participants to use a browser other than Internet Explorer so that the audio files would play. Throughout the experiment, each item showed an audio file player on screen followed by a question and two answers. There were 5 items displayed per page. Participants could play the audio file as many times as desired and then answer the question about its meaning. However, there was little incentive to replay the sentences, given that they would receive the same amount of money regardless of how long they took to complete the experiment.

The questions and answer choices for the experimental items were the same as in Experiment 2a, shown in (13). The experiment included 20 ellipsis sentences (sentences varying between comparative, gapping, and VP Ellipsis versions, such as *Mika wanted to bake more muffins than Leah/Mika wanted to bake muffins, and Leah, cupcakes/Mika wanted to bake muffins and/before Leah did too*), 24 embedded clause sentences (e.g., *During the interview, the politician claimed that not all votes were counted and (that) the wrong man won*), 20 much-less sentences requiring a choice between completions (e.g., *The police didn't arrest a/any suspect, much less... a dangerous one/charge one*) and 22 unrelated filler sentences with a variety of structures, for a total of 110 items. The items were counterbalanced so that each participant heard only one prosodic version of each item and heard an equal number of items in each condition over the experiment. The items appeared in one of four pseudo-randomized lists such that no consecutive items were of the same type. After completing the experiment, participants answered demographic questions and received a code to let Amazon Mechanical Turk know to release payment.

Results

The results are expressed as the percentage of high attachments in each condition and appear in Figure 3.

The overall level of high attachments was lower than in Experiment 2a. The data for the experimental items were analyzed in R with a linear mixed-effects regression using glmer. Fixed effects of accent position (on Verb1 vs. Verb2) and prosodic boundary presence (none vs. IPh) and their interaction were entered into the model using dummy coding; both fixed effects were within participants and items. Model specification and selection procedures were the same as for Experiment 1. The best-fitting and most parsimonious model had two fixed effects (Vcond and Bnd) and random intercepts for participants and items but no interaction term ($dv \sim Vcond + Bnd + (1|Subject) + (1|SentNum)$), with results shown in Table 5.

The conditions represented in the intercept are V1 for Vcond (accent on Verb1) and nobnd for Bnd (no prosodic boundary). We found that both matrix verb accent ($\beta = 0.51$) and a prosodic boundary before the ambiguous phrase ($\beta = 0.94$) significantly increased high attachment, with no significant interaction. As expected, a major prosodic boundary between the nearest attachment site and the ambiguous phrase resulted in more high attachment answers. Contrastive accent on the first verb also led to more high attachments than when the second verb was accented.

Discussion

In Experiment 2a, all conditions had a high attachment bias because all conditions had the only notable prosodic boundary separating the ambiguous phrase from the nearest attachment site. The difference in size of the prosodic boundaries did not affect interpretation, because regardless of the size of the boundary, it was the largest one in the sentence and located in the same place. The placement of the contrastive accent, however, did significantly affect interpretation: accenting the first verb increased high attachments into that VP, and accenting the second verb favored the lower attachment.

In Experiment 2b, the accent effect was clearly replicated, with accents on the first verb increasing high attachment responses, in an experiment containing no other sentences with attachment ambiguities. This suggests that the accent effects in other experiments in this paper cannot be explained away by overlap in processing between different ambiguities of the same type (a priming explanation of some sort). Further, the effect of prosodic boundaries was also significant in this experiment, showing the usual pattern of a late prosodic boundary (immediately before the ambiguously attached phrase) increasing high attachments compared to no boundary. As in Experiment 1, there was no significant interaction between the accent and boundary effects on interpretation, suggesting that the two prosodic markers independently affect decisions about attachment.

The significant effects of accent position on attachment in Experiments 2a–b extends the results of Experiment 1 to a different structure with different lexical items. While the sentences in Experiment 1 all used higher verbs which take complement clauses, the sentences in Experiment 2a–b had higher verbs that were simple transitives. These verbs took object NPs which were definite and contained restrictive object or preposition relative clauses modifying them. The final adverbials could modify either the verb in the relative clause or the higher verb. Also, while the Experiment 1 sentences had a strong low attachment bias in written norms, the sentences in Experiment 2a–b were much more ambiguous. Regardless, accent placement had a similar, small but reliable effect on attachment preferences in both experiments. The results of Experiment 2b are not consistent with the Boundary-Dependent Hypothesis, while the results of both experiments are consistent with the Focus Attraction and Salience Hypotheses.

Experiment 3

This experiment looked for accent effects on attachment in a different syntactic structure, one with a simpler within-clause syntactic ambiguity (PP attachment to a Verb or Noun) than the previous experiments. This experiment also explored accent effects on attachment

to a verb vs. a noun in a single matrix clause, while Experiments 1–2 showed that accenting one of two verbs could affect attachment. Sentences with the structure in (15) usually have a verb-attachment (high) bias in interpretation (Britt, Perfetti, Garrod, & Rayner, 1992; Ferreira & Clifton, 1986; Sedivy & Spivey-Knowlton, 1994). Schafer (1997) and Pynte & Prieur (1996) both studied the effects of prosodic phrasing on attachment of final PPs to either a verb or noun (15), though Pynte and Prieur were studying French and Schafer studied English.

