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Utilization of Prosodic Information in Syntactic Ambiguity Resolution

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Abstract

Two self paced listening experiments examined the role of prosodic phrasing in syntactic ambiguity resolution. In Experiment 1, the stimuli consisted of early closure sentences (e.g., "While the parents watched, the child sang a song.") containing transitive-biased subordinate verbs paired with plausible direct objects or intransitive-biased subordinate verbs paired with implausible direct objects. Experiment 2 also contained early closure sentences with transitively and intransitive-biased subordinate verbs, but the subordinate verbs were always followed by plausible direct objects. In both experiments, there were two prosodic conditions. In the subject-biased prosodic condition, an intonational phrase boundary marked the clausal boundary following the subordinate verb. In the object-biased prosodic condition, the clause boundary was unmarked. The results indicate that lexical and prosodic cues interact at the subordinate verb and plausibility further affects processing at the ambiguous noun. Results are discussed with respect to models of the role of prosody in sentence comprehension.

Keywords

Prosody; Verb transitivity bias; Plausibility; Syntactic ambiguity resolution

Introduction

Understanding the processes underlying sentence comprehension requires determining the types of cues that guide the construction of sentence structure and meaning, when they become available to the parsing and interpretative systems, and how they interact. Many studies have shown that lexical information such as verb subcategorization biases and pragmatic information such as the plausibility of thematic roles influence syntactic parsing (e.g., Garnsey et al. 1997; Snedeker and Yuan 2008; Trueswell and Tanenhaus 1994). There is also evidence that prosodic contour affects syntactic analysis (e.g., Blodgett 2004; Carlson et al. 2001; Kjelgaard and Speer 1999; Millotte et al. 2007; Pynte and Prieur 1996; Schafer 1997; Snedeker and Yuan 2008). However, there are few investigations of how and when prosodic cues are integrated with lexical or pragmatic cues (Blodgett 2004; Pynte and Prieur 1996; Snedeker and Yuan 2008). The present study used self paced listening to examine early closure ambiguities in the auditory modality, in order to investigate whether, when, and how prosodic cues interact with lexical and pragmatic cues.

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Sentences with temporary syntactic ambiguities such as (1) and (2) provide a means of studying interactions between different types of cues during on-line sentence processing. In these *early* and *late closure* sentences, the phrase *the child* is temporarily ambiguous because it may be the direct object of the subordinate verb as in (2) or the subject of a new clause as in (1). The main verb, *sang*, is the point of disambiguation in early closure sentences (1), because at that point it becomes clear that *the child* is the only available subject for the main clause. In late closure sentences (2), *she* is the point of disambiguation because the pronoun cannot be integrated into the subordinate clause and so must be the beginning of a new clause.

(1) While the parents watched, the child sang a song with her grandmother. (Early closure)

(2) While the parents watched the child, she sang a song with her grandmother. (Late closure)

Closure ambiguities are well suited to studying the effect of prosody because the subordinate clause boundary can be clearly marked prosodically. There have been several studies of these sentences in the written modality (e.g., Adams et al. 1998; Mitchell 1987; Staub 2007; Van Gompel and Pickering 2001). Though such work does not provide direct data about prosody, effects of punctuation point to the possible role of prosody in processing these ambiguities. When the subordinate clause boundary of an early closure sentence is not marked with a comma, reading times may be disrupted for the ambiguous noun phrase or the main verb, depending on the lexical features of the words in the sentence. Such disruptions in reading times are typically minimized when the clausal boundary is marked with a comma. This suggests that the presence of a comma disambiguates early closure sentences.

Staub (2007) demonstrated that the absence of a comma also affected reading of late closure sentences. In particular, reading of the disambiguating noun phrase in a late closure sentence (*she* in example 2 above) was disrupted when the end of the subordinate clause was not marked with a comma. This suggests that readers did not realize the subordinate clause was complete, and so tried to integrate the disambiguating noun phrase into it. Staub tied this result to prosody, suggesting that readers did not subvocally mark the syntactic boundary with a prosodic boundary when there was no comma. On this view, the disruption in reading times reflected revision of the subvocal prosodic contour triggered by the disambiguating noun phrase and the realization that the subordinate clause was complete.

Regardless of whether the presence or absence of a comma in the written modality is identical to the presence or absence of a prosodic boundary in auditory comprehension and whether subvocalization creates mental intonation contours (Fodor 2002; Steinhauer and Friederici 2001), prosodic contour is clearly a source of information that may affect interpretation of ambiguities (e.g., Nicol 1996). Prosodic contours can mark clausal boundaries, such as the syntactic boundary following the subordinate verb in sentences with early closure syntax, and potentially increase the likelihood that the early closure interpretation will be pursued.

Prosodic contours are most frequently described using the Tones and Break Indices (TOBI) system of transcription for Mainstream American English (Pierrehumbert and Beckman 1988; Shattuck-Hufnagel and Turk 1996). This system describes two hierarchically related prosodic units, marked by intermediate (ip) and intonational phrase (IP) boundaries. In general, intermediate phrases represent a lesser degree of disjuncture between constituents than intonational phrases. Intermediate phrases contain nuclear pitch accents and a phrase accent. High (H*) and low (L*) nuclear pitch accents are associated with the stressed syllables of prominent words within the phrase. Phrase accents (H− or L−) extend from the last pitch-accented word in the ip to the end of the phrase. Intermediate phrases are grouped into intonational phrases (IP), which end with a phrase accent and a boundary tone (H% or L %). Both phrase accents and boundary tones are marked by durational cues such as lengthening of the final syllable, but these cues tend to be more pronounced in IPs. IPs are also more likely than ips to be followed by pauses.

Although not obligatory, prosodic cues marking syntactic structure are reliably present in speech, even when other sources of information disambiguate the intended structure (Kraljic and Brennan 2005; Schafer et al. 2000; Selkirk 1984; Snedeker and Trueswell 2003). Many studies have shown that listeners are sensitive to the presence of prosodic boundaries during sentence comprehension (Kjelgaard and Speer 1999; Marslen-Wilson et al. 1992; Speer et al. 1996; Warren et al. 1995). For example, Kjelgaard and Speer (1999) examined the interaction between prosodic contour and syntactic structure in a series of on-line (cross modal naming) and off-line (e.g., acceptability judgment) experiments. They found that processing early closure sentences was faster when the syntactic clausal boundary was marked by a prosodic boundary and slower when the prosodic contour conflicted with the correct interpretation of the sentence. These data were interpreted as evidence that prosody constrained syntactic parsing, such that prosodic boundaries could trigger an early closure interpretation despite other syntactic constraints.

One important question is how prosodic cues interact with other constraints, such as verb subcategorization biases and plausibility. One model that describes how these constraints interact is the Phon-Concurrent Model (Blodgett 2004). The Phon-Concurrent Model extends the Concurrent Model (Boland 1997) to account for how prosody influences syntactic parsing. Briefly, the Concurrent Model claims that there are independent syntactic and semantic processors. The syntactic processor generates multiple structural analyses in parallel using lexical information and syntactic rules. Selection from among the proposed structures is influenced by probabilistic constraints such as verb subcategorization bias. The semantic system generates a single assignment of thematic roles on the basis of inputs that include word meaning, thematic schemata, and the product of the syntactic processor (Boland 1997). The semantic processor discards any analysis that is plausible but ungrammatical. According to Boland (1997), the semantic and syntactic processors work in parallel but are independent in the sense that both can begin to build an interpretation in the absence of information from the other.

The Phon-Concurrent Model (Blodgett 2004) added a prosodic processor to the Concurrent Model, resulting in three autonomous processors. The prosodic cue is input to both the semantic and syntactic processors. It acts as a separate constraint on the generated syntactic (but not semantic) analyses, giving weight to the syntactic alternative that most closely matches the prosodic analysis. In addition, strong prosodic (intonational phrase) boundaries trigger semantic and syntactic wrap-up, which is when the semantic and syntactic processors independently commit to the best available analysis at that point in the sentence. While the exact nature of the commitment is somewhat unclear, it seems that it involves both selection of the best analysis and elimination of other, inconsistent, structures (Blodgett 2004; Boland 1997). Also note that the syntactic and semantic processors may commit to different analyses if there are conflicting cues at the point of wrap-up, which may result in increased processing times.

