Informative Prosodic Boundaries

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Abstract

In principle, a prosodic boundary in an utterance might affect its interpretation in a local, context-independent fashion. In a right-branching language like English, the presence of a large prosodic boundary might signal the end of the current constituent, requiring the following constituent to be attached high in the syntactic tree. We present three listening experiments that test an alternative position suggested in Carlson, Clifton and Frazier (2001) as the "informative boundary" hypothesis. This hypothesis claims that the interpretation of a prosodic boundary is determined not by its absolute size but by its size relative to relevant certain other boundaries. Experiment 1 confirmed the predictions of this hypothesis in phrases like the old men and women with very large houses, manipulating the boundaries before and and with. Experiment 2 investigated the effect in a variety of diverse syntactic structures, varying syntactic category and status (head vs. nonhead) of the ambiguous constituent. It confirmed the predictions of the informative boundary hypothesis in every structure tested except for "-ly" adverbs that are ambiguous between a manner interpretation and a speaker-evaluation interpretation. Experiment 3 demonstrated that sentence interpretation was affected by the size of the late boundary relative to a relevant early boundary, but not relative to an early boundary that was predicted to be irrelevant.

KEY WORDS: Prosody, prosodic boundaries, ambiguity, prosodic structure

Many studies have shown that local prosodic information may influence listeners'
analysis of an ambiguous phrase (e.g., Nespor & Vogel, 1983, Lehiste, 1973, Price, Ostendorf,
Shattuck-Huffnagel, & Fong, 1991). Recent evidence also indicates that listeners exploit global
prosodic representations during sentence processing, not just local prosodic cues (Schafer, 1997;
Schafer, Speer, Warren, & White 2000). Schafer (1997) proposed that attachments within a
prosodic phrase are favored over (more "visible" than) those across a prosodic phrase boundary.
She examined V-NP-PP attachment ambiguities (see also Pynte & Prieur, 1996; Watson &
Gibson, 2002) and found that a prosodic boundary before the NP (with or without a boundary
before the PP) favored attachment of the PP to the NP rather than the VP.   Although she did not
discuss the relative size of boundaries at different positions, she did argue that the global
prosodic representation rather than local prosodic cues guided parsing, and she advanced the
claim that visibility was graded across multiple phrases (see Carlson et al., 2001, for further
discussion of the relation of Shafer's claims to the present claims).

In previous work (Carlson, Clifton, & Frazier, 2001), we provided similar evidence that
global prosodic representations drive comprehension. We investigated the interpretation of
sentences like (1), where the final phrase "after John visited" may be attached low, modifying
telephone in the complement clause, or high, into the matrix clause, where it modified learn.

(1)   Susie learned$_\uparrow$ that Bill telephoned$_\uparrow$ after John visited.

We introduced prosodic boundaries of different types at the points marked by ↑. The
phonological types we used are those described in the phonological theory of Pierrehumbert and
Beckman (Beckman, 1996; Beckman & Pierrehumbert, 1986; Pierrehumbert, 1980;
Pierrehumbert & Hirschberg, 1990). In this theory, an utterance is made up of one or more

intonational phrases (IPh). Each IPh ends with a boundary tone (H%, L%), and is made up of one

or more intermediate phrases (ip). Each ip contains at least one pitch accent (e.g. H*, L*) and

ends with a phrasal tone (H-, L-). An IPh boundary is larger than an ip boundary in that an IPh

boundary includes an ip boundary together with an intonational boundary tone.

Manipulating the phonological type of the "late" prosodic boundary immediately before

the ambiguous adjunct (after John visited in (1)) did not by itself have any invariant effect on

sentence interpretation. An IPh boundary did not necessarily trigger more high attachments than a

phonologically smaller ip boundary. What did matter was the relative phonological sizes of the

boundary immediately before the adjunct and the earlier boundary, before that. By contrast,

manipulation of only an acoustic property (duration) of the later boundary did not affect

interpretation (Carlson et al., 2001, Experiment 2). When the pre-adjunct boundary was

phonologically larger than the earlier boundary, more high attachments of the adjunct were

observed (as indicated in (2a), where the types of the first and the second possible prosodic

boundary are indicated for each item). When the pre-adjunct boundary was phonologically

smaller than the relevant early boundary, more low attachment interpretations were observed

(2c). When the two boundaries were of equal size, an intermediate number of high attachments

were observed (2b).

(2)   a.   more high attachments [0, ip], [ip, IPh]

          b.   intermediate number of high attachments [ip, ip], [IPh, IPh]

          c.   fewer high attachments [ip, 0] [IPh, ip]

In our prior studies and those reported below, we tested the effect of optional prosodic

boundaries, i.e. a boundary that the grammar permits but does not require immediately before an

ambiguously attached phrase. Our hypothesis is that the perceiver interprets such a boundary with

reference to the size of any boundary at the beginning of a constituent containing the low

attachment site but not the high attachment site as illustrated in the schema in (3):

(3)
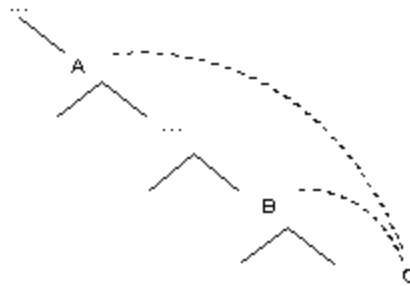
Consider an ambiguous constituent C that follows B's already-identified constituents. C

is ambiguous in that it may be attached to the constituent B or to the constituent A. A prosodic

boundary immediately before C that is large relative to any prosodic boundary preceding a

constituent including B but not A encourages high attachment of C to A. A pre-C boundary that

is small relative to a boundary before constituent B but not A encourages low attachment to B.

Equal boundaries at these two positions are uninformative in the sense that the pre-C boundary

conveys no specific information about the attachment site of C.[1]

In other words, a pre-C boundary (which we will refer to as a "late" boundary) is informative if it

differs in size from the other boundary flanking a constituent containing B but not A. The

presence of an informative boundary affects attachment decisions. We call this the informative

boundary hypothesis.

The evidence reported in Carlson et al. (2001) was consistent with the informative

boundary hypothesis, but was limited to a single syntactic structure (a sentence with a

complement clause followed by an ambiguously-attached adjunct phrase or clause that could modify the main clause or the complement clause). It tested a subset of the possible relations among the two prosodic boundaries, and did not explore the effects of possible boundaries that are not relevant according to the hypothesis in (3) (e.g., a boundary before A). In the present paper, we report three auditory comprehension experiments designed to test the informative boundary hypothesis more thoroughly. In particular, Experiment 1 examines a set of prosodic configurations that permits a more complete and systematic test of the claim that the relative, not the absolute, size of the late boundary matters, extending this test to a structure in which a preposition phrase can modify a simple or a conjoined noun phrase. Experiment 2 examines a variety of different structures and show that the informative boundary hypothesis applies to all of them, save one. Experiment 3 returns to the sentence structures investigated by Carlson et al. (2001), and determines whether the position of the early boundary (whether or not it precedes A in the schema of (3)) as well as its size relative to the late boundary affects interpretation.