(15) Paula phoned a friend from Alabama.

In general, prosodic boundaries which had the effect of separating the PP from the nearby noun (*friend*) increased higher attachment to the verb, while boundaries grouping the noun with the PP favored noun attachment. This experiment thus varied whether a prosodic boundary was present between the noun and the following PP, helping us to see whether accents affect attachment regardless of the presence of a prosodic boundary which was likely to affect interpretation.

Method

Materials—The items in this experiment were based on the stimuli from Schafer (1997) and were single-clause sentences ending in PPs that could attach to the preceding noun or verb. A full list of items appears in Appendix C. There were 20 items recorded in four prosodic conditions, as in (16).

(16)

- a. Paula PHONED a friend from AlaBAMA.
- b. Paula PHONED a friend ip from AlaBAMA.
- c. Paula phoned a FRIEND from AlaBAMA.
- d. Paula phoned a FRIEND ip from AlaBAMA.

Conditions (a–b) had a L+H* accent on the verb (*phoned*), and conditions (c–d) had similar accents on the noun heading up the verb's object (*friend*). Conditions (a,c) had no prosodic boundaries above the word level within the sentences, and conditions (b,d) had intermediate phrase boundaries following the noun.

To ensure that the recordings had the intended prosodic features, their pitch tracks were examined and acoustic measurements were taken. Any disfluent productions or recordings with incorrect prosody were re-recorded and re-analyzed. Table 3 shows the F0 averages for the conditions, with the accented peaks in bold, as well as the duration averages.

In conditions (a–b), the highest F0 averages were on the verbs (significantly higher verbs in (a–b) than (c–d), $F(1,19) = 233$, $p < 0.001$), while in conditions (c–d) the highest F0 averages were on the following object noun (significantly higher objects in (c–d): $F(1,19) = 405$, $p < 0.001$). The conditions with ip boundaries (b,d) showed a low F0 target near the end of the object noun. The verb durations were longer when the verb was accented than when it was not ($F(1,19) = 178$, $p < 0.001$). The object durations showed two patterns: longer objects

followed by pauses in the conditions with boundaries (b,d), and longer durations for in (c–d) for accented objects (boundary effect: $F(1,19) = 362$, $p < 0.001$; accent effect: $F(1,19) = 79$, $p < 0.001$). The pre-boundary lengthening is more extreme than the accent-related lengthening, but the F0 averages clearly show that objects in (c–d) had high F0 targets.

In order to establish a baseline for the interpretation of these sentences, these items also appeared in the written norming questionnaire discussed in Experiment 1. A group of 30 participants (separate from those in Experiments 1 or 3) read the 20 items and chose between written paraphrases of them, as in (17) without the parenthetical labels:

(17) Paula phoned a friend from Alabama.

- a. Paula phoned from Alabama. (high V attachment)
- b. The friend was from Alabama. (low N attachment)

The sentences had a baseline of 43% high attachment to the verb.

Participants and Procedure—This experiment was run at Morehead State University in conjunction with Experiment 2a, and thus the same set of 48 participants, same fillers, and same procedure hold here. The question and answer choices for these experimental items are shown in (18):

(18) Which is true?

- a. Paula phoned from Alabama. (high V attachment)
- b. The friend was from Alabama. (low N attachment)

Results

The results are shown in Figure 4, expressed as the percentage of high (verb) attachment interpretations.

The data for the experimental items were analyzed in R with a linear mixed-effects regression using the `glmer` function. Fixed effects of accent position (on the Verb vs. Noun) and prosodic boundary presence (none vs. ip) and their interaction were entered into the model using dummy (treatment) coding; both fixed effects were within participants and items. As described for Experiments 1–2, the model was fitted first with a maximal random effects structure, and random slopes were removed until convergence was achieved. The best-fitting and most parsimonious model had two fixed effects (Accent and Bnd) and random intercepts for participants and items ($dv \sim \text{Accent} + \text{Bnd} + (1|\text{Subject}) + (1|\text{SentNum})$) but no interaction, with results shown in Table 6.

The conditions represented in the intercept are Object for Accent (accent on object) and bnd for Bnd (presence of a prosodic boundary). We found that the position of accent on the verb significantly increased high attachment compared to accent on the noun. The presence of a prosodic boundary before the ambiguous phrase also significantly increased high attachment. The two factors did not interact in the best model. As in the complement clause

and relative clause structures in earlier experiments, contrastive accent on the head of the VP or NP drew attachment to the relevant phrase.