Blodgett (2004) claimed that the Phon-Concurrent Model best accounted for the results of a cross modal naming experiment that examined the interactions between verb transitivity bias, plausibility, and prosodic contour in sentences with early closure ambiguities. Participants heard fragments such as "*Whenever the lady loads*" (see example 3). Immediately after the offset of the verb, they named a visually presented target word that was plausible (e.g., *the van*) or implausible (e.g., *the sun*) as a direct object for the subordinate verb (e.g., *loads*). As seen in examples (3) – (5), the subordinate verb was biased to occur in a transitive frame, an intransitive frame, or not strongly biased to occur in either frame. The fragments were pronounced with prosodic contours that were biased toward the early or late closure interpretation of the sentence.

(3) Whenever the lady loads [the van/the sun] (Transitive-Bias)

(4) Whenever the lady moves [her elbow/the weather] (Intransitive-Bias)

(5) Whenever the lady checks [the weather/the IRS] (Equi-Bias)

The naming times for the ambiguous noun phrase were modulated by prosodic contour and verb bias in conditions with implausible direct objects. Consider first early closure sentences with prosodic boundaries that were strongly biased to the early closure interpretation (intonational phrase boundaries, or IPs), intransitive-biased verbs (e.g., *moves* in example 4), and implausible direct objects (e.g., *the weather*). Recall that under the Phon-Concurrent Model, an IP marking the subordinate verb would trigger syntactic and semantic wrap-up processes. At that point, all of the available cues support the early closure interpretation. As predicted under these conditions, Blodgett found that naming times for the ambiguous noun phrase (e.g., *the weather*) were faster for verbs that were more strongly biased to occur in intransitive frames.

For stimuli with prosodic boundaries that were weakly biased toward the early closure interpretation (intermediate phrase boundaries, or ips), transitive-biased verbs (e.g., *loads*), and implausible direct objects (e.g., *the sun*), naming times were faster for more transitivebiased verbs. According to the Phon-Concurrent Model, a weak prosodic boundary would reduce the weight of the late closure interpretation but not trigger wrap-up. Blodgett suggested that more transitive-biased verbs would add weight to the late closure interpretation and thus facilitate integration of the ambiguous noun phrase into the subordinate clause (i.e., the late closure interpretation). In this case, the implausibility of the ambiguous noun phrase as the object may have led to reanalysis later in the sentence. However, the timing of this reanalysis could not be observed because the cross modal naming task in this experiment only measured on-line processes at the ambiguous noun phrase.

Although Blodgett (2004) work suggests that lexical, pragmatic and prosodic cues interact on-line, there are unanswered questions about her results. First, she did not find evidence of interactions between lexical, pragmatic and prosodic cues in analyses of variance at the ambiguous noun phrase, and not all of the predicted effects were significant. Second, the cross modal naming task only provides information about one point in each sentence per trial, but the interpretation of results at one point in an ambiguous sentence may be influenced by the pattern across multiple segments. Although Blodgett did examine naming times at the main verb and ambiguous noun phrase, she did not do so within one experiment.

Two other studies have investigated interactions between lexical and prosodic information in structures containing ambiguous prepositional phrases, meaning that the prepositional phrase might be attached to the noun phrase (e.g., *The spies informed the guards of the palace*) or verb phrase (e.g., *The spies informed the guards of the conspiracy*) (Pynte and Prieur 1996; Snedeker and Yuan 2008). Pynte and Prieur (1996) used a word monitoring task to examine the interactions between verb bias and prosodic contour during processing of this type of ambiguity. They reported that both cues affected sentence processing, but that the effects of prosody were greatest when the verb's argument structure conflicted with the disambiguation of the sentence. They concluded that verb bias plays a role in building the initial interpretation of a sentence, while prosodic contour either facilitates adoption of a particular interpretation or plays a role in the revision of an incorrect initial interpretation.

A more recent study concluded that lexical and prosodic cues interact to guide syntactic ambiguity resolution (Snedeker and Yuan 2008). They investigated effects of verb bias and prosodic contour on attachment of globally ambiguous prepositional phrases using the visual world paradigm, in which eye-movements were tracked while the participants interacted with objects in a visual display. Participants listened to sentences such as "*You can feel the frog with the feather*," in which the prepositional phrase could be attached to the verb as an instrument or to the noun phrase as a modifier. Verbs were biased towards the instrument interpretation (e.g., *tickle*), the modifier interpretation (e.g., *choose*), or were equally biased towards either interpretation (e.g., *feel*). Prosodic contours consistent with the instrument interpretation contained an intonational phrase boundary after the direct object, while contours consistent with the modifier interpretation contained an intonational phrase boundary after the verb.

Snedeker and Yuan (2008) found that prosody and verb bias both influenced interpretation of the ambiguous prepositional phrase in adults, and that the effect of prosodic contour was greatest when the verb was equi-biased. This result is consistent with early effects of both prosodic contour and lexical information. However, a number of issues limit the strength of this conclusion. First, Snedeker and Yuan (2008) only found interactions between verb bias and prosodic contour in eye-movement analyses across the entire trial. That is, verb bias and prosodic contour did not interact in any of the time windows that were analyzed within the trial, making the time course of the interaction unclear. It is also unclear whether the interaction between prosodic contour and verb bias in the overall analyses was significant for all three verb bias conditions, or only for the equi-biased condition. If the interaction was only significant for equi-biased verbs, then it is possible that prosodic cues only play a role when lexical effects are weak (cf., Kjelgaard and Speer 1999).

To summarize, there are now three conflicting claims in the literature: that prosodic cues are used before other types of cues (Kjelgaard and Speer 1999), that lexical cues are used before prosodic cues (Pynte and Prieur 1996), and that prosodic cues interact with other probabilistic cues (Blodgett 2004; Snedeker and Yuan 2008). These claims are based on different syntactic structures, prosodic manipulations, and tasks. While the most recent work is consistent with an interaction account, the existing studies have not shown how effects unfold across different segments of a sentence. Both the basic question of whether prosodic and probabilistic cues interact, and if so, the nature of the interaction, require further study.

The present study used self paced listening to explore the relationship between prosodic and lexical-pragmatic (here, transitivity bias and plausibility) cues in sentences with early closure ambiguities. In contrast to cross modal naming, self paced listening allows measurement of syntactic processing at multiple points in the sentence in the same trial. As noted above, the ability to measure processing at multiple points in the sentence is important because the effects of a factor at one point in the sentence may be interpreted in different ways depending upon effects at other points. Studies of early closure ambiguities in the written modality suggest that there are two critical segments: the ambiguous noun phrase and the point of disambiguation. The present study also examined effects of prosody at the subordinate verb, a position that has received no attention, but at which an effect might be found because it carries potentially disambiguating prosodic information. Experiment 1 extended previous studies of early closure ambiguities in the written modality to the auditory modality. Experiment 2 asked whether the nature of interactions between cues would change when the plausibility of the ambiguous noun phrase was held constant.

Experiment 1

Experiment 1 focused on how lexical-pragmatic and prosodic cues interact during on-line syntactic ambiguity resolution in early closure sentences. The lexical-pragmatic and prosodic cues were manipulated so that they were biased towards the subject (early closure) or object (late closure) interpretation of the ambiguous noun phrase. Following previous studies of this ambiguity in the written modality (e.g., Van Gompel and Pickering 2001; Staub 2007), the lexical-pragmatic factor combined the transitivity bias of the subordinate verb and the plausibility of the ambiguous noun phrase as a direct object for the subordinate verb. Intransitive-biased subordinate verbs were always followed by implausible direct objects (subject-biased) and transitive-biased subordinate verbs were always followed by plausible direct objects (object-biased). The prosodic factor varied the presence or absence of an intonational phrase boundary following the subordinate verb. The prosodic factor corresponds, roughly, to the presence or absence of a comma to mark the end of the subordinate clause and disambiguate early and late closure sentences. The four conditions are summarized in Table 1.

If the lexical-pragmatic and prosodic cues interact, then there should be evidence of processing disruption, that is, slowed listening times, for the ambiguous noun phrase in conditions with conflicting cues. The conditions with conflicting cues contained (1) subject-biased prosody, a transitive-biased verb, and a plausible object, and (2) object-biased prosody, an intransitive-biased verb, and an implausible object. The pattern of listening times at the main verb in these conditions will depend on whether the conflict is resolved to the subject or object interpretation. Slowed processing at the main verb would be evidence of reanalysis, suggesting that the conflict was resolved to the object interpretation. For sentences without conflicting cues, there should be no processing disruption at the ambiguous noun phrase. In the condition with subject-biased prosody, an intransitive-biased verb, and an implausible object, processing should be relatively fast across the sentence because all cues support the correct interpretation. In the condition with object-biased prosody, a transitive-biased verb, and a plausible object, all cues support the object interpretation so processing should be fast at the ambiguous noun phrase but slowed for the main verb, reflecting reanalysis from the object to the subject interpretation.

