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Intonational Disambiguation in Sentence Production and Comprehension

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Speakers' prosodic marking of syntactic constituency is often measured in sentence reading tasks that lack realistic situational constraints on speaking. Results from such studies can be criticized because the pragmatic goals of readers differ dramatically from those of speakers in typical conversation. On the other hand, recordings of unscripted speech do not readily yield the carefully controlled contrasts required for many research purposes. Our research employs a cooperative game task, in which two speakers use utterances from a predetermined set to negotiate moves around gameboards. Results from a set of early versus late closure ambiguities suggest that speakers signal this syntactic difference with prosody even when the utterance context fully disambiguates the structure. Phonetic and phonological analyses show reliable prosodic disambiguation in speakers' productions; results of a comprehension task indicate that listeners can successfully use prosodic cues to categorize syntactically ambiguous fragments as portions of early or late closure utterances.

INTRODUCTION

A wide range of sentence comprehension studies have now shown that prosody can disambiguate syntactic structure. However, these studies have relied largely on materials pronounced by trained speakers who intend to provide a disambiguating contour. The relevance of such materials has been

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questioned in the comprehension literature (Watt & Murray, 1996), and also in recent production studies. These suggest that the utterances used are atypical (Albritton, McKoon, & Ratcliff, 1996), since speakers are far more likely to use prosody to disambiguate syntax when explicitly instructed to do so, or when the sentence is not disambiguated by the preceding context (Straub, 1997). Such arguments echo earlier work on the relationship between syntactic structure and speech features (Cooper & Paccia-Cooper, 1980). However, these production studies may also involve atypical utterances. They have relied on oral reading tasks, which lack realistic situational constraints on speaking. Because the pragmatic goals of a reader differ dramatically from those of speakers in typical conversation, production results from reading tasks may not accurately reflect the prosody of natural conversation and thus may misrepresent the degree of prosodic disambiguation found in everyday speech.

On the other hand, recordings of natural conversation do not readily yield a sufficiently rich sample of the carefully controlled contrasts required for many research purposes. In between these two types of study—sentence lists and unscripted speech—sits research that attempts to constrain the range of likely utterance types by involving speakers in some kind of role play. For instance, map tasks (Anderson *et al.*, 1991), in which speakers have to give directions from one point on a map to another, have proved useful in eliciting such contrasts as that between given and new information; picture description tasks have revealed much about the the generation of syntactic and thematic structure (Bock & Loebell, 1990); and descriptions of networks of colored nodes have supplied a wealth of data on aspects of the planning, sequencing, and repair of utterances (Levelt & Cutler, 1983). Yet these tasks are not designed for the study of syntactic ambiguities and they cannot provide a large enough set of contrasting structures. In order to produce such contrasts, our research employs a cooperative game task, in which two speakers use utterances from a predetermined set to negotiate moves around gameboards. This set of utterances is designed to include a number of syntactic ambiguities commonly included in comprehension research. Our expectation is that sufficient practice with this set will ensure that speakers use these utterances fluently and without the need to read them from a list, thus providing a rich source of data for the study of syntactic ambiguity resolution in speech.

In this paper, we focus on just one ambiguity from our set, the early versus late closure ambiguity illustrated in (1). Here, (1a) is an early closure sentence where the verb *moves* is intransitive and the noun phrase *the square* is the subject of the second clause, while (1b) is a late closure sentence where the noun phrase *the square* is the direct object of the verb *moves*. We report first on a set of production results from our game task. We then present results from a comprehension task, in which we presented the ambiguous portion of the utterances collected in our production task to listeners and had them match each fragment to an early or late closure continuation. The results show that naive speakers can reliably disambiguate this type of syntactic ambiguity, even when the syntactic structure has already been fully disambiguated by the discourse context, and that naive listeners are sensitive to the prosodic disambiguation provided by naive speakers.

(1) a. When that moves the square will . . .
b. When that moves the square it . . .

We will also consider the manner in which our speakers disambiguated the syntactic structure. We will suggest that while some form of disambiguation was quite common across speakers, there was considerable variation both within and across speakers in the particular prosodic structures that were employed.