Discussion

This experiment extended the results in Experiments 1–2 to another structure, finding that accenting attachment sites draws the attachment of a final ambiguous phrase. This time, the attachment sites included one verb and one noun, since the ambiguity was between VP and NP attachment of the last PP. So it cannot be the case that the accent effect is restricted only to attachment to verbs (or attachment to nouns, as in Schafer et al. 1996), nor is it necessary that the competing attachment sites be the same syntactic category. Also, these sentences were much simpler than those in the previous experiments, consisting of a single clause with a transitive verb and its object. Accent effects are thus not limited to between-clause attachment ambiguities or found only in complex sentences.

The prosodic boundary between the noun and the final PP slightly increased high attachments to the verb over a condition with no major prosodic boundaries within the sentence. This result is expected from prior research on prosodic boundaries in this structure (Pynte & Prieur, 1996; Schafer, 1997). The prosodic phrasing with the boundary before the final phrase had the effect of separating the ambiguous phrase from the closest attachment site (the noun), and that favored high attachment.

Because effects of accent were found regardless of the presence of a prosodic boundary, this experiment is not consistent with the Boundary-Dependent Hypothesis. We conclude that this hypothesis has been ruled out, then, given that the results of Experiment 1 and 2b are also inconsistent with it. The Focus Attraction Hypothesis and the Salience Hypothesis are both consistent with the results.

Experiment 4

This experiment returned to the complement clause items from Experiment 1 in order to address two remaining questions. One was whether the previous results could be explained purely by Lee & Watson's (2011) question-answering strategy, in which participants choose answers containing salient (accented) words regardless of the interpretation of the sentences. Although the answer choices in Experiments 1–3 did consist of complete sentences instead of the NP answers found in Lee & Watson's experiments, it was still true that each answer only contained one of the attachment sites. It is possible, therefore, that participants simply showed a bias towards choosing answers that contained the salient, accented word in each sentence (the post-sentence selection version of Lee & Watson's Salience Hypothesis), rather than using the accent in their interpretation of the sentences.

The second question addressed in this experiment was whether it is necessary to accent the head of the phrase into which the ambiguous phrase could attach. That is, Experiments 1–3 accented verbs to attempt to draw attachment into each verb's VP, and accented the object noun in Experiment 3 to attempt to draw attachment into its NP. This seemed like the most logical placement of accents. But this experiment added conditions with accents on the subjects of either the matrix or the complement clause in order to test whether accents

elsewhere in a clause could also draw attachment into that clause. This could be seen as another test of the Salience Hypothesis, since it is quite possible that contrastively accenting the subject of one verb but not the other would make the first verb salient as an attachment site. Thus the Salience Hypothesis could predict that subject accents would affect attachment. The Focus Attraction Hypothesis, on the other hand, would not, since focus does not project from subject position to the verb of the VP (Selkirk 1984, 1995).

Method

Materials—The 20 sentences from Experiment 1 (seen in Appendix A) were produced in another four prosodic conditions, as in (19).

(19)

- a. SANDY claimed that Robbie left IPh last week
- b. Sandy claimed that ROBBIE left IPh last week
- c. Sandy CLAIMED that Robbie left IPh last week.
- d. Sandy claimed that Robbie LEFT IPh last week.

Conditions (a–b) varied whether the subject of the matrix clause or the complement clause bore a contrastive (L+H*) pitch accent. Conditions (c–d) varied whether the verb in the matrix clause or the complement clause had a contrastive pitch accent. All conditions had an identical continuation rise IPh boundary before the final adverbial phrase.

All sentences were checked for consistent renditions of the intended prosodic features and acoustic measurements were taken. The average F0 measurements appear in Table 1, with the contrastive accent peaks in bold. The F0 measurements show that the accented words were by far the highest peaks within their sentences. Subject1 when accented was 100 Hz higher on average than its production in unaccented conditions, and the same was true of the other accented elements (significant accent effect on each element in one-factor four-level ANOVAs: Subject1, $p < 0.001$; Verb1, $F(3,57) = 324$, $p < 0.001$; Subject2, $F(3,57) = 1760$, $p < 0.001$; Verb2, $F(3,57) = 1937$, $p < 0.001$). Durational measurements are in Table 2. Consistent with the accent patterns, the durations show that each element was longest in the condition when it was accented (significant accent effect on each element in one-factor four-level ANOVAs: Subject1, $F(3,57) = 58$, $p < 0.001$; Verb1, $F(3,57) = 51$, $p < 0.001$; Subject2, $F(3,57) = 64$, $p < 0.001$; Verb2, $F(3,57) = 52$, $p < 0.001$).

Participants—The participants were 59 people recruited through Amazon Mechanical Turk. They self-reported as native English speakers after completing the study and being assured that they would be paid regardless of their native language. Any non-native English speakers were removed from the data set. They were paid up to \$4 for their participation. Participants ranged in age from 18 to 68 and 51% were female.