Methods

Participants—Twenty-six individuals (age range 18–24 years) participated. All were native English speakers, defined as learning English before the age of 6 and in a home setting. No participant reported a history of central nervous system disease, learning disabilities, or language disorders.

Stimulus Development—Fifteen pairs of sentences containing early closure syntax were developed (Table 1). One member of the pair was biased toward the subject (early closure) interpretation of the ambiguous noun phrase. It contained an intransitive-biased verb followed by an implausible direct object. The second sentence contained a transitive-biased subordinate verb followed by a plausible direct object, and so was biased toward the object (late closure) interpretation of the ambiguous noun phrase. Sentences were identical except for the subordinate verbs. The two verb sets did not differ significantly in frequency, $F(1, 28) = 1.16$, $p = .29$ (mean: 55 for intransitive & 110 for transitive verbs; Francis and Kuçera 1982). Appendix A shows all of the stimuli, with transitivity and plausibility ratings for each item.

Verb Transitivity Biases: Transitivity biases were determined on the basis of a verb norming study of 125 verbs. Participants ($n = 50$) were provided with a list of target verbs (in isolation) and instructed to write a sentence using each one. Responses were coded by hand, and the percentage of total responses for each verb was calculated for three categories: (1) active transitive uses (2) active intransitive uses and (3) other structures (including gerunds, passives, etc.). Verbs were classified as transitive-biased if they were used at least twice as often in transitive than intransitive frames (cf., Garnsey et al. 1997), and if the difference in usage between the two frames differed by at least 40%. The analogous criteria were used to classify intransitive-biased verbs. The criterion that usages must differ by at least 40% was included to ensure that there was a strong bias towards one interpretation and that the verb was not biased to occur in some other syntactic frame. Table 2 presents the proportion of intransitive and transitive usages for the transitive- and intransitive-biased verbs.

Plausibility Norming Studies: A second norming study was conducted to assess the plausibility of the ambiguous noun phrase as a direct object to the subordinate verb. Fifty participants rated active sentences on a seven-point scale (1= implausible, 7= plausible). The stimuli consisted of the critical verb with its subject and either a plausible or an implausible direct object; for example, "*The parents watched the child*" or "*The parents danced the child*." Because of the nature of the stimuli, transitivity bias and plausibility were confounded in these materials. Average plausibility ratings were compared using ANOVAs, and ratings for sentence pairs were inspected to ensure that plausibility ratings differed by at least three points (cf., Garnsey et al. 1997). The results are summarized in Table 2. There was a main effect of plausibility, $F(1, 88) = 3, 935.2$, $p < .001$, but several sentence pairs did not differ by at least three points. Additional materials were developed and rated by twenty additional participants. The second set of stimuli included a subset of the materials from the first plausibility norming study, and the second group's ratings of these sentences did not differ from those in first study (All $F's \leq 1.5$). In this second study, average plausibility ratings for the sentence pairs differed significantly, t (54) = 49.2, $p < .01$, and all sentence pairs differed by a minimum of three points.

Development and Pretests of Auditory Stimuli

Overview: The stimuli were recorded with prosodic contours biased toward the early and late closure interpretation of the sentence (i.e., subject vs. object biased prosodic contours). They were then subjected to pretests to ensure that (1) the pronunciation of the stimuli was acceptable to naïve listeners (*Acceptability Judgments of Auditory Stimuli*) and (2) the acoustic signals in the prosodic conditions only differed in expected ways (*Acoustic Analyses*). Next, the stimuli were segmented for self paced listening. An additional pretest established that naïve listeners were sensitive to the prosodic manipulations and that segmentation did not distort the prosodic cues (*Rating of Prosodic Contour in Segmented Stimuli*).

Creation of Auditory Stimuli: A female speaker of American English trained in phonetics and phonology recorded the sentences in a sound-attenuated booth using Praat (Boersma and Weenink 2007). Sentences were recorded as 16-bit sound files sampled at 44.1 kHz.

Sentences were pronounced with prosodic contours that were biased toward the subject and object interpretations of the ambiguous noun phrase following Kjelgaard and Speer (1999). Figure 1 illustrates critical differences between the subject-biased (A) and object-biased (B) prosodic conditions. In the subject-biased prosodic contour, the clausal boundary following the subordinate verb was marked with an intonational phrase boundary to create a bias toward the early closure interpretation. The subordinate verb was marked with a high (H*) pitch accent. The phrase boundary following the subordinate verb was marked by lengthening the clause-final syllable, an L–L% phrase accent and boundary tone, and by pitch discontinuity between the subordinate and main clauses (cf., cooperating prosodic contours in Kjelgaard and Speer 1999). Pauses were not used to mark clausal boundaries because it was anticipated that this cue would be susceptible to disruption in self paced listening. Object-biased structures were neutral in that neither potential clause boundary was marked by a clear prosodic boundary. Similar to the baseline prosodic contour in Kjelgaard and Speer (1999), the sentences were produced with an H* pitch accent on the subject of the subordinate clause with deaccentuation of the remainder of the clause.

Acceptability Judgments of Auditory Stimuli: Naïve listeners were asked to judge whether or not the pronunciation of each stimulus sounded “okay.” Participants ($n = 77$) listened to the sentence twice before making their judgment in order to minimize effects of syntactic structure or meaning on the acceptability judgments. For the purposes of this pretest, a *conflicting* prosodic contour was created by recording sentences with prosodic markers consistent with an intonational phrase boundary after the ambiguous noun phrase. These items, which were biased towards the late closure interpretation, were included so that there were prosodic contours that were clearly inconsistent with the meaning of the sentence (cf. Kjelgaard and Speer 1999). Stimuli were re-recorded and re-piloted until an acceptable set was obtained, so all participants did not judge all stimuli. A minimum of 15 judgments was obtained for each stimulus.

The mean and range of acceptability ratings for the final stimulus set are in Table 3. Judgments were analyzed in 3 (Prosody: subject-biased, object-biased, conflicting) × 2 (Lexical-Pragmatic Condition: transitive bias/plausible object, intransitive bias/implausible object) ANOVAs. There was a significant main effect of prosody, $F(2, 81) = 1, 109.3$, $p < .0001$. Sentences with subject- and object-biased prosodies were significantly more acceptable than those with conflicting prosodies, but the subject- and object-biased prosodic conditions did not differ from one another. There were no significant effects of lexical-pragmatic condition.

Acoustic Analyses: Acoustic measurements were made using Praat to quantify differences in the recorded stimuli for the two prosodic conditions and to ensure that the recorded stimuli only differed in expected ways (Boersma and Weenink 2007; see Table 4). These measures were compared in separate 2 (Prosody) ×2 (Lexical-Pragmatic Condition) ANOVAs.

The duration of the first noun phrase, the subordinate verb, the ambiguous noun phrase, and the main verb were measured. As expected, the first noun phrase (NP1) was significantly longer in object-biased than subject-biased prosodies, $F(1, 56) = 14.62$, $p < .01$, and the subordinate verb was significantly longer in subject- than object-biased prosodies, $F(1, 56) = 12.18$, $p < .01$. Intransitive subordinate verbs were, on average, 59ms longer than transitive subordinate verbs, $F(1, 56) = 6.9$, $p = .01$. This may be because there were different lexical items in the sets. Transitivity did not interact with prosodic contour ($F < 1$). This indicates that the difference in length did not reflect a difference in the strength of the boundary cues for transitive and intransitive verbs. There were no other significant differences in segment duration. Pause lengths following the subordinate verb and ambiguous noun phrase were also calculated, but there were no significant differences as a function of lexical-pragmatic or prosodic condition.

Pitch change across critical segments was measured as the difference between the maximum and minimum pitch level within words. As expected, pitch change was greater in the first noun phrase (NP1) in sentences with object-biased prosody, $F(1, 56) = 10.43$, $p < .01$, and in the subordinate verb in sentences with subject-biased prosody, $F(1, 56) = 90.61$, $p < .01$. There were no other significant differences in pitch change.

Segmentation for Self paced Listening: Sentences were broken into segments using Praat (Boersma and Weenink 2007; see Table 1). Segmentation was determined by areas with low signal amplitude at the end of words, as identified through visual and auditory inspection, and the breaking point that maximized the intelligibility of each segment. The waveforms were then converted into SoundEdit files (Dunn 1994) and entered into PsyScope experimental software (Cohen et al. 1993) for use in the experiment.