The first finding, that speakers used disambiguating prosody for a structure already disambiguated by context, suggests that prosodic disambiguation may be quite common in natural speech. This supports the claim of previous studies of prosody and sentence comprehension that prosodic effects on comprehension must be incorporated into any satisfactory model of sentence processing. The second finding, that there is variability in the prosody used to disambiguate, helps to constrain how prosody might fit into processing models. In particular, it supports the argument that the relationship between prosody and syntactic disambiguation is a complex one, involving much more than just the parser's sensitivity to the presence or absence of prosodic boundaries at key points in the utterance.

PROSODIC THEORY

We assume the intonational theory of Pierrehumbert and Beckman (Pierrehumbert, 1980; Beckman & Pierrehumbert, 1986) and follow the conventions of the ToBI transcription system (Beckman & Ayers, 1997; Silverman *et al.*, 1992). In these systems, it is assumed that each utterance of American English is produced in one or more intonation phrases (IPhs). Each IPh is made up of one or more intermediate phrases (ips), each of which must contain at least one pitch accent. At the phonological level, the end of each prosodic phrase is associated with an edge tone. The end of an IPh is delimited by a boundary tone, which can be high (H%) or low (L%). The end of an ip is delimited by a phrase accent, which can be high (H-), low (L-), or a downstepped high (!H-), and controls the tone from the final pitch accent of the phrase to the right edge of the phrase. American English employs several distinct pitch accents, including high (H*), low (L*), and bitonal accents (e.g., L+H*).

Roughly speaking, high edge tones and pitch accents are realized phonetically with a relatively high fundamental frequency (Fø) and low edge tones and pitch accents with a low Fø. However, the exact Fø contour depends on the particular tone sequence, plus such factors as the kind of segments that carry the tune. Prosodic phrase boundaries can also be marked phonetically by lengthening of the final syllable of the prosodic phrase and a following silent interval (Wightman *et al.*, 1992; Ferreira, 1993), segmental variation in the initial or final segments (Pierrehumbert & Talkin, 1992; Fougeron & Keating, 1997), and a new pitch range (Beckman & Pierrehumbert, 1986). In general, IPh boundaries show more extreme effects than ip boundaries. For example, an IPh-final syllable tends to have a longer duration than an ip-final syllable.

PRODUCTION EXPERIMENT

Method

We employed a cooperative game language production task in which two players, called the "Driver" and the "Slider," used scripted sentences to negotiate moves of gamepieces from starting positions to goals. Although players were restricted to the set of sentences we provided, they were responsible for choosing the order of moves and thus had some freedom in choosing which sentences to use and when to use them. Experimenters were careful to never utter the scripted sentences themselves, to avoid biasing the subject's choice of prosodic structures. For similar reasons, the early and late closure sentences were written without commas at the end of the subordinate clause in the subjects' scripts. Subjects were never told of the syntactic ambiguities in the game sentences and never told to use disambiguating pronunciations.

The game was noncompetitive and the players were encouraged to work together to accumulate points for the successful movement of objects to their goals, while avoiding the deduction of points for false moves or incorrect usage of expressions. There was a small set of gamepieces, which were either pushed by another gamepiece or allowed to slide on their own across a gameboard, following a few simple rules. There were two versions of each board. The one used by the Driver was marked with the goal locations for the gamepieces, but did not show the locations of bonuses (cookies) and hazards (ravenous goats). The Driver's role was to tell the Slider which piece to move (although the Slider had to choose the direction in which to move that piece), to inform the Slider when he or she moved incorrectly, and to confirm that a gamepiece had reached its goal position. The Slider's board was not marked with the goal locations, but it did indicate the whereabouts of bonuses and hazards. The Slider had to choose directions to move in, report moves back to the Driver, and ask the Driver for more information when necessary. Neither player could see the board being used by the other and the design of the boards and the rules of the game encouraged negotiation and the strategic use of moves. Four pairs of gameboards, with differing layouts, were used, plus a pair of practice boards and a demonstration board. Each pair of subjects played multiple rounds of the game, switching roles and gameboards between rounds. They wore head-mounted microphones and their utterances were recorded simultaneously to both computer disk and cassette tape.

Materials

The utterances of interest here, shown in (1) above, contain an intransitive/transitive verb ambiguity, resulting in a temporary ambiguity between early or late closure of a subordinate clause and its verb phrase. Comprehension research using materials produced by a trained speaker has shown that prosody can have immediate effects in parsing this structure (Speer *et al*., 1996; Kjelgaard & Speer, 1999). In production research, using materials such as those in (2), with a standing ambiguity between early and late closure of the subordinate clause, researchers have found reliable disambiguation by trained speakers (Price *et al*., 1991), but not by naive speakers in an oral reading task (Albritton *et al*., 1996).