EXPERIMENT 1

Experiment 1 tested phrases with 4 versions each, as illustrated in (4), with IPh and ip boundaries indicated.[2] [3]

(4)   Who came out ahead?

a.   Old men and women$_{\text{IPh}}$ with very large houses   [0 IPh]

b.   Old men$_{\text{IPh}}$ and women$_{\text{IPh}}$ with very large houses   [IPh IPh]

c.   Old men and women$_{\text{ip}}$ with very large houses   [0 ip]

d.   Old men$_{\text{ip}}$ and women$_{\text{ip}}$ with very large houses   [0 ip]

These phrases appear similar to the phrases investigated by Lehiste (1973) and Cooper and

Paccia-Cooper (1980), who examined the ambiguous attachment of the prenominal modifier old.

However, we are examining a different ambiguity. In (4), the prepositional phrase (PP) modifier

may attach low, to the preceding phrase women, or high, where it modifies the entire conjoined

phrase old men and women. In these structures, recency may favor low attachment. On the other

hand, readers seem to prefer conjoined phrases which are structurally similar to each other

(Frazier et al., 1984, Frazier, Munn & Clifton, 2000), which should discourage the low

attachment analysis in which only the second conjunct contains a PP. To make such an

attachment more attractive, the first noun was always preceded by an adjective that could be

taken to modify this noun alone. Without the possibility of a modifier on the first noun, taking

the postnominal modifier to modify only the second noun was likely to be strongly dispreferred.

Indeed, as the data showed, the postnominal modifier phrases had a fairly strong high attachment

bias even with a modifier preceding the first noun. Thus these sentences contrasted strongly with

the low-attachment biased sentences studied by Carlson et al. (2001).

The phrases in (4) include a prosodic boundary higher than a word-level break

(specifically, an ip or an IPh boundary) only where indicated.[4] Whatever the baseline preference

is in (4), the informative boundary hypothesis predicts that there will be more high attachments in

(4a), with an informative late boundary, [0, IPh], than in (4b), with an uninformative one, [IPh,

IPh]. Further (4c), with a [0, ip] prosody, and (4d), with a [ip, ip] prosody, are predicted to mirror

(4a) and (4b). It is also interesting to see if (4a), whose prosody was [0, IPh], will show a larger

high attachment bias than (4c), with a [0, ip] prosody, due to the phonological type of the

informative (late) boundary.

Methods

Materials. We constructed 18 phrases like those in (4) (see Appendix A for a list of all the phrases). A female phonologically-trained linguist, reading from a ToBI annotated script, recorded the sentences in four prosodies each. Either an ip or an IPh boundary immediately preceded the sentence-final prepositional phrase, and either the same type of boundary or no boundary larger than a word boundary preceded the second conjunct.

A lead-in question was recorded with each phrase (e.g., Who came out ahead?) (see Appendix A). In addition, a question to be visually displayed to the participant was made up for each phrase. Each question had two alternative answers (e.g., Who has large houses? Old men and women; Only the women) and the participant was to pull a trigger under the correct answer.

The recorded utterances were digitized (16 bits, 22.5 kHz) and analyzed by a ToBI-trained linguist (KC) following the ToBI transcription scheme (Beckman & Elam, 1997; Beckman & Hirschberg, 1994; Silverman, Beckman, Pitrelli, Ostendorf, Wightman, Price, Pierrehumbert, & Hirschberg, 1992). The F0 plots for a typical set of utterances with ToBI annotations appear as Figure 1. The ToBI transcriptions were augmented by measurements of F0 and duration at critical regions of each sentence. The means of these measurements are presented, for each experiment to be reported, in Appendix D. The transcription and measurements were used to ensure that all experimental items in each condition clearly fit the intended prosodic contour and boundaries. If measurements revealed any deviations for a particular item, that item was re-recorded and re-analyzed. Thus the example transcriptions can be taken to be representative of all items in each condition, particularly with respect to the realization and type of prosodic boundaries.

**** Figure 1 about here ****

The most informative acoustical measures will be briefly summarized in order to give a fuller picture of how the phonological categories were realized. Major differences between conditions were found on the first noun, men. N1 durations averaged 380-382 ms in conditions (a, c), but 574 ms in condition (d) and 624 ms in condition (b). Condition (d) also had a slight pause following N1, averaging 14 ms, and condition (b) had a larger pause, averaging 93 ms. These durations suggest the presence of prosodic boundaries in conditions (d) and (b). The boundary following the initial NP in (b) was realized with a low F0 averaging 183 Hz rising to a H% of 219 Hz.

The second noun, women, averaged 670-684 ms in duration for conditions (a) and (b), with a following pause of 131-153 ms. Conditions (c) and (d) averaged 612 ms on N2, with a following pause averaging 24-40 ms. All conditions had H* accents on N2, followed in (a-b) by low F0 values averaging 175-179 Hz and continuation rises reaching an F0 average of 214-215 Hz. This set of F0 movements is consistent with IPh boundaries at N2 in conditions (a) and (b). In conditions (c-d), the H* accents were followed by F0 values averaging 202-210 Hz, with no following rise.

Participants and procedures. Forty-eight University of Massachusetts undergraduates, all native speakers of English, were tested individually in an IAC acoustical chamber. They received course credit for their participation. Following a practice list of seven sentences, they heard one version of each of the 18 experimental phrases, embedded in a list of 118 sentences in all (including the various sentences described in Experiment 2 plus 34 ambiguous sentences from other, unrelated experiments). The sentences were played by a computer over loudspeakers to

each participant in an individually-randomized order. Each phrase was preceded by a visually-presented ready signal (terminated when the participant pulled a response trigger) and was followed by a visually-presented question with two response alternatives. The two alternatives allowed the participant to indicate his or her resolution of the ambiguity by pulling a response trigger under one alternative. One choice reflected a high attachment resolution of the ambiguity, in which the PP modified the entire preceding NP (the men and the women had large houses). The other choice reflected a low attachment resolution (only the women had large houses). Participants were instructed to choose the answer that most closely matched his or her intuitive interpretation of the preceding auditory sentence, and although response time as well as the answer chosen were recorded and participants were encouraged to respond intuitively, the instructions contained no requirements for speeded responses.

Counterbalancing procedures were used so that each participant heard three phrases in each of the four conditions tested in the experiment (plus three in the two relative clause conditions described in footnote 3). Over the full experiment, an equal number of participants heard each phrase in each condition.

Results

The mean proportions of choices of the high attachment interpretation appear in Table 1. While the effects of prosody were small, they were significant in some important cases. Analyses of variance permitting generalization to participants (F1) and to items (F2) were conducted. The two factors in these analyses were the size of the final boundary (IPh vs ip) and the presence vs. absence of the initial boundary. Only the effect of the presence vs. absence of the initial boundary was significant (.84 vs .91; $F1(1,47) = 7.53$, $p < .009$; $F2(1,17) = 5.79$, $p < .03$). The contrast

between 0-IPh and IPh-IPh was significant or nearly significant by t-tests (t1(47) = 2.93, p < .05; t2(17) = 2.07, p = .054). The difference between 0-ip and ip-ip was not significant (p > .20).