Procedure—Participants on Amazon Mechanical Turk clicked through to a Qualtrics survey. This began with a page of instructions, including directing participants to use a browser other than Internet Explorer so that the audio files would play. Throughout the

experiment, each item showed an audio file player on screen followed by a question and two answers. There were 5 items displayed per page. Participants could play the audio file as many times as desired and then answer the question about its meaning. However, there was little incentive to replay the sentences, given that they would receive the same amount of money regardless of how long they took to complete the experiment.

In order to avoid any salience-based question-answering strategy, all answers for the critical items included all of the possibly accented words. For the item in example (19), the question and answers were as in (20):

(20) What happened?

- a. Sandy claimed last week that Robbie left. (high attachment)
- b. Robbie left last week and Sandy claimed that later. (low attachment)

The words that could be contrastively accented in the stimuli were the clause subjects (*Sandy* or *Robbie*) or the clauses' verbs (*claimed* or *left*). Since all of these words were present in both answers, participants could not simply choose answers that contained the contrastively accented word and coincidentally choose the interpretation on which the ambiguous phrase modified that word.

Stimuli included 20 sentences with other attachment ambiguities in question contexts (e.g., *What did the detective do? The detective startled a thief with a mallet*), ellipsis sentences of two types (16 gapping sentences, such as *The surgeon suspects the maids prefer black beans and the pilot pinto beans.* and 18 VP ellipsis sentences, e.g., *Eric wanted to eat cake and Shaun did, too*), and 30 unrelated filler sentences with a variety of structures, for a total of 104 items. The items were counterbalanced so that each participant heard only one prosodic version of each item and heard an equal number of items in each condition over the experiment. The items appeared in one of four pseudo-randomized lists such that no consecutive items were of the same type. After completing the experiment, participants answered demographic questions and received a code to let Amazon Mechanical Turk know to release payment.

Results

The results are shown in Figure 5, expressed as the percentage of high attachment interpretations.

The data for the experimental items were analyzed in R with a linear mixed-effects regression using the glmer function. Fixed effects of accented word (on Subject vs. Verb) and clause (early accent in first clause vs. late accent in second clause) and their interaction were entered into the model using dummy (treatment) coding; both fixed effects were within participants and items. The model was fitted first with a maximal random effects structure with random slopes and random intercepts for both items and participants (Barr et al. 2013), and random slopes were removed until convergence was achieved. The best-fitting and most parsimonious model had two fixed effects (Accent and Clause), random intercepts for participants and items, and an interaction between the effects ($dv \sim \text{Accent} + \text{Clause} + \text{Accent} * \text{Clause} + (1 | \text{Subject}) + (1 | \text{SentNum})$), with results shown in Table 7. Models

with random slopes did not converge or did not have AIC and BIC values that would be considered a significant improvement over the selected model; the model without an interaction term had a similar but higher AIC value. The conditions represented in the intercept are Subject for Accent (accent on subject) and First for Clause (accent in first clause).

We found that accents on the verb led to slightly higher average rates of high attachment than those on the subject. This effect is likely a byproduct of the significant interaction shown in the data, however: accents on the subject in either clause did not lead to any differences in interpretation, while accenting the verb in the first clause led to more high attachments.

Discussion

This experiment replicated Experiment 1 (which used the same syntactic structure) in the verb attachment conditions, showing that accents on the verbs drew attachment. Further, it repeated this effect while showing that the formulation of the answer choices was not critical. Here, each answer contained both verbs which were possible attachment sites, and participants still chose the answer expressing high attachment more when the higher verb was accented. These results cannot, therefore, be explained away by the question-answering strategy proposed by Lee & Watson (2011), in which answers containing accented words are preferred regardless of interpretation. Instead, this suggests that the results of Experiments 1–3 and Schafer et al. (1996) are due to some other mechanism (e.g., focus) rather than the byproduct of a question-answering strategy. It is possible, of course, that answers which contain accented words are more attractive due to salience than those without, in addition to the interpretive effect, but this experiment shows that an effect of accents on interpretation does exist beyond that possibility.

Secondly, this experiment showed that accenting the subjects of verbs which are the heads of attachment sites (instead of the verbs themselves) did not affect attachment. Any salience that the accent gives to the subject does not seem to transfer to its associated verb. It may be that accent effects require the the head of the phrase into which attachment is possible to be accented (verbs in VPs, nouns in NPs, etc.). It is still possible, following Selkirk's (1984) theory of focus projection, that accenting a constituent that projects focus to an attachment site could bias attachment (e.g., a complement of a verb to indicate focus on the whole VP). It remains an empirical question whether accenting an element which projects focus to the VP would attract attachment to that verb. Birch & Clifton (1995) have shown that accenting only the object of a verb is consistent with VP focus according to appropriateness ratings and comprehension of sentences in context. Here, subject NPs, which do not project focus outside the NP, did not affect attachment into different VPs in these sentences. This lack of effect is expected under the Focus Attraction Hypothesis, while the Salience Hypothesis could have accommodated an effect of accenting subjects through a transfer of salience.