(2) When you learn gradually you worry more.

Our materials were typically uttered as part of a stretch of dialogue like the one shown in (3). Note that in the first two utterances a triangle was being used as an instrument to push a square. The target sentences are in italics.

(3) Example Portion of Game Dialogue with Early and Late Closure Sentences

DRIVER: I want to change the position of the square with the triangle.

SLIDER: Which triangle do you want to change the position of the square?

DRIVER: The red one. *When that moves the square it should land in a good spot.*

SLIDER: Good choice. *When that moves the square will encounter a cookie.*

Throughout the game dialogue, the ambiguity of *moves the square* was consistently constrained or resolved by four nonprosodic sources of information. (1) The syntactic category of the word immediately following *square:* either *it* for late closure or *will* for early closure. (2) The identity of the speaker: only the Driver uttered the late closure sentence, and only the Slider uttered the early closure sentence. (3) The game configurations: only the Driver knew the locations of goals, and only the Slider knew the locations of cookies and goats; and (4) The preceding discourse: for example, the phrase *Good choice* was uttered only preceding an early closure sentence, and only by the Slider. Since the number of sentences included in the game was small and subjects were familiar with the range of sentences by the end of the practice game, we believe that our early versus late closure sentences were always fully disambiguated by nonprosodic factors.

Predictions

When trained speakers disambiguate these sentences, they tend to place the strongest prosodic boundary at the subordinate clause boundary (Price *et al.,* 1991). If naive speakers disambiguate with prosody only when the context for the sentence fails to do so, or only when they have been instructed to disambiguate, we would not expect our speakers to prosodically disambiguate these early/late closure sentences. The prosody should not differ in the *moves the square* region across the two syntactic conditions; presumably, in each condition, the prosodic boundaries following *moves* and *square* would have the same strength (e.g., they would both be ip boundaries), or the strength would vary in a way not reliably predicted by the syntax.

In contrast, if naive speakers tend to prosodically disambiguate such sentences regardless of the degree of disambiguation from nonprosodic factors and whether they have been told to disambiguate or not, we would expect them to behave similarly to the trained speakers and place the strongest prosodic boundary at the subordinate clause boundary. In the early closure condition, they should systematically produce a stronger boundary following *moves* than following *square* and, in the late closure condition, they should produce a stronger boundary following *square* than following *moves.*

Subjects

Nine pairs of subjects, all native speakers of American English, were recorded at the University of Kansas. Of these, four speakers were excluded because they failed to complete enough games to make the analysis of their data valid. All subject pairs completed a practice game, with one participant as Driver and one as Slider. In addition, each pair played at least two more games, using a separate board. Players played for 2 h and completed as many games as they could within that time, playing each board twice, once in the role of the Slider and once in the role of the Driver. The maximum number of games played, not including practice, was five, involving three different boards.

Results

The fourteen speakers collectively produced thirty-six fluent early closure tokens and fifty-one fluent late closure tokens. The critical region (*moves the square*) of each experimental token was transcribed in the ToBI system by two teams of transcribers. The first team had access to the complete phonetic and syntactic context of the critical region. The transcribers analyzed full discourse turns, which contained an initial phrase plus the complete early or late closure sentence, as shown in (4).

(4) a. The red one. When that moves the square it should land in a good spot.
b. Good choice. When that moves the square will encounter a cookie.
c. Bad luck. When that moves the square will encounter a ravenous goat.

This provided the transcribers with the syntactic resolution, the full duration of the critical region, all phonetic cues to boundaries in the critical region, and important information about the pitch range of the speaker.

The second team of transcribers analyzed sentence fragments, which had been digitally edited to remove the disambiguating lexical material, including phonetic cues to the identity of the segment following *square*. Thus, the second team analyzed only the string in (5):

(5) When that moves the square

These transcribers should not have been biased in their transcriptions by the syntactic resolution. However, because *square* was often truncated to remove the disambiguating segmental information of coarticulated following segments, they often received incomplete information about the duration of *square* and lost Fø evidence for phrase accents and boundary tones realized at the end of *square*. They also lost any cues to the prosodic boundary at *square* that were realized on the following material, such as segmental cues at the beginning of *will* and *it*. Further, they had reduced information about each speaker's pitch range. Because they heard only the initial portion of the experimental sentences, these transcribers could not necessarily establish the low end of a speaker's range and use that information to guide the identification of ambiguous tones in the contour.