*** Table 1 about here ***

Discussion

Overall, the presence vs. absence of an early boundary affected the interpretation of the phrase-final modifier. While no effect involving the type of the later boundary (IPh vs ip) was significant, the presence of the early boundary had a significant effect only for phrases with a full IPh boundary before the modifier. We cannot confidently decide on the basis of the present data whether or not the phonological type of the pre-adjunct boundary affected interpretation. However, Carlson et al. (2001) and Schafer (1997) showed that a late ip boundary successfully affected syntactic analysis, and Carlson et al. reported a difference between 0-ip and ip-ip in Experiment 4, suggesting that the marginal effects found for the ip boundary in the present experiment may simply represent a type II error. Apart from this limitation, the general pattern of the results is what was predicted by the informative boundary hypothesis, which proposed that the effect of the boundary immediately before the ambiguously-attached phrase would be determined by its size relative to the earlier boundary.

Our earlier tests of the informative boundary hypothesis (Carlson et al., 2001) used sentences like (1), which had a strong baseline preference for low attachment. The current results show that comparable prosodic effects emerge in phrases like (4), which involve a different ambiguity and a strong high attachment preference. In both sentence or phrase types, the prosodic effects predicted by the informative boundary hypothesis are significant but small in size.

EXPERIMENT 2

The informative boundary hypothesis, presented in (3), is based on tree geometry but does not distinguish among phrases of distinct syntactic categories (PP, DP, CP, etc.) or among constituents with distinct syntactic roles (modifier vs. head, etc.). In Experiment 2, four distinct ambiguities were tested to see whether the informative boundary hypothesis applies across distinct categories and roles. The first ambiguity is illustrated in (5), where three prosodically-different versions of twelve items with two proper names separated by a conjunction were tested:

(5)   Who arrived?

a.   Johnny and Sharon's$_{ip}$ in-laws   [0 ip]

b.   Johnny$_{ip}$ and Sharon's$_{ip}$ in-laws   [ip ip]

c.   Johnny$_{IPh}$ and Sharon's$_{ip}$ in-laws   [IPh ip]

In (5) the head noun "in-laws" may attach low, where it heads the phrase <u>Sharon's in-laws</u>, or high, where it heads the phrase <u>Johnny and Sharon's in-laws</u>. The informative boundary hypothesis predicts the most high attachments in (5a), where the late boundary is informatively larger than the earlier boundary, and the fewest high attachments in (5c), where the early boundary is phonologically larger than the late boundary. The interpretation of phrases like (5) was tested with questions like <u>According to the answer, who arrived? Sharon's and Johnny's in-laws; Sharon's in-laws and Johnny</u>. Choice of the first answer indicates a high attachment interpretation.

12 phrases like (6) were also tested. The first noun in these examples was a relational noun taking an argument introduced by <u>of</u>.

(6)   Who was it?

a.   The daughter of the Pharaoh's$_{ip}$ son   [0 ip]

b.   The daughter$_{ip}$ of the Pharaoh's$_{ip}$ son   [ip ip]

c.   The daughter$_{IPh}$ of the Pharaoh's$_{ip}$ son   [IPh ip]

The head noun "son" is ambiguous. It may attach low, as the head of <u>Pharaoh's son</u>, or high, as the head of <u>the daughter of the Pharaoh's son.</u> The most high attachments should occur in (6a) and the fewest in (6c), according to the informative boundary hypothesis. The interpretation of phrases like (6) was evaluated with questions like <u>How would you describe this individual?</u> <u>There's a daughter of the Pharaoh, and we're talking about her son; There's a Pharaoh's son, and</u> <u>we're talking about his daughter.</u> Choice of the first answer indicates a high attachment resolution of the ambiguity, while choice of the second answer indicates low attachment.

In addition, 12 relative clause attachment sentences like (7) were tested, with three prosodic versions of each.

(7)   a.   I met the daughter of the colonel$_{ip}$ who was on the balcony   [0 ip]

b.   I met the daughter$_{ip}$ of the colonel$_{ip}$ who was on the balcony   [ip ip]

c.   I met the daughter$_{IPh}$ of the colonel$_{ip}$ who was on the balcony   [IPh ip]

The relative clause may attach low, modifying <u>the colonel</u>, or high, modifying <u>the daughter of the</u> <u>colonel</u> (see Cuetos and Mitchell, 1988, Frazier and Clifton, 1996, Hemforth, Konieczny, & Scheepers, 2000, Schafer, Carter, Clifton and Frazier, 1996; and many others for processing of this structure). The informative boundary hypothesis predicts more high attachments in (7a) than (7b) and fewest in (7c). The questions had the form <u>Who was on the balcony? The daughter; The</u> <u>colonel.</u> Choice of the first answer indicated high attachment.

The final structure tested in Experiment 2 is somewhat different in character from those

described above. 12 sentences like (8) were tested, with three versions of each.

> (8) a. My Uncle Abraham recited his poem$_{ip}$ naturally.   [0 ip]
>
> b. My Uncle Abraham$_{ip}$ recited his poem$_{ip}$ naturally.   [ip ip]
>
> c. My Uncle Abraham$_{IPh}$ recited his poem$_{ip}$ naturally.   [IPh ip]

Naturally is ambiguous. If attached low into the VP it is interpreted as a manner adverb. If it is attached high, it is interpreted as a sentence-level evaluative adverb: Of course my Uncle Abraham recited his poem. Early research by Cooper (see Cooper & Paccia-Cooper, 1980) treated this ambiguity as a simple attachment ambiguity and demonstrated greater phrase-final lengthening of poem (the VP final word) when the speaker intended the sentence adverb interpretation. Making up a range of examples of this type was difficult and we remain uncertain about whether these ambiguities involve only an ambiguity of attachment height (see below). In any case, assuming they instantiate a simple attachment height ambiguity, the informative boundary hypothesis predicts more sentence adverb interpretations in (8a) than (8b) and fewest in (8c). The question that followed the sentence was of the form What happened? It was natural that my Uncle Abraham recited his poem; My Uncle Abraham recited his poem in a natural manner. The first answer indicates high attachment of naturally.

Methods

Materials. Twelve phrases or sentences of each type just described (illustrated in (5), (6), (7), and (8)) were constructed. A simple lead-in question was constructed for each of the possessive phrases of (5) and (6). Each phrase or sentence was recorded in three prosodically different versions and digitized and analyzed using the procedures described in Experiment 1. All three versions had an ip boundary before the final ambiguously-attached phrase, and differed in having

only a word boundary (or smaller), an ip boundary, or an IPh boundary at the earlier position. A

two-choice question was constructed for each item. The items appear in Appendix B.

*** Figure 2 about here ***

Pitchtrack plots of typical utterances of the type of sentences in (7), together with ToBI

annotations, appear as Figure 2. The pitch excursions and timing properties of these utterances

were typical of all four types of utterances. As in Experiment 1, measurements of acoustic

parameters were made and used to evaluate whether the utterances were as intended.

In phrases like those in (5), duration of N1 increased from 319 ms to 455 ms to 557 ms in

conditions (a) - (c). A pause, averaging 172 ms, appeared only in condition (c). F0 measurements

indicated an average H* peak on N1 of 214 Hz in (a), with no following fall; a peak of 281 Hz

with a following low averaging 207 Hz for (b); and an F0 peak of 285 Hz, falling to 176 Hz and

then rising to 218 Hz in condition (c). At the second noun, Sharon, the conditions became very

similar. N2 durations averaged 490 and 481 ms for conditions (a) and (c), and a slightly longer

511 ms for condition (b). Following pauses were infrequent and short, averaging between 6 and 8

ms for all three conditions. F0 values on N2 first rose to a H* averaging between 264 and 280 Hz

for the three conditions, and then fell to a L- averaging between 197 and 205 Hz.