Rating of Prosodic Contour in Segmented Stimuli: Participants ($n = 10$) listened to auditory fragments, which were truncated after the ambiguous noun phrase, and reported where they “heard” a comma. In an effort to minimize semantic and syntactic effects on comma placement, participants were instructed that they could insert a comma at any point in the sentence. They were also given practice items in which the prosodic contour indicated a "comma" at unexpected points in a sentence, for example, between a determiner and noun (e.g., "the, ball is red"). Participants were told that they did not have to insert a comma in every stimulus; these items were coded as late closure interpretations. Stimuli were tested in both the self paced listening (SPL) format, in which participants paced through the first three segments of the sentence, and a whole sentence presentation format in which participants heard the unsegmented version of the sentence. The stimuli were randomly assigned to two lists, and SPL and whole sentence presentation formats of both lists were developed. Participants listened to one list in SPL format and the other in whole sentence presentation format. The presentation order was counterbalanced across participants.

The results (Table 5) show that segmentation for SPL does not eliminate or distort the effects of the prosodic manipulation. There was a main effect of prosodic contour, $F(1, 76) = 484.8$, $p < .001$, with more early closure interpretations of stimuli presented with subject- than object-biased prosodic contours. The main effect of presentation format was not significant ($F < 1$). Although the interaction between presentation format and prosodic contour was not significant, $F(1, 76) = 2.92$, $p = .10$, its terms were explored with *t*-tests to rule out the possibility that segmentation had different effects in the prosodic conditions. There were significant differences in the number of early closure interpretations in the subject- and object-biased prosodic conditions in both presentation formats (SPL: $t\ (38) = 14.26$, $p < .001$; Whole: $t\ (38) = 16.89$, $p < .001$) but no significant differences as a function of presentation condition (Subject-biased Prosody: $t\ (38) = 1.59$, *ns*; Object-biased Prosody: $t\ (38) = 1.10$, *ns*). Thus, there was no evidence that the segmentation distorted the prosodic cue.

Creation of Presentation Lists: The stimuli were randomly assigned to four lists such that each version of the stimulus (2 lexical-pragmatic conditions ×2 prosodic contours) appeared in only one list. They were combined with 78 fillers so that the experimental items comprised less than 20% of the items in each list. There were 15 filler sentences with late closure syntax in each list, to guard against development of expectations for early or late closure syntax. Late closure sentences were recorded with two prosodic contours. The first contained a prosodic boundary that coincided with the syntactic boundary, marking the boundary between the ambiguous noun phrase and the subject of the main clause. Like subject-biased prosodic contours for early closure sentences, this prosodic contour was consistent with the final interpretation of the sentence. The second prosodic contour was identical to the object-biased prosodic condition for early closure sentences, and did not mark either potential boundary. As a result, the object-biased prosodic contour was equally likely to occur in early and late closure sentences. The remaining fillers were unrelated structures, 37% of which contained other prosodically disambiguated syntactic ambiguities (e.g., parenthetical constructions). These were included so that the experimental stimuli were not the only ones in which sentence interpretation might be affected by the prosodic contour. With 15 stimuli, it was not possible to balance the conditions within list, but because all participants saw all lists (see "Procedures"), the conditions were balanced across the experiment.

Comprehension Probes: Comprehension of each item was tested with true/false questions (see Table 1). There was a different question for each version of the stimulus, so that participants did not answer the same question more than once. Lexical items in the four probes for each set of sentences were matched for word frequency and length. Comprehension probes were recorded by a male speaker of American English who was blind as to whether the statements were true or false. The speaker was instructed to read the sentences "naturally."

Procedures

All participants were tested on all four lists in separate testing sessions that were separated by a minimum of 1 week. Order of list presentation was counterbalanced across participants. Participants were tested individually in a quiet room at Boston University. Stimuli were presented in pseudo-random order, with the constraint that no more than two sentences of the same type occurred in succession. All lists were preceded by a practice session of ten sentences to familiarize participants with the task. At the beginning of each trial, participants saw the prompt "Ready?" and then paced through each segment of the sentence by pressing a button on a button box interfaced with a Macintosh computer. The auditory stimuli were played over high-quality earphones at comfortable listening levels. A tone marked the end of the sentence, after which the comprehension probe was presented. The button box collected response accuracy and reaction times for each button press with millisecond resolution.

Results

Accuracy and listening time data were analyzed in 2 (Prosody: Subject- vs. Object-biased) × 2 (Lexical-Pragmatic Cue: Transitive/Plausible vs. Intransitive/Implausible) ANOVAS by subjects and items. 95% confidence intervals were computed using the Masson and Loftus (2003) method for within-subjects designs. Tukey-tests were used to examine significant interactions using a criteria of $p < .05$.

Comprehension Probes—Table 6 presents the proportion of true/false questions that were correctly answered for each condition. There were no significant effects of lexical-pragmatic or prosodic condition on accuracy (all *F′s* < 1.0).

Segment Listening Times—The measure of on-line sentence processing was the listening time for the critical segments (in italics in Table 1), which were: (1) the ambiguous noun phrase, (2) the point of disambiguation (main verb), and (3) the spillover region, which follows the main verb and precedes the final segment of the sentence. The lexical items in these segments were identical in all four conditions. Response time for each button press was measured from the onset of the segment. The duration of the spoken segment was then subtracted from the response time to calculate the **listening time** (i.e., the amount of time spent listening to the segment beyond its spoken length). Listening times greater than 2.5 seconds were deleted, because they were not considered to reflect normal sentence processing. Listening times greater or less than three standard deviations from the mean for each participant and condition were treated as outliers and replaced with the value of the upper or lower limits. These procedures resulted in the deletion or replacement of less than .5% of the data. Results are presented in Fig. 2.

Ambiguous Noun Phrase: There was a significant interaction between the prosodic and lexical-pragmatic conditions, $F1(1, 25) = 36.73$, $p < .001$, $F2(1, 14) = 4.57$, $p < .05$, min $F'(1, 18) = 4.06$, $p = .06$. The interaction effect was 76 ms, with a 95% confidence interval of ±27. In general, listening times were longer in conditions with conflicting cues. Listening times in the Object Prosody-Intransitive/Implausible condition were longer than those in the Subject Prosody-Intransitive/Implausible or Object Prosody-Transitive/Plausible conditions. Listening times were also significantly longer in the Subject Prosody-Transitive/Plausible condition than in the Subject Prosody-Intransitive/Implausible or Object Prosody-Transitive/Plausible condition. There were no other significant effects (*F′s* < 1.0).

Disambiguating (Main) Verb: The main effect of lexical-pragmatic condition was significant, $F1(1, 25) = 13.33$, $p < .01$, $F2(1, 14) = 5.60$, $p < .05$, min $F'(1, 26) = 3.94$, $p = .06$. Listening times were longer for transitive/plausible sentences than intransitive/implausible sentences (effect size=43ms, 95% confidence interval of ±25). Although listening times for the main verb were numerically longer in the object-biased than subject-biased prosodic condition, the main effect of prosodic contour was only significant in the analysis by items, $F1(1, 25) = 2.22$, $p = .15$, $F2(1, 14) = 4.50$, $p < .05$, min $F'(1, 39) = 1.48$, *ns* (effect size=28ms, 95% confidence interval of ±38). The interaction between the lexical-pragmatic and prosodic conditions was significant in the analysis by subjects only, $F1(1, 25) = 4.92$, $p < .05$, $F2(1, 14) = 2.81$, $p = .12$, min $F'(1, 29) = 1.78$, $p = .19$. The effect size was 47ms, with a 95% confidence interval of ±44. Listening times were longer in the Object Prosody-Transitive/Plausible condition than in any other condition. These data suggest that reanalysis occurred in the condition in which all of the manipulated cues supported the late closure (object) interpretation of the ambiguous noun phrase.

Spillover Region: The main effects of lexical-pragmatic condition and prosodic contour were not significant (F's < 1.0). The interaction of lexical-pragmatic condition and prosodic contour approached significance in the subjects analysis, $F1(1, 25) = 3.82$, $p = .06$, but was not significant in the items analysis, $F2(1, 14) = 2.09$, $p = .17$, min $F'(1, 29) = 1.35$, $p = .25$.