Summaries of the transcriptions by the two teams are shown in Figs. 1 and 2. Both sets of transcriptions show strong evidence of prosodic disambiguation. The transcriptions done with full syntactic and phonetic context categorize 91% of early closure utterances with a stronger prosodic boundary following *moves* than *square* and 96% of late closure utterances

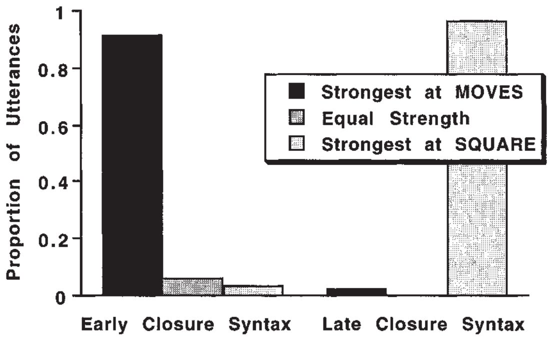

Fig. 1. Prosodic boundary patterns for transcriptions done with full syntactic and phonetic context.

with a stronger prosodic boundary at *square* than at *moves*. The transcriptions done without the syntactic disambiguation and with reduced phonetic information exhibit a similar pattern, with 83% disambiguation for the early closure utterances and 71% disambiguation for the late closure utterances. The main difference between the two sets is a strong pattern of transcribing a weaker prosodic boundary following *square* in the transcriptions done without context. Presumably, this is a result of the loss of phonetic information in the truncated utterances, as described above.

Phonetic analyses of the materials supported the phonological analyses. Word durations increased as prosodic boundary strength increased and there was a significant interaction between syntactic structure and the durations of the critical words *moves* and *square* $F(1, 13) = 4.8$, $p < .05$.

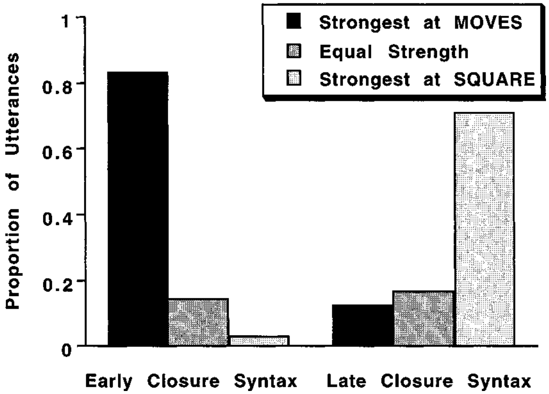

Fig. 2. Prosodic boundary patterns for transcriptions done without syntactic context.

Although speakers consistently used prosody to disambiguate these utterances, they varied in the contours they chose to supply the disambiguation. Both within and across speakers, many different pitch accent, phrase accent, and boundary tone combinations were used for the same morphosyntactic structure. In the transcriptions done with full context, there were 25 distinct intonational patterns on *moves the square* for 35 early closure utterances and 22 distinct patterns on *moves the square* for 48 late closure utterances, even after eliminating one speaker whose intonational contours seemed inappropriate for the kind of discourse the task was intended to elicit. As there was little variation in the discourse structure preceding these utterances, or in the discourse situation, this is an intriguing finding. However, we will postpone further discussion of it until after we have presented the results of the comprehension experiment.

COMPREHENSION EXPERIMENT

It is conceivable that the experimental tokens could seem disambiguated to transcribers who have been trained in prosodic analysis, and show systematic phonetic differences, but might nevertheless contain prosodic cues that are too subtle to disambiguate the syntactic structure for untrained listeners. Thus, we presented the ambiguous portion of the experimental tokens to naive listeners in a forced-choice categorization task. The materials consisted of the fragments analyzed by the second team of transcribers, from which the disambiguating syntactic information had been removed.

Subjects

Sixteen native speakers of American English from the University of Kansas community participated in the experiment.