Turning to phrases like those in (6), the duration of the first noun of the phrase ranged

from 363 ms to 456 ms to 612 ms in (a) - (c), with an average pause of 94 ms following the noun

in (c). F0 values on N1 averaged 211 Hz in condition (a), 254 Hz with a fall to 200 Hz in (b), and

264 Hz with a fall to 171 Hz and a continuation rise to 208 Hz in (c). Following N1, the

conditions were very much alike, and were suggestive of an ip boundary following the second

noun, Pharaoh.

The analysis of sentences like those in (7) indicated that the duration of the first relevant noun, <u>daughter</u>, ranged from an average of 354 ms to 483 ms to 568 ms in conditions (a) - (c), with a following pause of 153 ms in (c). F0 peak values averaged 212 Hz in (a), 242 Hz followed by a L- of 194 Hz in (b), and 260 Hz followed by a low of 170 Hz and a continuation rise to 203 Hz in (c). The extra duration and pausing in condition (c) suggest an IPh boundary, as does the continuation rise, contrasting with the ip boundary of (b). The rest of the sentence was quite similar in the different conditions.

Finally, in sentences like (8), the duration of the main accented noun within the noun phrase (<u>Abraham</u>, in this example) averaged 390 ms in (a), 512 ms in (b), and 571 ms in (c). F0 measurements showed a rise to 212 Hz in (a), 243 Hz in (b) followed by a fall to 195 Hz, and a peak of 261 Hz followed by a fall to 160 Hz and a rise to 205 Hz in (c). Within the VP, all conditions were very similar. On the final adverb, F0s were deliberately kept low and fairly even, with very little final lowering. Average F0s on the adverb began at 184-189 Hz and fell to 178-181 Hz.

<u>Participants and procedures</u>. Experiment 2 was run concurrently with Experiment 1, so the same participants and procedures were used.

Results

Figure 3 presents the mean proportions of high attachment choices for each of the four types of phrases or sentences. Analyses of variance were conducted separately on the data for each type of item, followed up by t-tests comparing individual means. The difference among the means of the three prosodic versions of the <u>inlaws</u> phrases (like (5)) was highly significant ($F1(2, 94) = 22.38$, $p < .001$; $F2(2,22) = 38.99$, $p < .001$). Each mean differed from each other mean by

simple t-tests ($p < .01$ in each case).

<div align="center">*** Figure 3 about here ***</div>

The difference among the means of the <u>Pharaoh's son</u> phrases (6) was also significant ($F1(2, 94) = 5.15$, $p < .01$; $F2(2, 22) = 7.43$, $p <. 01$). Simple t-tests indicated that the difference between the 0-ip and the IPh-ip means was significant ($p < .01$) but the other comparisons did not reach an acceptable level of significance (p always $> .07$).

The difference among the means of the <u>daughter of the colonel</u> sentences (7) was significant as well ($F1(2, 94) = 6.30$, $p < .01$; $F2(2, 22) = 3.62$, $p < .05$. However, once again, simple t-tests indicated that only the largest difference (between 0-ip and IPh-ip) was significant ($p < .05$). The other differences all had $p > .06$.

The prosody of the <u>naturally</u> sentences (like (8)) did not significantly affect their interpretation ($F < 1$). The means of the three prosodic conditions differed only very slightly, as can be seen in Figure 3.

Pooling the data from the first three types of items ((5), (6), and (7)) resulted in significant effects of prosodic structure ($F1(2, 94) = 28.63$, $p < .001$; $F2(2, 66) = 32.45$, $p < .001$), item type ($F1(2, 94) = 24.69$, $p < .001$; $F2(2, 33) = 12.98$, $p < .001$), and the interaction between the two factors ($F1(4, 94) = 2.53$, $p < .05$; $F2(4, 66) = 2.62$, $p < .05$). Simple t-tests indicated that the mean of each prosodic condition differed significantly from the mean of each other prosodic condition (p always $< .001$).

Discussion

The results of Experiment 2 straightforwardly confirm the predictions of the informative boundary hypothesis in the head-ambiguities (5) and (6) and the RC ambiguity in (7). There were

consistently more high attachments of the final phrase when the preceding prosodic boundary

was larger than the earlier boundary than when it was smaller.

There are interesting but not fully interpretable differences among the sentence types in

the size of the effect of prosody. One possibility that has been suggested (Carlson et al., 2001;

Fodor, 1998) is that a relatively large prosodic boundary is more likely to be associated with a

major syntactic boundary when it precedes a syntactically simple ('light') ambiguously-attached

phrase than when it precedes a syntactically heavy one (the weight of the phrase itself could

motivate a prosodic boundary). In fact, the largest effect of the prosodic manipulation was

observed for a nonclausal ambiguity (33% for Johnny and Sharon's in-laws in (5)). However, the

syntactically heavy relative clause attachment ambiguities like (7) showed as large an effect

(16%) as the syntactically light nonclausal structure of (6), the daughter of the Pharaoh's son

(15% maximal difference due to the prosodic manipulation). One possible generalization is that

the largest prosodic effects are obtained for the items with the weakest attachment bias. Whether

this is an accident or whether it holds generally will take further research to determine.

The naturally ambiguities (8) fail to confirm the predictions of the informative boundary

hypothesis. We suggest that sentence adverbs exhibit numerous special properties. Intonationally,

they pattern with parentheticals in tending to be separate intonation units, regardless of their

placement at the edge of a sentence or within a sentence, as in (9) (Cruttenden, 1997, pp. 69-71).

(9)   John, naturally, went to Harvard.

They make independent contributions to discourse, since the truth of the main assertion is

independent of the truth of these constituents. They may even be attached into the syntactic

representation on a separate dimension, capturing their failure to interact with other constituents

(see Emonds, 1973, for discussion of the syntax of parentheticals). Thus we propose that sentence-level adverbs should be grouped with parentheticals, rather than with the other structures tested here, in their processing as well.

EXPERIMENT 3

The final experiment tested a prediction of our statement of the informative boundary hypothesis, namely, that prosodic boundaries preceding a constituent dominating both attachment sites are "irrelevant." Eighteen triples of sentences like those illustrated in (10) were constructed.

(10) a. Susie learned that Bill called$_{IPh}$ on Monday   [0 0 IPh]

   b. Susie learned$_{IPh}$ that Bill called$_{IPh}$ on Monday   [0 IPh IPh]

   c. Susie$_{IPh}$ learned that Bill called on Monday   [IPh 0 IPh]

These sentences are similar to those tested in our prior work (Carlson et al., 2001; see (1)) in that a final adverbial adjunct may attach into the immediately preceding clause or into a higher clause. Assuming that <u>on Monday</u> may attach to either the lower VP <u>called</u>, termed B in (3)), or to the higher VP <u>learned...</u> (termed A in (3)), the informative boundary hypothesis predicts that the boundary before the adjunct <u>on Monday</u> will be compared to any boundary preceding a constituent that dominates the lower VP which does not also dominate the high attachment site. This includes any boundary before the lower VP, the lower IP, or the entire complement clause CP. In (10b), with an IPh boundary preceding the complement clause, fewer high attachments should occur than in (10a), where no boundary precedes the complement clause.