Discussion of Experiment 1

Experiment 1 showed that the lexical-pragmatic and prosodic cues interacted during on-line syntactic ambiguity resolution. Consider the conditions with object-biased prosody, in which the subordinate verb was not marked with a prosodic boundary. Overall, the results in these conditions were consistent with those reported in studies of written sentence processing for conditions without a comma (e.g., Van Gompel and Pickering 2001). Listening times for the ambiguous noun phrase were slow in the Intransitive/Implausible condition and fast in the Transitive/Plausible condition. The pattern was reversed at the main verb: Listening times were slower in the Transitive-Plausible condition than in the Intransitive-Implausible condition. This pattern suggests that listeners first attempted to interpret the ambiguous noun phrase as the direct object of the subordinate verb in both conditions. In the Transitive-Plausible condition, this resulted in reanalysis at the main verb. In the Intransitive-Implausible condition, longer listening times for the ambiguous noun phrase likely reflected difficulty integrating it into the subordinate clause. The fast listening times at the verb in this condition suggest that reanalysis to the subject interpretation of the ambiguous noun phrase was completed before the main verb. An alternative explanation is that longer listening times for the ambiguous noun phrase in the Intransitive-Implausible condition reflect extra processing associated with building a new clause (i.e., the main clause). However, the fast listening times in the condition with subject-biased prosody and intransitive/implausible lexical-pragmatic cues are inconsistent with this account.

Now consider the results from the subject-biased prosodic conditions, in which the subordinate verb was marked with a prosodic boundary. As predicted, there were no signs of processing disruption at any of the critical segments in the Subject Prosody-Intransitive/Implausible condition, in which all of the cues were consistent with the early closure interpretation of the sentence. In the Subject Prosody-Transitive/Plausible condition, there was evidence of processing disruption at the ambiguous noun phrase (but not main verb). This result suggests that the prosodic cue interacted with the lexical-pragmatic cues, as suggested by Blodgett (2004) and Snedeker and Yuan (2008), rather than one cue being used before the other as suggested by Kjelgaard and Speer (1999) and Pynte and Prieur (1996).

These results raise several issues. The ambiguous noun phrase is not the first point in time at which the interactions between transitivity bias and prosodic contour could emerge. Because the verb bias and prosodic cues were available at the subordinate verb, interactions between the cues might be observed at that point in the sentence. Another question is whether the nature of sentence processing was changed by the self paced listening task or by practice effects across the four experimental sessions. These issues are addressed in the analyses below.

Analyses of Listening Times for the Subordinate Verb

Listening times were analyzed to determine whether conflicting prosodic and verb transitivity cues would disrupt processing of the subordinate verb. For the subordinate verb, the cues in the Subject Prosody-Transitive/Plausible condition were conflicting because the prosodic cues signal that the clause is ending, but the verb's transitivity bias predicts that the clause should continue. However, the prosodic and transitivity cues are not necessarily conflicting in the Object Prosody-Intransitive/Implausible condition because intransitive verbs may be followed by prepositional phrases or adverbs.

Analyses of listening times for the subordinate verb are challenging because the stimuli differ at that segment. Examining effects of transitivity bias requires comparison of listening times for different words, which is problematic because listening times are affected by word frequency (e.g., Ferreira et al. 1996). Recall that the lists of transitive- and intransitive- biased verbs were matched for frequency, but that the mean frequency for the two sets was not identical. For this reason, potential frequency effects were controlled using an approach in which each participant's raw listening times are regressed against word frequency to determine the response times for each individual predicted on the basis of word frequency alone. The residuals of this analysis were used in the analysis of listening times (cf., Caplan and Waters 2003). Note that the use of residuals sometimes results in negative listening times. The two prosodic conditions could not be directly compared because the differences in length for the subordinate verb were too great. Subtracting out the spoken segment length does not control for the variation introduced by the prosodic manipulation, because it does not account for the extra time available for processing during the spoken segment. For this reason, listening times for the subordinate verb were not compared across prosodic contours. Instead, oneway ANOVAs were used to compare residual listening times for transitive- and intransitive-biased verbs, separately for the subject-biased and object-biased prosodic conditions.

Residual listening times for the subordinate verb are presented in Table 7. In the subject-biased prosody condition, residual listening times for transitive-biased subordinate verbs were significantly longer than those for intransitive-biased verbs, $F1(1, 25) = 19.78$, $p < .001$, $F2(1, 14) = 8.51$, $p < .01$, min $F'(1, 26) = 5.95$, $p < .05$. The effect size of the difference was 49 ms, with a 95% confidence interval of ±22 ms. In the object-biased prosody condition, residual listening times were numerically longer for transitive-biased verb, but the effect of transitivity bias was not significant, $F1(1, 25) = 3.12$, $p = .09$, $F2 < 1.0$, min $F' < .1$.

This result was further investigated by correlating residual listening times for the subordinate verb with the transitivity ratings obtained in the verb norming study (cf., Blodgett 2004). The correlation between transitivity bias and listening time was .45 ($p < .05$) in the subject-biased prosodic condition and .13 (*ns*) in the object-biased prosodic condition. These results suggest that an interaction between transitivity bias and prosodic contour is observable in listening times for the subordinate verb.

Effects of Segmentation on the Prosodic Manipulation

A methodological concern is whether segmentation for self paced listening disrupted the prosodic contour and changed the nature of incremental parsing. This seems unlikely given the pilot study showing that prosodic cues were maintained following segmentation and prior studies showing that self paced listening is sensitive to effects of prosodic contour (e.g., Ferreira et al. 1996; Titone et al. 2006). Another argument against this concern is the similarity of these results to findings in previous eye-tracking studies in all conditions except the one with subject-biased prosody and transitive/plausible lexical-pragmatic cues (e.g., Van Gompel and Pickering 2001).

An alternative way to ask whether self paced listening introduced spurious effects is to examine effects of prosodic contour and lexical-pragmatic condition in the same stimuli without segmentation. Twenty-four participants (age range 18–24 years) completed a version of Experiment 1 using the unsegmented acoustic files. The procedures were the same, except that participants heard the whole sentence rather than self-pacing through each segment. Participants responded more slowly to comprehension probes after stimuli pronounced with object-biased (939.9 ms) than subject-biased prosodic contours (867.5 ms), $F1(1, 23) = 5.30$, $p < .05$, $F2(1, 14) = 3.59$, $p = .08$, min $F'(1, 31) = 2.14$, $p = .15$. Listening times were also longer for sentences in the Transitive-Plausible condition than in the Intransitive-Implausible condition, though the effect was only marginally significant, $F1(1, 23) = 4.28$, $p = .05$, $F2(1, 14) = 3.83$, $p = .07$, *min* $F'(1, 34) = 2.02$, $p = .16$. The interaction was not significant, which is not surprising because the on-line effects were transient and in opposite directions at different points in the self paced presentation version. Overall, these results suggest that cues that were inconsistent with the final interpretation of the sentence resulted in relatively slow response times, and are consistent with the view that self paced listening did not distort on-line processing.

Effects of Practice across Multiple Sessions

The participants in this experiment completed all lists over multiple sessions, which may have introduced practice effects due to participants remembering sentences across sessions. This concern was addressed by analyzing only data from the first sessions. For the ambiguous noun phrase, the interaction between lexical-pragmatic and prosodic conditions was significant by subjects but not items, $F1(1, 24) = 4.85$, $p < .05$; $F2(1, 14) = 1.54$, $p = .23$, min $F'(1, 23) = 1.17$, $p = .29$. At the main verb, the interaction reached the level of a trend, $F1(1, 24) = 3.51$, $p = .07$; $F2(1, 14) = 4.21$, $p = .06$, min $F'(1, 37) = 1.91$, $p = .17$. No other effects approached significance. This pattern is similar to the one described above, even though it is based on only 25% of the dataset. The fact that the basic pattern of results was present in the first session suggests that the within-subject design did not result in adoption of atypical strategies.

Experiment 2: Effects of Transitivity Bias

In Experiment 1, plausibility and transitivity bias were combined into a single factor. As a result, the interaction between lexical-pragmatic and prosodic cues at the ambiguous noun phrase may be due to the transitivity cue alone, the plausibility cue alone, or may require both. Experiment 2 addressed this issue by studying effects of transitivity bias and prosodic contour during syntactic ambiguity resolution when plausibility cues were held constant.