Method

The syntactically ambiguous fragments were presented over headphones to subjects seated in front of a computer monitor in a sound-attenuated booth. Each fragment was played twice. The subject then chose between an early or late closure continuation of the fragment, displayed on the left and right sides of the computer monitor, with presentation order and screen location counterbalanced across subjects. In one block of the experiment, the continuations were the original continuations of the sentences, as shown in (6). In a second block, the initial segments of the continuations matched those of the opposite condition for the original sentences, as shown in (7), allowing us to separate effects of prosodic disambiguation from any disambiguating effects of coarticulated material. Each fragment was tested with both the original and the crossed continuation. The order of blocks was balanced across subjects.

(6) Original continuations
When that moves the square
a. . . . it should land in a good spot. [ɪ], Late Closure
b. . . . will encounter a cookie. [w], Early Closure

(7) Segmentally-crossed continuations
When that moves the square
a. . . . we'll encounter a problem. [w], Late Closure
b. . . . is shut off from the best path. [ɪ], Early Closure

Results

The results are presented in Figs. 3 and 4, for original and crossed continuations, respectively. Within each syntactic condition, we have separated the items into three sets. Those with "cooperating" prosodic boundary strength were tokens analyzed as having the strongest prosodic boundary at the subordinate clause boundary, as determined by a conflation of the two sets of transcriptions. These make up the majority of tokens, for both the early closure and the late closure condition, as shown above in Figs. 1 and 2. The items with "ambiguous" prosodic boundary strength were analyzed

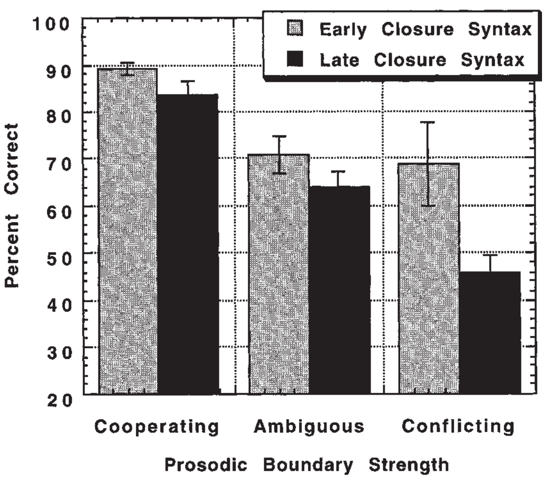

Fig. 3. Percentages of correct categorizations with original continuations.

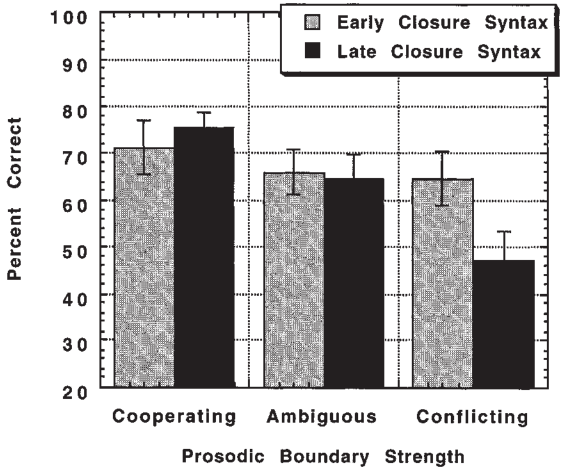

Fig. 4. Percentages of correct categorizations with rhythmically- and segmentally-crossed continuations.

with equal strength boundaries following *moves* and *square* and those with "conflicting" boundary strength were judged to have a weaker prosodic boundary at the major syntactic boundary than at the other critical location.

For both the original and the crossed continuations, the percentages of correct categorizations were significantly above chance for items overall (72% for late closure and 76% for early closure sentences) and for items in the cooperating boundary strength subset. If the relative strength of the prosodic boundary at *moves* and *square* was the only factor responsible for syntactic disambiguation, items in the cooperating boundary set should have been significantly above chance, those in the ambiguous set should have been at chance, and items in the conflicting set should have been below chance. Surprisingly though, items with ambiguous boundary strength patterns were also significantly above chance and items in the conflicting boundary strength set were at chance, not below it, for the late closure items, and significantly above chance for the early closure items, for both original and crossed continuations.[5]