What is of most interest is what happens in (10c). Here there is an 'early' IPh prosodic boundary, but that boundary precedes the higher VP, a constituent that contains the high attachment site. Thus the 'early' boundary in (10c) should be irrelevant. Put differently, the

"relevant" pre-B boundary in (10b) marks the left edge of a constituent that contains the low attachment site, but not the high attachment site, whereas the "irrelevant" early boundary in (10c) marks the left edge of a constituent that contains both the high and the low attachment site. According to the statement in (3), the late boundary immediately before the ambiguously-attached adjunct is informative if it is smaller or larger than the pre-B boundary. But (3) says nothing about the relative size of the late boundary and boundaries at other positions in the sentence. Consequently, (3) predicts that (c) should behave like (a), as if the late boundary is large compared to relevant earlier boundaries, and not like (b), where the late boundary is uninformative.

Method

Materials. We constructed 18 sentences like those in (10), in three versions each (see Appendix C for a list of all the sentences). The same linguist who recorded the sentences in Experiments 1 and 2 recorded these sentences together with 46 filler items. In each experimental utterance, the only prosodic breaks higher than a word-level break are those indicated in the ToBI analyses shown in (10). Figure 4 presents a typical set of F0 plots with ToBI transcriptions. Duration and F0 measurements were made, as in Experiments 1 and 2. The first noun, Susie, averaged 318, 343 and 566 ms in conditions (a) - (c), with a following pause averaging 186 ms in condition (c). F0 peaks averaged 217 Hz in (a) and 295 Hz in (b) and (c), with a fall to a L- value of 173 Hz followed by a continuation rise reaching an average F0 of 215 Hz in (c). These measurements are most consistent with an IPh boundary at N1 in condition (c), but no boundary in conditions (a) or (b).

V1, learned, averaged 367 and 384 ms for conditions (a) and (c), but 564 ms plus a

following break of 190 ms for condition (b). F0 measurements showed a general rising of pitch through the verb in condition (a), which averaged 223 Hz; some sentences had a prominence, analyzed as a H* accent, on V1. In condition (c), V1 was the first word in a new phrase, following the IPh boundary on N1. F0 averaged 207 Hz on V1 in this condition. In condition (b), a L- value averaging 173 Hz was reached, followed by a continuation rise averaging 221 Hz, consistent with an IPh boundary on V1.

All conditions had similar realizations from N2 to the end, with evidence of an IPh boundary at the end of V2. Within the final adverbial phrase, high F0 values were reached, averaging between 257 and 262 Hz. The final lowering that followed averaged 161 or 162 Hz. <u>Participants and procedures.</u> After listening to a seven-item practice list, forty-eight University of Massachusetts undergraduates listened to the 18 sentences described above together with 46 filler items from three other unrelated experiments. Sixteen participants were assigned to each of three counterbalanced lists, each containing six experimental items in each of the prosodic conditions listed in (10). One list was played via loudspeakers to a participant in a sound-deadened chamber. Each participant received his or her list in an individually-randomized order. As in Experiments 1 and 2, each sentence was followed by a presentation of a question plus two choices on a video terminal. The two choices reflected the two possible interpretations of the sentence (e.g., for the sentence in (10), the question and answers were <u>What happened on Monday? Susie learned something; Bill called.</u>) The participant indicated his or her understanding of the sentence by pulling a trigger under the appropriate answer, just as in Experiments 1 and 2.

Results

The mean proportions of high attachment choices for the three prosodic conditions are

indicated in Table 2. The difference among the three means was significant ($F_1(2, 94) = 9.79$, $p <$ .001; $F_2(2, 34) = 7.69$, $p < .002$). The difference between the 0-IPh-IPh condition (B) and each of the other two conditions was also significant ($t_1(47) = 3.64$, $p < .002$, and $t_2(17) = 3.58$, $p < .002$, for the 0-0-IPh condition (A); $t_1(47) = 4.25$, $p < .001$, and $t_2(17) = 4.40$, $p < .001$ for the IPh-0-IPH condition). These results are precisely those predicted by the informative boundary hypothesis in (3). The only early boundary that impacts the effectiveness of the late, pre-adjunct, boundary is one that divides the two constituents into which the adjunct could be attached.

<div align="center">*** Table 2 about here ***</div>

GENERAL DISCUSSION

The main finding of the three experiments is clear. An optional prosodic boundary immediately before an ambiguous constituent is interpreted relative to any boundary before a constituent that contains only the lower but not the higher potential attachment site. Any boundary before the higher potential attachment site for the ambiguous item does not influence the interpretation of the late boundary. In other words, what's informative about prosodic constituents is what they imply about syntactic tree structure, at least in cases where the ambiguous item differs only in its attachment site (vs. adverb ambiguities which may involve more than a simple attachment ambiguity). All experiments presented here are consistent with this conclusion, and Experiment 3 provides the most direct support of the informative boundary hypothesis with respect to which earlier prosodic boundaries are relevant.

How do these results jibe with earlier research interpreted in terms of local boundaries (e.g., Price et al., 1991)? In early studies the exact prosodic structures tested is often unclear. The apparent effectiveness in much prior work of a strictly local prosodic boundary might simply

indicate that the local prosodic boundary tested in these studies was not preceded by a relatively

large relevant early boundary. In other words, a condition presented as a local [IPh] boundary

may better be analyzed (in retrospect) as [0, IPh], using the notation adopted in the present paper.

The results of the present studies raise many issues. One is what determines the size of

the prosodic effect observed. In Experiment 1, the largest difference between prosodic conditions

(the prosodic "swing") was rather small (9%). Perhaps a ceiling effect is at play given the very

high level (82%) of high attachments. In Experiment 2, examples like (5) Johnny and Sharon's

in-laws showed the largest difference among prosodic conditions (33%). One might suspect that

prosody is most effective in these examples because the ambiguous constituent in-laws is the

head of the phrase, not phrasal and not an adjunct. However, this account is not really supported

by the other data in Experiment 2. In particular, examples like (6) the daughter of the Pharaoh's

son also involve an ambiguous constituent which is a head, son. Nevertheless, the examples in

(6) only show at most a 15% swing between the extreme low and extreme high condition. This is

no larger than the difference for (7) the daughter of the colonel who was on the balcony where

the ambiguous constituent is a clausal adjunct. Thus, the variation in the size of the prosodic

effect in (5-7) does not support in any straightforward way the obvious hypotheses that breaks

before long or clausal constituents should have the weakest effects (being possible reflexes of the

long upcoming constituent; see Footnote 3) or that breaks before nonphrasal or head constituents

should be strongest, resulting in the largest prosodic swing.