General Discussion

Together, Experiments 1–4 show that prominent accents on attachment sites can draw the attachment of an ambiguous upcoming phrase across several different structures: the ambiguous phrase could be an adverbial phrase or PP; the attachment sites could be verbs in matrix clauses, verbs in complement clauses, verbs in relative clauses, or even object nouns. In combination with previous work showing that accents can affect the attachment of relative clauses to different nouns (Lee & Watson, 2011; Schafer et al., 1996), this work shows that accents can affect syntactic attachment decisions over a range of structures. The replication of the Experiment 1 effects in Experiment 4 with different answer choices shows that a question-answering strategy tied to salient (accented) words in the answers does not explain away the accent effects. Thus the effects are not simply an artifact of incautious experiment design, but a genuine effect of prosodic structure on interpretation.

The structures tested here also varied in their level of ambiguity. The matrix-complement structures from Experiments 1 and 4 had a very strong low bias, with only 10% high attachment in the written norming questionnaire and less than 30% high attachment in all conditions of Experiment 1. The matrix-relative and verb-noun structures from Experiments 2–3 were less biased, with high attachment percentages around 50% in isolation. Accent effects were numerically quite similar in size across these different structures. If prosodic information were used as a last resort in processing, then we would expect more ambiguous sentences to show larger effects of prosodic elements on interpretation. The results are more consistent with prosody being one of the sources of information that is available to the processor, and one which is always used.

In addition, the results show that accent effects are not dependent on prosodic boundaries. It would have been easy to imagine a system in which local attachment would overwhelm any accent effects unless a local boundary intervenes (as in the disconfirmed Boundary-Dependent Hypothesis). That is, since prosodic grouping is so similar to syntactic grouping, we might expect that prosodic boundaries would be the first type of prosodic information used by the processor. Accents could be consulted afterwards, as long as the accents were within a prosodic phrase with the attachment site and ambiguous phrase. This model would have led to interaction effects (instead of main effects) in Experiments 1 and 3, with the no-boundary conditions showing no accent effects. But although prosodic boundaries separated the ambiguous phrases from the nearest attachment site in some conditions, accent effects were not restricted to such cases. And no interactions between prosodic boundaries and accents were significant in the experiments. So despite the closer connection intuitively between prosodic boundaries and syntactic phrasing, which might be expected to play out in their level of influence on attachment, accents seem to affect attachment independent of prosodic boundaries, ruling out the Boundary-Dependent Hypothesis.

In all but Experiment 2a, prosodic boundaries did have an effect on attachment, as expected, and the results are consistent with current theories of prosodic boundary effects on attachment. The primary position of the boundaries was immediately in front of the ambiguously attached phrase. This boundary position is one which most theories of prosodic boundaries in processing agree should reduce attachment to the local attachment site

(Watson & Gibson (2005), Carlson et al. (2001)). The experiment without a significant effect of prosodic boundaries, Experiment 2a, tested conditions with prosodic boundaries in the same location varying only in size. These results therefore also align with predictions from both Watson & Gibson (2005) and Carlson et al. (2001).

The results of Experiments 1–4 demonstrate that, in addition to affecting things like pronoun reference and information structure, pitch accents in English can influence syntactic attachment. This work suggests that assuming separate roles for prosodic boundaries and accents in sentence processing may be too strong, and that they can both be active in certain ambiguities. In particular, the division of labor suggested in Carlson, Clifton, & Frazier (2009) needs revision in light of these results, so that both accents and boundaries can influence the attachment of optional modifying phrases. It is still true, though, that Carlson, Clifton, & Frazier (2009) showed accents to be effective in an ellipsis structure where prosodic boundaries had no effect, and so we also cannot assume that both prosodic features will be active in all ambiguous structures. It is a matter for further empirical study to determine the full range of application of prosodic boundaries and pitch accents within sentence processing.

There are two potential caveats about our results, based on the accents used and the lack of contexts. First, all of the pitch accents manipulated in Experiments 1–4 were L+H* accents (or very prominent, steep H* accents, if the accent types are not distinct categories). These accents are said to be contrastive (Ito & Speer, 2008; Pierrehumbert & Hirschberg, 1990), as opposed to the more common H* accents used on new information. They are also more prominent and probably more memorable. This was a deliberate prosodic choice, as we felt that accent effects would be easier to find with more obvious accents. But the question remains whether accent effects on attachment only show up with these contrastive accents, or whether simple H* accents could also influence attachment. Second, we know that accents and focus are intimately related to the information structure of a discourse, and therefore are most natural in the context of larger structures than a single sentence. Studies such as ours, which look at isolated sentences, are certainly not the only way to gain understanding of the effects of accents. We believe that people are able to accommodate missing contexts and still make productive use of accents when hearing isolated sentences, but we also acknowledge that studies of larger discourse units will be needed in order to gain a full picture of the role of accents in processing.