The stimuli in Experiment 2 were early closure sentences with either transitive-biased subordinate verbs followed by plausible direct objects or intransitive-biased subordinate verbs followed by plausible direct objects (see Table 1). The Subject Prosody-Transitive/Plausible and Object Prosody-Transitive/Plausible conditions from Experiment 1 were repeated in Experiment 2, providing the opportunity to observe whether a subset of the effects observed in Experiment 1 would be replicated with a different stimulus set. The plausibility cues in Experiment 2 differed from those in Experiment 1 in the conditions with intransitive-biased subordinate verbs. In the Subject Prosody-Intransitive/Plausible condition, the transitivity and prosodic cues were biased towards the subject (early closure) interpretation of the ambiguous noun phrase and the plausibility cue was biased towards the object (late closure) interpretation. In the Object Prosody-Intransitive/Plausible condition, the transitivity cue was biased to the subject interpretation, and the prosodic and plausibility cues were biased to the object interpretation.

One question that Experiment 2 addressed is whether the direct object interpretation of the ambiguous noun phrase is considered when all of the cues available at the subordinate verb are strongly biased towards the subject interpretation. In the conditions with an intransitive-biased verb and subject-biased prosody, the cues available at the *subordinate verb* are the same in Experiments 1 and 2. When all of the manipulated cues were biased to the subject interpretation in Experiment 1 (the Subject Prosody-Intransitive/Implausible condition), listening times for the ambiguous noun phrase were relatively fast. If the direct object interpretation was not considered at all in this condition, then changing the plausibility of the ambiguous noun phrase should not change the pattern of listening times. Experiment 2 tested this prediction by including a condition in which all of the cues at the subordinate verb were biased to the subject interpretation, but the ambiguous noun phrase was a plausible direct object (i.e., the Subject Prosody-Intransitive/Plausible condition).

An alternative hypothesis is that listeners consider both interpretations of the ambiguous noun phrase, and the lexical-pragmatic and prosodic cues affect the ease of accepting or rejecting a particular analysis. Rejection of the direct object interpretation may have been relatively easy in the Subject Prosody-Intransitive/Implausible condition in Experiment 1 because the lexical-pragmatic and prosodic cues all supported the subject interpretation. Accepting the direct object interpretation would be relatively easy in the Object Prosody-Transitive/Plausible condition because all of the cues support that interpretation. These processes might be slowed when the cues conflict, resulting in the relatively slow listening times observed in the Subject Prosody-Transitive/Plausible and Object Prosody-Intransitive/Implausible conditions. On this view, conflicting cues in the Subject Prosody-Intransitive/Plausible condition in Experiment 2 might result in longer listening times at the ambiguous noun phrase compared to the analogous condition in Experiment 1, where the ambiguous noun phrase was an implausible object.

Methods

Participants—There were twenty-seven participants (age range 18–23 years) who met the same inclusion criteria as described for Experiment 1.

Stimulus Development—Thirteen pairs of sentences containing early closure syntax were developed (see Table 1). Sentence pairs were identical except for the subordinate verbs. The mean lexical frequency (59 for intransitive- and 100 for transitive-bias verbs) did not significantly differ for the two sets, $F(1, 24) = 2.1$, $p = .16$ (Francis and Kuçera 1982). The ambiguous noun phrase was always a plausible direct object for the subordinate verb. Verb transitivity bias and plausibility norms were obtained from the pilot studies described above, and are reported in Table 2. Appendix A presents all of the Experiment 2 stimuli with transitivity and plausibility ratings.

Development and Pretests of Auditory Stimuli

Overview: As for Experiment 1, the stimuli were recorded with subject- and object-biased prosodic contours. The stimuli were subjected to the same pretests as Experiment 1, to ensure that (1) the stimuli were acceptable to naïve listeners (*Acceptability Judgments of Auditory Stimuli*), (2) the acoustic signals differed only in expected ways (*Acoustic Analyses*), and (3) segmentation did not distort the prosodic cues (*Rating of Prosodic Contour in Segmented Stimuli*). Procedures for the pretests were identical to those described above except as noted.

Creation of Auditory Stimuli: The methods of stimulus recording were identical to those used in the creation of stimuli for Experiment 1.

Acceptability Judgments of Auditory Stimuli: Participants ($n = 34$) judged whether the pronunciation of the sentence sounded "okay."As in Experiment 1, stimuli were recorded with conflicting prosodic contours for this pretest. Judgments were analyzed in 3 (prosodic contour: subject-biased, object-biased, conflicting) × 2 (lexical-pragmatic condition: intransitive/ plausible vs. transitive/plausible) ANOVAs. The mean acceptability ratings are in Table 3. There was a significant main effect of prosody, $F(2, 123) = 2, 282.2$, $p < .001$. Sentences produced with subject- and object-biased prosodies were judged to be significantly more acceptable than those produced with conflicting prosodies, but the subject- and object-biased prosodic conditions did not differ from one another. There were no other significant effects.

Acoustic Analyses: Segment duration, pause lengths following the subordinate verb and ambiguous noun phrase, and pitch change across each segment were measured for each recorded stimulus using Praat (Boersma and Weenink 2007; see Table 4). Differences in duration and pitch change were tested by 2 (Prosody) ×2 (Lexical-Pragmatic Condition) ANOVAs. The results were similar to those described for Experiment 1. The first segment (NP1) was significantly longer in object- than subject-biased prosodies, $F(1, 46) = 10.86$, $p < .01$, and duration of the subordinate verb was longer in subject-than object-biased prosodies, $F(1, 46) = 30.01$, $p < .01$. Pitch change was greater in the first noun phrase in sentences with object-biased prosody, $F(1, 47) = 44.91$, $p < .01$, and in the subordinate verb in sentences with subject-biased prosody, $F(1, 47) = 101.23$, $p < .01$. There were no other significant differences in the acoustic measures.

Segmentation for Self paced Listening: Sentences were segmented using the same methods as described for Experiment 1.

Rating of Prosodic Contour: Stimuli were tested to ensure that naïve listeners ($n = 34$) were sensitive to the prosodic manipulations, and that segmentation for self paced listening did not distort the prosodic manipulation. Stimuli were re-recorded and re-piloted until an acceptable set was obtained, so all participants did not make judgments on all of the final stimuli. Stimuli were presented with subject-biased (early closure), object-biased, and conflicting (late closure) prosodic contours. A minimum of ten judgments was obtained for each stimulus.

The ratings were analyzed in a 3 (Prosody) ×2 (Presentation) ANOVA (see Table 8). The main effect of lexical-pragmatic condition was significant, $F(1, 147) = 4.70$, $p < .05$, with more early closure interpretations of sentences with intransitive-biased subordinate verbs. There was also a main effect of prosody, $F(2, 147) = 604.7$, $p < .001$, a significant main effect of presentation format, $F(1, 147) = 19.46$, $p < .001$, and a significant interaction between presentation format and prosodic contour, $F(2, 147) = 5.85$, $p < .05$. For both presentation formats, there were more early closure interpretations in stimuli with subject-biased vs. object-biased or conflicting prosodic contours, and in stimuli with object-biased vs. conflicting prosodic contours. The interaction was due to more early closure interpretations of sentences with subject- and object-biased prosodic contours in the whole sentence than SPL presentation format (Subject-biased: $t(50) = 5.63$, $p < .002$, Object-biased: $t(51) = 2.46$, $p < .05$), but not in sentences produced with conflicting prosody, $t(52) = .34$, *ns*. These results indicate that segmentation somewhat reduced, but did not eliminate, the strength of the prosodic cue.

Creation of Presentation Lists: The stimuli were randomly assigned to four lists such that each version appeared in only one list. These items were combined with 71 filler sentences so that the experimental items comprised 15% of the items in each list. Twelve of the filler sentences in each list contained late closure syntax, which were recorded with two pro-sodic contours (as in Experiment 1). The remaining fillers were unrelated structures, 15% of which contained other prosodically disambiguated syntactic ambiguities (e.g., parenthetical constructions).

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Comprehension Probes: True/False comprehension questions were developed and recorded under the same conditions as described for Experiment 1. Examples are in Table 1.

Procedures

Procedures were identical to those described above for Experiment 1.

Results

Accuracy and listening time data were analyzed in 2 (Prosody: Subject- vs. Object-biased) ×2 (Transitivity: Transitive/Plausible vs. Intransitive/Plausible) ANOVAs by subjects and items. Tukey-tests were used to examine significant interactions using a criteria of $p < .05$.

Comprehension Probes—Accuracy data are presented in Table 6. There were no significant effects of prosodic contour or transitivity bias on accuracy for the comprehension probes (all *F′s* < 1).