Before turning to Experiment 3, we wish to address the issue of why so many high

attachment responses are observed in the "prosodically uninformative" condition of several of the

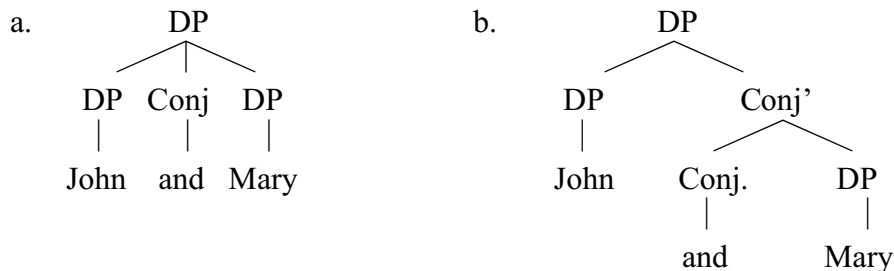phrase types investigated in Experiments 1 and 2. It is well-known that the human sentence

parser generally exhibits a preference for low attachment (Kimball, 1973, Frazier, 1978, Gibson, Pearlmutter, Canseco-Gonzalez, & Hickok, 1996, for example). So it is interesting that Experiment 1 shows over 85% high attachment in the [ip ip] condition, for example. We think that there exists a strong preference for parallel analyses of ambiguous conjunction structures (see Carlson, 2001; Frazier et al., 1984, 2000; Henstra, 1996). In Experiment 1, this surfaces as a preference for high attachment of the PP. Under this interpretation two relatively simple NPs are conjoined, while under a low attachment interpretation, one conjunct (the one with the attached PP) is substantially more complex than the other. The parallelism preference also explains the level of high attachment (69%) in the [ip ip] condition of (5) Johnny and Sharon's in-laws.

In examples without conjunction, (7) and (8), roughly a third of the responses were high attachment in the [ip ip] condition – a figure in line with many written studies of attachment ambiguities.[5] This is interesting because it suggests that auditory sentence processing and visual sentence processing show similar preferences in cases where the sentences are ambiguous in the modality in which they are presented.

The results reported in this paper also provide another source of evidence about the correct constituent structures of the constructions tested. For example, given the 'symmetric' view of conjunction in (11a), the schema in (3) incorrectly predicts that a pre- and boundary will be irrelevant to the interpretation of a boundary between Mary and a following phrase. In (11a) there is no constituent beginning with and that contains the low attachment site but not the high attachment site. A boundary before and therefore does not precede a constituent into which the following phrase could be attached, and so it is not relevant to interpreting the boundary before

the following phrase.

(11)

```
    a.          DP                  b.           DP
            /   |   \                          /      \
         DP  Conj  DP                       DP         Conj'
          |    |    |                        |        /     \
        John  and  Mary                    John    Conj.     DP
                                             |        |       |
                                            and     Mary
```

However, given a structure like (11b), there is a constituent beginning with and and containing

the low but not the high attachment site, namely Conj'. The pre-and boundary should therefore be

relevant, as it was in Experiment 1 and in examples like (5). Thus the present results favor

structure (11b) over (11a) as the correct structure for conjunction, as argued originally by Ross

(1967) and more recently by Munn (1993).

In the phonological literature on syntax-prosody mapping, two distinct kinds of

approaches can be discerned. One (Truckenbrodt, 1995, 1999; Selkirk, 1997) treats prosodic

boundaries as phonological edge-alignment constraints. For English, prosodic alignment is

claimed to be right-edged, or "end-based." Phonological theory specifies the conditions for

placing a prosodic boundary at the end of a syntactic constituent; a listener obeying a grammar of

this sort will use the presence of a prosodic boundary to constrain assumptions about the ends of

syntactic constituents. An alternative view, recently articulated by Truckenbrodt (2001; cf. also

Hayes & Lahiri, 1991) treats prosodic constituency in terms more similar to syntactic

constituency.   Prosodic constituency reflects syntactic constituency, when possible. Limits on a

transparent one-to-one mapping of syntax and prosody arise because prosodic structure, unlike

syntactic structure, is not recursive and thus the two types of structure often cannot coincide

completely. Certain length and focus constraints on prosodic constituency may also render the

prosody-syntax mapping less transparent than a one-to-one mapping. Presumably, a listener using

a grammar of this sort must determine what the prosodic constituency of a sentence implies about

its syntactic description.

The basic generalization established here, that a local prosodic boundary is informative

with respect to the presence and size of prosodic boundaries at other positions determined by tree

geometry, is puzzling under an edge-alignment or end-based view. For example, consider a

prosodic boundary between the matrix verb and complementizer in (1), repeated as (12).

(12)   Susie learned$_\uparrow$ that Bill telephoned$_\uparrow$ after John visited.

The stretch of sentence that ends at the early prosodic boundary is the matrix subject plus

verb, regardless of the presence of a following prosodic boundary. Or consider (13).

(13)   Johnny$_\uparrow$ and Sharon's$_\uparrow$ in-laws

The constituent that ends at the early prosodic boundary is a DP independent of the attachment of

later material. It is not obvious why the early boundary in either (12) or (13) should influence

attachment of material later in the sentence. If one wanted to maintain an end-based approach,

one might try to argue that an 'overly large' prosodic boundary at some early point must be

rationalized by what happens later in the sentence. But this proposal assumes that a prosodic

boundary can be identified locally as being 'overly large' in an absolute sense. This assumption is

very problematic, given the considerable variability within and across individuals in how they

prosodically realize sentences (see, e.g., Schafer et al., 2000).

On the other hand, the observation that the effect of a prosodic boundary depends on its

size relative to other relevant prosodic boundaries is exactly what one would expect on the more

syntactic view of prosodic constituency proposed by Truckenbrodt (2001) and Hayes and Lahiri (1991). The processor could identify a prosodic constituent on the basis of the relative size of the boundaries at its start and end, and take the resulting constituency to constrain syntactic constituency. Our results thus favor an approach where prosodic structure involves real constituency (units in a part-whole structure), not linear stretches of speech preceding a prosodic boundary.

At present, it is unclear whether the informative prosodic boundary effects established here occur early in processing, influencing the initial parse of constituents, or later in some post-sentence interpretive judgment process. If the effects do occur early, the question arises as to how the parser keeps track of relevant prosodic boundaries. In general, we have advocated a "no book-keeping" approach to sentence processing (see in particular Frazier, 1990). If the processor needed to tag each syntactic boundary with a prosodic boundary annotation, compute all possible attachment sites for a new syntactic constituent, and then identify relevant early boundary positions and compare the size of all relevant early boundaries to whatever late boundary preceded an ambiguous constituent, the computational cost of implementing the informative boundary hypothesis would be substantial. But this is not the process we envision. An alternative is a sausage machine (Frazier & Fodor, 1978) sort of parser which establishes 'sausages' (packages) based on prosodic information when possible, and on other considerations such as length when necessary. Imagine that this general sort of parser systematically begins a new package when it receives a prosodic boundary larger than any prosodic boundary at the beginning of the current package, and systematically doesn't begin a new package where no prosodic boundary occurs or only a smaller boundary does, as illustrated in (14).[6]

(14)   Susie learned↑ that Bill telephoned↑ after dinner.

a.   IPh   0, ip   [no new package started at late boundary]

b.   0   ip, IPh [new package started at late boundary]

c.   ip   IPh   [new package started at late boundary]

In the case of prosodic boundaries of equal size, presumably the parser's decision about whether to start a new package would be based on other grounds, not prosodic boundary size.