The finding that accents can affect attachment tells us that listeners are making use of a whole prosodic contour and the prosody-syntax interface conditions during processing. In particular, their syntactic choices appear to be affected by the prosodic phrases they perceive and by the focus structure that they generate based on accent patterns. If prosodic boundaries but not accents influenced attachment, it would be possible to argue that this is a simple grouping effect which could happen independent of the grammar. That is, effects of prosodic boundaries on attachment basically come down to the idea that a prosodic grouping of words favors a structure with a similar syntactic grouping. Almost any means of grouping words that coincided with a syntactic grouping ought to have the same effect, even without the type of grammatical connection that most linguists believe links prosody and syntax. Presenting one group of words in one color and another group of words in another color might lead

readers to interpret each group as syntactically grouped, simply through the general cognitive ability to notice and use features of the environment. But accents do not group material: a word bearing an accent does not obviously link that word with a later phrase. Therefore, the effect of accents on the attachment of an upcoming phrase cannot be driven by any general cognitive mechanism that uses structural parallels between prosodic form and syntactic structure. Instead, it is the relationship between prosodic and syntactic structures in the grammar that must explain accent effects.

There are two main proposals for how and why accents attract attachment. One, expressed in the Focus Attraction Hypothesis of Schafer et al. (1996), is that accented attachment sites are interpreted as focused. Because they are focused, they are seen as conveying important information in the sentence, and given the choice, people prefer to interpret a later phrase as modifying that important information (this idea is related to earlier hypotheses in Frazier 1990, and Frazier & Clifton 2005). Traxler & Frazier (2008) present studies of PP attachment in different types of clauses that also support a related hypothesis. They suggest that the most memorable elements in a semantic or discourse structure would be the most syntactically important elements (i.e., those in main clauses instead of subordinate clauses), and they found that such important elements would be more likely to be modified by upcoming material.

Alternatively, accenting an attachment site could simply make it salient and memorable. Experiment 4 established that attachment effects could not be explained away as being solely based on perceivers choosing answers containing the accented word (cf. the post-sentence selection version of the Salience Hypothesis, Lee & Watson, 2011). But a sentence-internal salience hypothesis could still explain the results of Experiments 1–4. Specifically, when encountering a later phrase that could attach to two possible sites, perceivers could find the accented one easier to recall or more visible for attachment, and thus be more likely to attach into it (Lee & Watson, 2011).

The challenge in distinguishing between the focus-based and the salience-based explanations for the accent effect is that it is difficult to see how to cue focus without salience (or salience without focus). The presence of focus itself is likely to increase salience, and thus could affect attachment for that reason. It is possible that most manipulations of focus are simultaneously manipulating salience. Bishop (2012) found, for example, that a mildly accented object was heard as more prominent by listeners following a wh-question that focused it (and the verb was heard as less prominent) than in a different focus context. So the information structure of an utterance based on discourse can change how prominent or salient the same prosodic unit is perceived to be. It seems then that marking an attachment site as focused but not making it salient may be impossible (indeed, we would agree that the accented attachment sites in Experiments 1–4 were also salient elements within each sentence). On the other hand, the cuing of an attachment site as salient without focusing it also seems difficult, since common ways of increasing salience, e.g. typographical variations like *italics*, **bold**, and underlining, as well as changes in the size, font, or color of text, would likely also indicate focus or accentedness (cf. Fraundorf et al., 2010).

Because focus and salience are similar and overlapping concepts, one of the main differences between the Focus Attraction Hypothesis and the Salience Hypothesis is that the former interfaces directly with a wide range of syntactic and semantic literature on focus. This literature discusses different means of conveying focus (accents, clefting, focus particles, focus positions in syntax, etc.), the semantic consequences of focus status, the way that focus status can project beyond an accented constituent, and so on (see, for example, Kadmon, 2001; Kiss, 1998; Rooth, 1992; Selkirk, 1984, among many others). This literature leads us to expect that a wh-question or focus particle picking out a sentence constituent should have similar consequences for attachment as a pitch accent would have. Also, accenting an element that projects focus to an attachment site ought to increase attachments to that site. Whether these further predictions based on focus are borne out in experiments remains to be seen. The Salience Hypothesis is less specific to language, and does not bring with it clear predictions about the syntax and semantics of accent effects (though it may relate to more general cognitive work, as in studies of vision or acoustics). If predictions derived from the Focus Attraction Hypothesis are supported in future experiments, this would suggest that the theory of focus is relevant to the effects of accents on attachment. In general, though, theories and experiments on syntactic attachment during sentence processing must now take account of the position of pitch accents as well as the pattern of prosodic boundaries.