Segment Listening Times—Listening times were calculated, and outliers calculated and discarded, as described for Experiment 1. This accounted for less than 1% of the listening time data. The critical segments were (1) the subordinate verb, (2) the ambiguous noun phrase, (3) the point of disambiguation (main verb), and (4) the spillover region. Listening times for the ambiguous noun phrase, main verb, and spillover region are presented in Fig. 3. Listening times for the subordinate verb, which are on a different scale due to use of residual listening times, are presented in Table 7.

Subordinate Verb: Listening times for the subordinate verb were analyzed to investigate whether there were effects of cue conflict at this point in the sentence, as were observed in Experiment 1. Effects of lexical frequency were controlled, and listening times were analyzed, as described for Experiment 1. There were no significant effects of transitivity bias in either of the prosodic conditions (all *F′s* ≤ 1) and no significant correlations (all *r′s* < .05).

Ambiguous Noun Phrase: Analyses of listening times for the ambiguous noun phrase revealed significant main effects of prosodic contour, $F1(1, 26) = 5.11$, $p < .05$, $F2(1, 12) = 5.18$, $p < .05$, min$F'(1, 33) = 2.57$, $p = .12$. The effect size was 27 ms, with a 95% confidence of interval of ±24 ms. Listening times were longer in the subject- than object-biased prosodic condition. The main effect of transitivity bias was also significant, $F1(1, 26) = 4.23$, $p < .05$, $F2(1, 12) = 4.86$, $p < .05$, min $F'(1, 34) = 2.26$, $p = .14$. Listening times were longer for sentences with intransitive- than transitive- biased subordinate verbs (effect size= 19ms, with a 95% confidence interval of ±18 ms). The interaction was non-significant ($F < 1$). Participants were slowed in all conditions with cues inconsistent with the late closure (object) interpretation.

Disambiguating (Main) Verb: Analyses of listening times at the point of disambiguation revealed a main effect of prosodic contour, $F1(1, 26) = 4.78$, $p < .05$, $F2(1, 12) = 7.26$, $p < .05$, min $F'(1, 37) = 2.88$, $p = .10$. Listening times were longer for sentences spoken with object- than subject-biased prosodic contours (effect size=38, 95% confidence interval=±37 ms). The main effect of transitivity bias was also significant, $F1(1, 26) = 5.14$, $p < .05$, $F2(1, 12) = 4.32$, $p < .05$, min $F'(1, 31) = 2.35$, $p = .14$. Listening times were longer for sentences with transitive-biased subordinate verbs (effect size=38, 95% confidence interval = ±37 ms).

Spillover Region: The main effect of prosodic contour was significant in the analysis by subjects but not items, $F1(1, 26) = 4.78$, $p < .05$, $F2 < 1$, min $F' < 1$. There were no other significant effects ($F < 1.0$).

Effects of Practice Across Multiple Sessions—As in Experiment 1, the data from each participant's first session were analyzed to address the concern that the within-subjects design led to strategic effects. The numeric trends were identical to the results of the complete dataset. For the ambiguous noun phrase, the main effect of transitivity bias reached the level of the trend in the analysis by subjects, $F1(1, 26) = 2.92$, $p = .10$, and was significant by items, $F2(1, 12) = 5.54$, $p < .05$, min $F'(1, 38) = 1.91$, $p = .17$. The main effect of prosodic contour reached the level of a trend in both analyses, $F1(1, 26) = 2.91$, $p = .10$, $F2(1, 12) = 2.32$, $p = .15$, min $F'(1, 30) = 1.29$, $p = .26$. At the main verb, the main effect of prosodic contour was significant by subjects but not by items, $F1(1, 3) = 5.25$, $p < .05$, $F2(1, 12) = 1.96$, $p = .19$, min $F'(1, 38) = 1.91$, $p = .17$. The main effect of transitivity bias was significant, $F1(1, 26) = 4.07$, $p = .05$, $F2(1, 12) = 3.38$, $p = .10$, min $F'(1, 30) = 1.29$, $p = .26$. The interaction was marginally significant by subjects only, $F1(1, 26) = 4.13$, $p = .05$, $F2(1, 12) = 1.92$, $p = .19$, min $F'(1, 23) = 1.31$, $p = .26$. The effects in Experiment 2 thus do not appear to be strategic, as they were found (in weaker form) in the data from first sessions.

Discussion of Experiment 2

Listening times were longer at the ambiguous noun phrase, which was always a plausible object, when either the subordinate verb's prosodic contour or transitivity bias was consistent with an early closure structure. This suggests that reconciling the combination of a subject-biased prosodic contour or an intransitive subordinate verb with a plausible potential direct object is demanding. The effects of prosodic contour and transitivity bias were reversed at the main verb, confirming that participants assigned the object reading at the ambiguous noun phrase more securely in conditions with object-biased prosody and transitive-biased subordinate verbs.

The pattern of listening times for the ambiguous noun phrase in sentences with transitive-biased subordinate verbs were similar across Experiments 1 and 2, as expected because both experiments contained sentences with transitive-biased subordinate verbs followed by plausible direct objects. For the intransitive bias conditions, the effects at the ambiguous noun phrase appeared to differ in Experiments 1 and 2. Listening times were numerically longer in the Subject Prosody-Intransitive/Plausible Condition in Experiment 2 (e.g., [*When the couple dances]*$_{IP}$*[the tango*…) than in the Subject Prosody-Intransitive/Implausible Condition in Experiment 1 (e.g., [*While the parents dance]*$_{IP}$*[the child*…). These results suggest that verb bias and plausibility have separate effects on processing. This possibility was further examined by directly comparing the results of Experiments 1 and 2.

Experiment 1 vs. Experiment 2

Data from Experiments 1 and 2 were compared to determine whether listening times in the replicated conditions were statistically equivalent and whether listening times were statistically different in the Subject Prosody-Intransitive conditions. These analyses may also shed light on two unexpected differences between the experiments. First, analyses of the listening times for the subordinate verb showed evidence of disruption in conditions with subject-biased prosodic contours and transitive-biased verbs in Experiment 1 but not 2. Second, listening times in the replicated conditions were approximately 100 ms longer in Experiment 2 than in Experiment 1. The latter finding may reflect the fact that different lexical items were used in the two experiments, and so comparing listening times directly should reveal whether the differences are significant. Because the lexical frequency was not controlled across experiments, residual listening times for each of the critical segments were calculated using the regression procedures to control for word frequency that were described above for the subordinate verb.

Subordinate Verb

Listening times in the subject and object biased prosodic conditions were analyzed in separate 2 (Experiment 1 vs. 2) ×2 (Transitivity bias: Transitive vs. Intransitive) ANOVAs by subjects and items. There were no significant differences in the analyses of the object-biased prosodic condition. For the subject-biased prosodic condition, listening times were numerically longer in Experiment 2 than 1, but the main effect of experiment only reached the level of a trend in the analysis by subjects, $F1(1, 54) = 3.14$, $p = .08$, $F2$ and min $F' < 1$. The main effect of transitivity bias reached the level of a trend in the analysis by subjects, $F1(1, 54) = 3.39$, $p = .07$, and was significant by items, $F2(1, 26) = 5.26$, $p < .05$, min $F'(1, 78) = 2.06$, $p = .15$. Listening times were longer in the subject-biased prosodic condition for transitive- than intransitive-biased verbs. The complete absence of an interaction between experiment and transitivity bias ($F < 1$) suggests the absence of the effect in the subject-biased prosody condition in Experiment 2 may be a matter of power. Correlations across experiments showed that listening times were positively correlated with transitivity bias in the subject-biased prosodic condition, $r = .29$($p < .05$), but not in the object-biased prosodic condition, $r = .02$, *ns*.

Ambiguous Noun Phrase

Listening times were analyzed in 2 (Experiment 1 vs. 2) ×2 (Prosodic Condition: Subject- vs. Object-biased) ×3 (Transitivity bias: Transitive/ Plausible vs. Intransitive/ Plausible vs. Intransitive/ Implausible) ANOVAs by subjects and items. The interaction of experiment, prosodic contour, and transitivity bias was significant in the analysis by subjects, $F1(1, 54) = 10.56$, $p < .01$, and reached the level of a trend in the analysis by items, $F2(1, 26) = 2.97$, $p = .09$, min $F'(1, 41) = 2.31$, $p = .14$. Tukey tests showed no significant differences between the two experiments in the Transitive/Plausible condition in either prosodic condition. Listening times for sentences with intransitive-biased subordinate verbs significantly differed across experiments. In the subject-biased prosodic condition, listening times were significantly longer when an intransitive-biased verb was followed by a plausible direct object (Experiment 2) than when followed by an implausible direct object (Experiment 1). In the object-biased prosodic condition, the opposite pattern was observed: Listening times were longer when an intransitive-biased subordinate verb was followed by an implausible object (Experiment 1) than by a plausible object (Experiment 2).