Given this packaging routine, we need only assume, as Schafer (1997) does, that attachments within a package are more readily available than attachments outside the current package. If no attachment site for the new constituent is available within the current package, then it is reasonable to suppose that high attachments outside the current package might be accessible due to tree geometry, and possibly to the lack of 'pull' from the low attachment site and the greater opportunity for interpretive principles to come into play later in processing. Consider now the situation where an early prosodic boundary is irrelevant, i.e., it precedes a constituent that contains both the high and low attachment sites, as in (15).

(15)   Susie↑ learned that Bill telephoned↑ after dinner.

                IPh   0, ip

Favoring an attachment within the current package will no longer uniquely favor low attachment. By definition, both attachment sites will now be present in the current package and consequently prosodic factors will no longer favor low attachment (though other principles might do so). No complex computation is needed: the relevance of 'relevant' early prosodic boundary positions will fall out automatically. As for the issue of keeping track of prosodic boundary sizes and positions, this too will be automatic on the assumption that what the parser parses is a

phonologically, and thus prosodically, structured input. In short, if the effects established in the

current experiments are early on-line parsing effects, implementing the informative boundary

proposal need not impose any substantial computational burden on the processor.

Author Note

Footnotes

1. We assume that function words preceding B cliticize onto the following phonological word in English. Thus the pre-B boundary may include one item to the left if that item is cliticized to the first word of B.

2. Following Munn (1993), we assume the structures in (i) and (ii), for low and high attachment of the PP respectively.
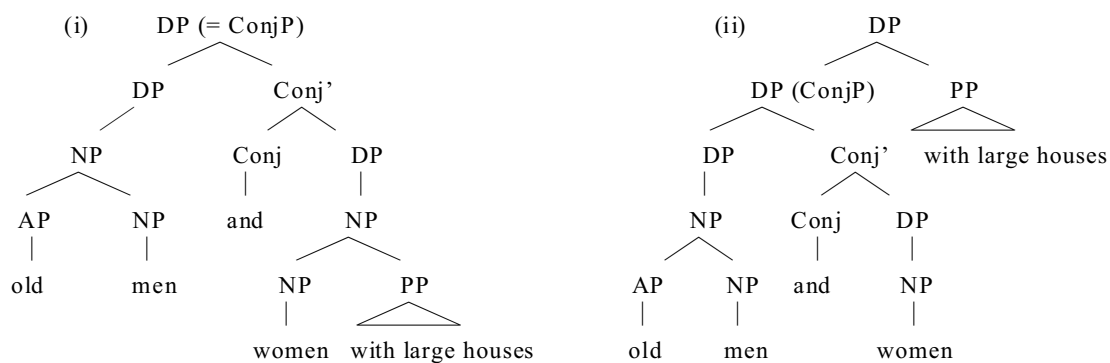
3. We included a third pair of sentences, like (4a, b) but with a final relative clause rather than a prepositional phrase. Our goal was to test the balanced sister hypothesis of Fodor (1998) and to examine the effect of syntactic "weight" in ambiguity resolution. However, the manipulation was

ineffective, yielding data very similar to those obtained with prepositional phrases, so we will not

report it here.

4. We did not analyze breaks at or below the word level, but concentrated on breaks accompanied

by the tonal changes expected for ip and IPh boundaries. There may be some variability in the

connectedness of speech at non-boundary positions, but we felt that this was unlikely to affect the

interpretation of the experimental sentences.

5. We suspect that the presence of a question preceding the examples like (5) and (6) might also

favor high attachments. But further work is needed to test this suspicion.

6. We speak of "packages" rather than "constituents" because in some cases speakers group

together in a prosodic phrase items that do not form a syntactic constituents, e.g., Subject + Verb.

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APPENDICES

Appendix A: Materials used in Experiment 1

1. Who came out ahead? Old men and women with very large houses.

2. Who benefits? Poor girls and boys with sports abilities.

3. Who would wear this? Tall girls and women with very long legs.

4. Who goes there? Privileged Americans and foreign tourists with lots of spare cash.

5. Who applies? Brilliant students and professionals with extensive computer training.

6. Who is the program designed for? New teachers and administrators with lots of promise.

7. Who is eligible? Biological scientists and assistants with lots of lab experience.

8. Who got awards? Famous artists and scholars with a national reputation.

9. Who quit? Passive players and participants with no prior experience.

10. Who was discussed? Seattle protesters and sympathizers with progressive views.

11. Who participated? Professional dancers and skaters with national awards.

12. Who is the class for? Young girls and boys with an interest in crafts.

13. Who suffers most from the policy? American farmers and workers with no health benefits.

14. Who was satirized? Arrogant hairdressers and stylists with an attitude.

15. Who influences food critics? Professional chefs and wine tasters with their own TV shows.

16. Who will perform? Talented teenagers and college students with an interest in acting.

17. Who would the program help? Impoverished students and artists with no visible income.

18. Who was affected most? Cold-war agents and spies with military records.

Appendix B: Materials used in Experiment 2

Set 1

1. Who arrived? Johnny and Sharon's in-laws

2. Who left? Lucy and Jason's friend

3. Who's here? Karen and Ralph's daughter

4. Who called? Sarah and Kevin's partner

5. Who showed up? David and Barbara's visitor

6. Who helped? Richard and Emily's assistant

7. Who was worried? Andrew and Maria's mother

8. Who got into trouble? Pablo and Anna's brother

9. Who quit? Matthew and Paula's secretary

10. Who was at the bar? Nicole and Steven's boss

11. Who sang at the party? Timothy and Ramona's guest

12. Who's coming for the holiday? Alice and Michael's uncle

Set 2

1. Who was it? The daughter of the pharaoh's son

2. Who was it? The friend of the boss's daughter

3. Who was it? The guest of the owner's friend

4. Who was it? The ex-husband of the victim's wife

5. Who was it? The fiancee of my friend's father

6. Who was it? The secretary of the CEO's assistant

7. Who was it? The girlfriend of the cook's brother

8. Who was it? The daughter of the chauffeur's lover

9. Who was it? The mother of the carpenter's helper

10. Who was it? The wife of the postman's colleague

11. Who was it? The enemy of the hit-man's assistant

12. Who was it? The opponent of the winner's tutor

Set 3.