The comprehension results show high percentages of successful disambiguation, both for the original and for the crossed continuations. Thus, the comprehension results confirm that the prosodic differences found in

[5] Because we presented truncated utterances, some of the phonetic information for the prosodic boundary at *square* may have been lost, as discussed above. This would presumably result in a tendency for poorer identification than expected for the late closure cooperating and late closure ambiguous subsets and more successful identification than expected for the early closure ambiguous and early closure conflicting subsets.

the phonological and phonetic analyses can be used by naive listeners to disambiguate syntactic structure. The comprehension results also suggest that while the relative strengths of prosodic boundaries at critical locations is an important source of disambiguating information, it is not the only aspect of prosody that can influence syntactic parsing. Some other type of prosodic information, such as the choice of pitch accents and edge tones or the use of varying pitch ranges, seems to have aided disambiguation, at least in the ambiguous and conflicting boundary cases.

GENERAL DISCUSSION

The results reported above consistently show prosodic disambiguation of syntax, whether judged by a phonological analysis of transcription categories, a phonetic analysis of the durations of critical regions or the ability of naive listeners to correctly categorize syntactically ambiguous fragments. These results contrast with other production studies, but are consistent with what would be expected on the basis of our comprehension work, which shows that listeners are very sensitive to prosodic disambiguation of syntax (Kjelgaard & Speer, 1999; Marslen-Wilson *et al.*, 1992; Schafer, 1997; Schafer *et al*, 1996; Speer *et al.*, 1996; Warren, 1985; Warren *et al.*, 1995), and are also consistent with results from this experimental paradigm for a PP-attachment ambiguity (Speer *et al.*, 1999). We take this finding as further evidence that prosody is an important source of information for sentence comprehension, presumably in a wide range of discourse situations.

Two factors distinguish our study from previous research that has not shown such a consistent relationship between syntax and prosody (Albritton *et al.*, 1996). First, our materials contain argument structures rather than ambiguously attached adjuncts. We would argue that the phonosyntactic constraints of the grammar might allow more ambiguity with adjuncts than with arguments. That is, we believe the ambiguously attached adjuncts used in previous work are most naturally set off in a separate intermediate phrase from other material in the clause, while our ambiguously attached NPs can be felicitously produced as part of an intermediate phrase that includes other material in the clause. Second, we believe that our task more closely simulates meaningful conversation and, to the extent that our results are different from those found in reading tasks, we can argue that our results are more representative of the degree to which prosodic disambiguation of syntax is likely to be found in "everyday" speech. Indeed, we claim that the adjunct structures tested in other work can be disambiguated prosodically, as evidenced by the performance of trained speakers (Price *et al.*, 1991), but that naive speakers may simply fail to do so in oral reading tasks.

Our results also provide further evidence that prosodic structure is not fully predictable from syntactic structure, even in a highly constrained discourse situation. We found that a disambiguated syntactic structure can be associated with multiple prosodic structures, which vary in such features as high versus low pitch accents and edge tones. It is our hope that further research with tasks like our production game will illuminate which aspects of this variability are predictable from minor differences in the discourse structure or from factors such as the speaker's speech rate or dialect, and which aspects truly represent free variation in the grammar.

Regardless of the source of prosodic variation in these results, its existence suggests that the syntactic parser must be sensitive, at least at some point in the parse, to far more prosodic information than the presence or absence of prosodic boundaries at points of syntactic ambiguity, currently the only kind of prosodic information commonly acknowleged in syntactic parsing studies. Our data show that local prosodic events must ultimately be interpreted with respect to a larger prosodic structure. For example, the presence of an ip boundary following *moves* seems to support an early closure analysis if there is merely a word boundary following *square,* but a late closure analysis if there is an IPh boundary following *square.* If both *moves* and *square* are followed by an ip boundary, other prosodic factors seem to influence which syntactic structure is selected—perhaps the relative pitch ranges of prosodic phrases, perhaps the choices of pitch accents and edge tones.

The experiments presented here cannot tell us when prosodic information is used in parsing, whether all types of prosodic information are used at the same time, or how different sources of prosodic and nonprosodic information are integrated by the parser. However, they do tell us that prosody is likely available in many discourse situations. They also suggest that the comprehension system performs a detailed analysis of the prosodic structure of an utterance and makes use of this detail in ways that we are just beginning to understand.

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