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Appendix

Appendix A: Stimuli for Experiments 1, 4

1. Sammy heard that Bill had called # on Monday.
2. Sally discovered that Pam had returned # on Sunday.

3. Brian announced that Tim was promoted # on Friday.
4. Sandy claimed that Robbie had left # last week.
5. Louie found out that Bob had quit # in June.
6. Mona insisted that Dennis had been mistaken # last night.
7. Linda reported that Thomas was bribed # last May.
8. Tony denied that Kevin had left early # on Tuesday.
9. Sarah testified that Mark had disappeared # last month.
10. Lucy confirmed that Beth had stepped down # last week.
11. Paula claimed that Alex had lied # on Monday.
12. Sharon complained that Jason had been rude # on Friday.
13. David admitted that Alison went bankrupt # last year.
14. Matt learned that Lisa had eloped # last Wednesday.
15. Cathy announced that Jeff had been elected # on Tuesday.
16. Danny mentioned that Emma had moved out # last week.
17. Anna revealed that Galen had graduated # in May.
18. Robert claimed that Ellen had run away # last Friday.
19. Mary stated that Andrew got engaged # last week.
20. Penny heard that Joe got in trouble # on Thursday.

Appendix B: Stimuli for Experiment 2

Prosodic conditions for Experiment 2a shown for item 1.

1. Jimmy COMFORTED the girl that he had insulted L– at the end of the party.
Jimmy comforted the girl that he had INSULTED L– at the end of the party.
Jimmy COMFORTED the girl that he had insulted L–H% at the end of the party.
Jimmy comforted the girl that he had INSULTED L–H% at the end of the party.
2. Sarah watched the lawyer that she had danced with # for several hours last night.
3. Allen avoided the banker that he had borrowed from # long before the deadline.
4. Jared hired the secretary that he had been mean to # after the business folded.
5. Diane charmed the landlord that she had badmouthed # at the tenants' meeting.
6. Karen called the chef that she had complimented # after the year-end banquet.
7. Brian interviewed the diplomat that he had misquoted # before the last UN session.

8. Nancy called the model that she had just hired # at breakfast time.
9. Jerry kissed the actress that he had recently met # at the Oscars ceremony.
10. Brenda snubbed the waiter that she had been rude to # at the pre-wedding dinner.
11. Gary robbed the professor that he had worked for # during spring vacation.
12. Hazel placated the critic that she had publicly slandered # before the summer season.
13. Chester thanked the janitor that he had left such a mess for # after the carpet installation.
14. Peggy applauded the juggler that she could see best # after the flaming baton act.
15. Earl pitied the students that he had sent outside # after the sudden downpour.
16. Amber recognized the picketer that she had photographed # during the political rally.
17. Lois complimented the set designer that she had disagreed with # before the first show.
18. Daniel ignored the dinner guest that he had accidentally tripped # during the heated discussion.
19. Joseph reassured the employee that he had chastised # at the first coffee break.
20. Denise greeted the plumber that she had complained about # at the Fourth of July picnic.
21. Nicholas cross-examined the witness that he had taken notes on # during the court session.
22. Janice fired the busboy that she had just hired # before the dinner rush.
23. Robert mentioned the candidate that he had campaigned for # before the fund-raising dinner.
24. Michelle supported the starlet that she had worked with # during the media frenzy.

Appendix C: Stimuli for Experiment 3

1. Paula PHONED a friend from AlaBAMA.
Paula PHONED a friend ip from AlaBAMA.
Paula phoned a FRIEND from AlaBAMA.
Paula phoned a FRIEND ip from AlaBAMA.
2. Nathan followed a woman in a Ferrarri.
3. The engineer repaired a machine with a metal lever.
4. The detective startled a thief with a mallet.

5. Alfie threatened a thug with a weapon.
6. Jenny sketched a child with crayons.
7. The producer recorded a band with lousy equipment.
8. Darrin greeted a visitor with a great smile.
9. Aaron spotted a girl from the party.
10. The girl frightened a boy with a snake.
11. Alison entertained a toddler with many toys.
12. The judge ruled against a lawyer with no justification.
13. The driver upset a passenger with an angry frown.
14. Heather jostled a man with a large bag.
15. The assistant described a problem in the report.
16. James read an article on a train.
17. Amy tripped a tourist with a cane.
18. Ryan pursued a suspect on a motorcycle.
19. The cops observed an intruder with binoculars.
20. Bobby read aloud a letter to his girlfriend.

Figure 1.
 Example pitch tracks for an item in Experiment 1
 a. Verb1 accent, IPh boundary
 b. Verb2 accent, IPh boundary
 c. Verb1 accent, no boundary
 d. Verb2 accent, no boundary

Figure 2.

Results of Experiment 1. V1 Accent = accent on Verb 1; V2 Accent = accent on Verb 2; IPh = Intonational Phrase prosodic boundary; none = no prosodic boundary. Error bars represent SE by subjects.

Figure 3.