1. I met the daughter of the colonel who was on the balcony

2. Sally described the pastor of the politician who was on the talk show

3. Joe recognized the maid of the widow who was very happy

4. Tim liked the driver of the executive who would be promoted

5. Terry talked with the lab partner of the student who was so lazy

6. Kevin called the agent of the singer who was very popular

7. The judge scowled at the lawyer of the comedian who was highly controversial

8. Pam ran into the killer of the journalist who received lots of attention

9. We all wondered about the secret admirer of the dancer who was painfully shy

10. We envied the patron of the chef who was so famous

11. The reporter described the wife of the scientist who opened a letter bomb

12. Lisa needs to speak with the supervisor of the student who was out of town

Set 4

1. My uncle Abraham recited his poem naturally.

2. Annie drew up a plan stupidly.

3. Sam's friend wrote the proposal cleverly.

4. Ernie's girlfriend left the room rudely.

5. Sam's mother entertained his friends foolishly.

6. The biologist left the table oddly.

7. Aunt Fran talked to the kids thoughtfully.

8. Pam spoke to the widow diplomatically..

9. My sister called home hopefully.

10. Tony's assistant left during the argument politely.

11. David's friend corrected the guest considerately.

12. Jeff locked the door carefully

Appendix C. Materials used in Experiment 3

1. Sammy learned that Bill called on Monday

2. Sally discovered Pat telephoned on Friday.

3. Brian announced Tim won a prize on Friday.

4. Sandra claimed Sam would leave on Monday.

5. Patricia found out Laurence had disappeared on Tuesday.

6. Linda testified that the boss hid the evidence in June.

7. Emmon reported Sam had arrived today.

8. Thomas discovered that Bill was sick yesterday.

9. Felix found out the mayor received a bribe yesterday.

10. Lucy announced Mark had resigned yesterday.

11. Melinda claimed the chairman lied today.

12. Carol complained that the baby was cranky yesterday.

13. Clinton admitted that his aide broke the rules last week.

14. Anna learned Patty was fired last week.

15. Martin insisted the lawyer evaded the issue this morning.

16. Alicia revealed that Terrence lost the files last Sunday.

17. Rodney complained that the bookkeeper cheated last year.

18. Jason assumed Tom went skiing last week.

Appendix D: Acoustic Measurements

Table D1. Means (and SDs) of durations, ms, Experiment 1

Condition	Adj1	N1	break	N2	break
a: 0 IPh	326 (117)	380 (117)	0	670 (153)	153 (31)
b: IPh IPh	326 (113)	624 (106)	93 (67)	684 (138)	131 (56)
c: 0 ip	314 (109)	382 (115)	0	612 (124)	24 (22)
d: ip ip	332 (108)	574 (97)	14 (38)	612 (132)	40 (28)

Table D2. Means (and SDs) of F0, Hz, Experiment 1

Condition	N1	N1		N2	N2		N3	Final
	H*	L-	H%	H*	L-	H%	H*	L-L%
a: 0 IPh	224 (7)			301 (9)	175 (6)	215 (6)	256 (10)	168 (8)
b: IPh IPh	299 (8)	183 (7)	219 (7)	293 (10)	179 (6)	214 (6)	250 (11)	169 (6)
c: 0 ip	214 (6)			280 (14)	210 (9)		239 (9)	167 (7)
d: ip ip	276 (11)	205 (7)		271 (13)	202 (6)		238 (8)	170 (5)

Table D3. Means (and SDs) of durations, ms, Experiment 2.

Set 1	N1	break	N2	break
in-laws				
a: 0 ip	319 (54)	0	490 (53)	8 (14)
b: ip ip	455 (56)	0	511 (64)	6 (14)
c: IPh ip	557 (54)	172 (35)	481 (46)	6 (13)

Set 2	N1	break	N2	break
pharaoh				
a: 0 ip	363 (104)	0	539 (90)	7 (17)
b: ip ip	456 (90)	0	540 (83)	4 (13)
c: IPh ip	612 (104)	94 (80)	531 (95)	4 (14)

Set 3	N1	break	N2	break
colonel				
a: 0 ip	354 (132)	0	588 (107)	23 (36)
b: ip ip	483 (101)	0	560 (116)	5 (13)
c: IPh ip	568 (94)	153 (53)	553 (109)	16 (25)

Set 4	N1	break	N2	break	Adv
naturally					
a: 0 ip	390 (143)	0	424 (62)	60 (41)	627 (85)
b: ip ip	512 (125)	8 (21)	410 (62)	45 (47)	617 (83)
c: IPh ip	571 (131)	134 (72)	416 (62)	71 (53)	608 (67)

Table D4. Means (and SDs) of F0 values, Hz, Experiment 2

Expt 2	N1	N1		N2	N2	N3	Final
Johnny	H*	L-	H%	H*	L-	H*	L-L%
a: 0 ip	214 (10)			280 (12)	205 (8)	250 (7)	170 (4)
b: ip ip	281 (12)	207 (7)		267 (13)	201 (8)	251 (10)	173 (6)
c: IPh ip	285 (11)	176 (6)	218 (7)	264 (11)	197 (7)	248 (8)	169 (7)
pharaoh							
a: 0 ip	211 (8)			255 (13)	198 (9)	241 (12)	171 (4)
b: ip ip	254 (9)	200 (6)		249 (13)	195 (11)	238 (11)	172 (5)
c: IPh ip	264 (12)	171 (5)	208 (6)	243 (14)	189 (6)	232 (26)	169 (5)
colonel							
a: 0 ip	212 (7)			250 (11)	196 (10)	226 (8)	166 (5)
b: ip ip	242 (8)	194 (6)		242 (8)	190 (5)	223 (8)	167 (5)
c: IPh ip	260 (17)	170 (3)	203 (7)	244 (8)	187 (6)	220 (6)	165 (6)

naturally	N1			V1	N2	Adv	Final
				H*	L-	L*	L-L% or L-
a: 0 ip	212 (6)			252 (9)	181 (4)	189 (4)	181 (4)
b: ip ip	243 (9)	195 (6)		243 (5)	178 (5)	184 (4)	180 (5)
c: IPh ip	261 (11)	169 (4)	205 (7)	245 (8)	175 (3)	184 (7)	178 (3)

Table D5. Means (and SDs) of durations, ms, Experiment 3

Inffol Sue	N1	break	V1	break	V2	break
a: 0 0 IPh	318 (59)		367 (81)		532 (81)	223 (55)
b: 0 IPh IPh	343 (45)		564 (79)	190 (50)	541 (84)	219 (55)
c: IPh 0 IPh	566 (56)	186 (45)	384 (74)		535 (80)	225 (53)

Table D6. Means (and SDs) of F0 values, Hz, Experiment 3

Inffol Sue	N1	N1		V1		V2		Final
	H*	L-	H%	L-	H%	L-	H%	L-L%
a: 0 0 IPh	217 (12)					170 (5)	218 (7)	161 (6)
b: 0 IPh IPh	295 (9)			173 (4)	221 (7)	171 (4)	217 (7)	162 (6)
c: IPh 0 IPh	295 (8)	173 (6)	215 (7)			170 (5)	214 (10)	161 (7)

Table 1: Proportion of high attachment choices (with SDs by participants and then by items),

Experiment 1

	Prosodic Condition		
0-IP	IPh-IPh	0-ip	ip-ip
.91	.82	.91	.86
(.22, .11)	(.24,.14)	(.22, .08)	(.25, .14)

Table 2. Proportion of high attachment choices (with SDs by participants and then by items),

Experiment 3

	Prosody	
0-0-IPh	0-IPh-IPh	IPh-0-IPh
.29	.17	.33
(.26, .13)	(.21, .13)	(.29, .17)

Figure Captions

Figure 1. Plots of F0 for illustrative item, Experiment 1. Panel 1: 0 IPh; Panel 2: IPh IPh; Panel 3: 0 ip; Panel 4: ip ip

Figure 2. Plots of F0 for illustrative item, first subexperiment of Experiment 2. Panel 1: 0 ip; Panel 2: ip ip; Panel 3: IPh ip

Figure 3: Proportion of high attachment choices, Experiment 2. Set 1: Items like "Johnny and Sharon's inlaws." Set 2: Items like "daughter of the Pharaoh's son." Set 3: Items like "daughter of the colonel." Set 4: Items like "gave his talk naturally."

Figure 4: Plots of F0 for illustrative item, Experiment 3. Panel 1: 0 0 IPh. Panel 2: 0 IPh IPh. Panel 3: IPh 0 IPh.