Results of Experiments 2a–b. V1 Accent = accent on Verb 1; V2 Accent = accent on Verb 2; IPh = Intonational Phrase prosodic boundary; ip = intermediate phrase prosodic boundary; none = no prosodic boundary. Error bars represent SE by subjects.

Figure 4. Results of Experiment 3. ip = intermediate phrase prosodic boundary; none = no prosodic boundary. Error bars represent SE by subjects.

Figure 5. Results of Experiment 4. Early Accent = accent in first clause; Late Accent = accent in second clause; Verb = accent on verb; Subject = accent on subject. Error bars represent SE by subjects.

Table 1

Average F0 measurements (in Hz) for critical words, Experiments 1–2, 4. Averages of accented elements shown in bold.

		Subject1 peak	Verb1 peak	Subject2 peak	Verb2 peak	L– or end of Verb2	H% boundary tone	Adverbial peak
Experiment 1	a	235	283		172	160	205	241
	b	234	216		260	160	189	232
	c	227	275		174	171		233
	d	233	215		264	174		232
Experiment 2a	a		302		185	169		236
	b		232		268	170		
	c		293		174	165	202	
	d		228		276	161	202	
Experiment 2b	a		318		195	181		213
	b		240		282	173		215
	c		315		173	161	199	223
	d		232		286	154	194	222
Experiment 4	a	331	218	184		160	224	265
	b	234	215	309		156	235	253
	c	222	318	177		159	236	259
	d	225	213	192	299		207	252

Table 2

Average durations (in ms) of critical elements, Experiments 1–2, 4. Averages of accented elements shown in bold.

		Subject1 duration	Verb1 duration	Subject2 duration	Verb2 duration	Pause duration
Experiment 1	a		450		539	124
	b		392		609	96
	c		430		383	0
	d		418		430	0
Experiment 2a	a		471		638	208
	b		399		688	209
	c		445		629	255
	d		396		703	278
Experiment 2b	a		481		547	1
	b		417		589	2
	c		473		685	202
	d		410		743	180
Experiment 4	a	370	413	304	746	185
	b	315	375	361	753	181
	c	296	452	297	720	198
	d	306	366	291	813	182

Table 3

Average F0 measurements (in Hz) and durations (in ms) for critical words, Experiment 3. Averages for accented elements shown in bold.

		Subject peak	Verb peak	Object peak or level	Object minimum if lower	Adverbial peak
F0 in Hz	a	244	290	200		232
	b	237	290	196	188 (10 items)	233
	c	240	223	269		230
	d	231	221	260	188 (20 items)	227
			Verb duration	Object NP duration	Pause duration	
Durations in ms	a		469	435	0	
	b		426	552	111	
	c		364	484	0	
	d		359	598	62	

Table 4

The linear mixed-effects regression model for Experiment 1.

Effects	Beta Estimate	SE	z-value	p-value
Intercept (V1, bnd)	1.205	0.285	−4.229	p < 0.001
Accent position (V2)	0.443	0.182	−2.433	p < 0.05
Boundary presence (noBnd)	0.833	0.186	−4.474	p < 0.001

Note: the parenthetical terms indicate which conditions are represented in the intercept and each fixed effect.

Table 5

The linear mixed-effects regression models for Experiments 2a–b

Experiment 2a:				
Effects	Beta Estimate	SE	z-value	p-value
Intercept (V1, large)	0.890	0.226	3.931	$p < 0.001$
Accent position (V2)	−0.333	0.138	−2.410	$p = 0.016$
Boundary size (small)	0.232	0.138	1.680	$p = 0.093$
Experiment 2b:				
Effects	Beta Estimate	SE	z-value	p-value
Intercept (V1, nobnd)	0.005	0.263	0.019	$p = 0.985$
Accent position (V2)	−0.511	0.141	−3.621	$p < 0.001$
Boundary presence (Bnd)	0.940	0.143	6.557	$p < 0.001$

Note: the parenthetical terms indicate which conditions are represented in the intercept and each fixed effect.

Table 6

The linear mixed-effects regression model for Experiment 3.

Effects	Beta Estimate	SE	z-value	p-value
Intercept (Obj, bnd)	0.369	0.341	1.084	p = 0.278
Accent position (Verb)	0.452	0.156	2.898	p < 0.005
Boundary presence (Bnd)	0.476	0.156	3.052	p < 0.005

Note: the parenthetical terms indicate which conditions are represented in the intercept and each fixed effect.

Table 7

The linear mixed-effects regression model for Experiment 4.

Effects	Beta Estimate	SE	z-value	p-value
Intercept (Subject, First)	-0.713	0.303	-2.352	p = 0.019
Accent (Verb)	0.720	0.205	3.520	p < 0.005
Clause (Second)	-0.001	0.207	-0.003	p = 0.997
Accent * Clause	-0.721	0.291	-2.478	p < 0.05

Note: the parenthetical terms indicate which conditions are represented in the intercept and each fixed effect.