Main Verb

The listening times for the main verb were analyzed in the same way as the ambiguous noun phrase. The main effect of experiment was significant in the analysis by subjects, $F1(1, 54) = 15.27$, $p < .01$, $F2(1, 26) = 1.92$, $p = .18$, min $F'(1, 33) = 1.71$, $p = .20$. Listening times were longer in Experiment 2 than in Experiment 1. The interaction between experiment and prosodic contour was significant in the analysis by items, $F1(1, 54) = 1.01$, $p = .32$, $F2(1, 26) = 6.49$, $p < .05$, min $F' \leq 1$. Listening times were longer in the object-biased prosodic condition in Experiment 2 than in Experiment 1, but did not significantly differ in the subject-biased prosodic condition. There were no other differences as a function of experiment.

Discussion of Experiment 1 vs. 2

Taken together, the results of the two experiments suggest that prosodic contour, transitivity bias, and plausibility all contributed to processing of the ambiguous noun phrase. If this were not the case, then the effects at the ambiguous noun for the intransitive bias conditions should not have differed in Experiments 1 and 2. Instead, for sentences with intransitive-biased verbs and subject-biased prosody, listening times for the ambiguous noun phrase were longer in Experiment 2, in which the noun was a plausible object, than in Experiment 1, in which it was an implausible object. This effect was reversed in sentences with object-biased prosody. In particular, the results suggest that listeners considered the direct object interpretation of the ambiguous noun phrase even when all cues at the subordinate verb were consistent with the early closure interpretation. This pattern suggests that the numerically faster processing times at the ambiguous noun in the Subject Prosody-Intransitive/Implausible condition in Experiment 1 reflected fast rejection of the direct object interpretation, rather than a failure to consider it.

General Discussion

The principal new result of this study is that prosodic cues influence syntactic parsing at the first point at which they are available. The second important observation is that the prosodic cues interacted with available lexical and plausibility cues at the first points possible, that is, at the subordinate verb and ambiguous noun phrase, respectively. This result is consistent with Blodgett (2004) and Snedeker and Yuan (2008). It differs from Kjelgaard and Speer (1999) claim that prosodic boundaries disambiguate early and late closure structures and from Pynte and Prieur (1996) finding that effects of prosody were reliable only when the verb's argument structure conflicted with the disambiguation of the sentence.

Though not the main focus of this study, the results of Experiments 1 and 2 also suggest that both transitivity bias and plausibility influence on-line sentence comprehension, and that transitivity bias is not more important than plausibility. In particular, plausibility influenced listening times even though the subordinate verbs were strongly biased to occur in either transitive or intransitive frames (e.g., the Subject Prosody-Intransitive/Implausible condition in Experiment 1 vs. the Subject Prosody-Intransitive/Plausible condition in Experiment 2). This finding is at variance with the claim by Garnsey et al. (1997) that plausibility cues influence resolution of syntactic ambiguity only when lexical cues such as verb subcategorization bias are relatively weak. It is possible that the present findings only pertain to sentences with early closure ambiguities presented in the auditory modality. Other structures, such as the complement/object ambiguity studied by Garnsey et al, may be subject to other principles, or perhaps there are auditory/written differences in the use of these types of information that remain to be described and explained.

Returning to the role of prosody, few theories have explicitly described how prosodic contour is used during parsing. On one account, prosodic cues may determine the initial interpretation of a syntactic structure (Kjelgaard and Speer 1999) Along the same lines, Schafer (1997) extending the Garden Path Model (Frazier and Clifton 1996) to prosody, tentatively claimed that prosodic structures acted similarly to other structural constraints (e.g., grammatical class) during syntactic parsing. The findings of the current study are clearly inconsistent with this view. If a prosodic boundary marking the syntactic clausal boundary disambiguated the early closure structure, then other cues should not have influenced listening times. However, the presence of a prosodic boundary following the subordinate verb did not cause listeners to commit to the early closure interpretation in the Subject Prosody-Transitive/Plausible conditions in Experiments 1 and 2. In addition, the plausibility of the ambiguous noun phrase influenced listening times when all of the cues at the subordinate verb supported the subject interpretation and plausibility cues supported the object interpretation (the Subject Prosody-Intransitive/ Implausible condition in Experiment 2). These results suggest that the prosodic boundary marking the syntactic clausal boundary did not cause the participants to commit to an early closure interpretation of the sentence.

One model that describes the role of prosodic cues in syntactic parsing in more detail is the Phon-Concurrent Model (Blodgett 2004), which was mentioned in the introduction to this paper. Unlike the prosody-first accounts discussed above, this model can explain the processing disruption that occurred at the ambiguous noun phrase in the Subject Prosody-Transitive/

Plausible condition (e.g., "[*While the parents watched]$_{IP}$[the child*…"). According to the Phon-Concurrent Model, the intonational phrase boundary (IP) marking the subordinate verb would trigger syntactic and semantic wrap-up, in which the processors commit to the representation with the strongest weight at that point in the sentence (i.e., the subordinate verb). In the syntactic processor, the prosodic boundary would increase the weight of the early closure interpretation and the transitive-biased verb would increase the weight of the late closure interpretation (cf., Blodgett 2004). However, the intransitive structure would be selected because it matches the lexical input at that point in the sentence (i.e., at the subordinate verb). The semantic processor, which only has access to the thematic structure of the verb, would commit to the late closure interpretation because transitive-biased verbs typically take a direct object. According to this model, the syntactic and semantic wrap-up processes are simultaneous and independent, which allows them to commit to conflicting representations. The processing disruption at the ambiguous noun reflects resolution of the conflict between these competing representations.

However, the Phon-Concurrent Model cannot account for longer listening times for the ambiguous noun phrase when both prosodic and transitivity cues supported the subject interpretation but plausibility supported the object interpretation (i.e., Experiment 2's Subject Prosody-Intransitive/Plausible condition, "[*When the boys fought*]$_{IP}$ [*the girls*…"). The Phon-Concurrent Model predicts that in the Subject Prosody-Intransitive condition, both the syntactic and semantic processors would commit to the early closure interpretation before encountering the ambiguous noun phrase. Thus, the plausibility of the direct object should not influence processing. The Phon-Concurrent model can account for these results by relaxing the claim that intonational boundaries trigger "commitment" to the most active structures assigned by the syntactic and semantic processors. The results presented here indicate that, if such commitment does occur, unselected interpretations (e.g., the direct object interpretation in an early closure sentence) must still be available to the syntactic processor. This may be because they are weakly present in a ranked parallel model, or because they are reconstructed in re-analysis. Blodgett did not explicitly address these issues, so it is unclear whether these mechanisms constitute a modification or an elaboration of the Phon-Concurrent Model; what seems clear is that the Phon-Concurrent Model cannot account for the results of the present experiments without a mechanism to reconsider structures and meanings after a prosody-induced wrap-up has occurred.

The reason that the Phon-Concurrent Model has been discussed at length is that it is one of few models that explicitly describe how prosody influences syntactic parsing. In principle, other theories that allow multiple sources of information to be used during sentence processing could account for the results of experiments presented here (e.g., MacDonald et al. 1994). An alternative hinted at above is that prosodic cues act as a separate weight on the range of possible representations. Representations may be selected at each point in the sentence depending on which one is most heavily weighted by all of the available cues. Note that this is similar to the original Concurrent Model (Boland 1997), which claimed that the most probable syntactic structure was selected at each point in the sentence, but that unselected structures would be reactivated if they were consistent with the syntactic input. However, prosodic cues need not trigger *commitments* to particular analyses. On this account, conflicting cues might result in longer listening times due to competition between different representations.

Seen from this perspective, the question arises of how various cues interact; just as Garnsey et al. (1997) suggested an ordering of lexical subcategorization and plausibility cues (which these results dispute, see above), we must ask how prosody and other cues are themselves weighted. One way to pursue this question is to ask why the subject-biased prosodic boundaries in the present experiments did not trump the lexical and pragmatic cues, as has been found in some previous studies. For example, Blodgett (2004) found some correlational evidence to support the interaction of prosodic and transitivity cues at the ambiguous noun phrase in the Subject

Prosody-Transitive condition, but she did not find significant interactions in analyses of variance, as was the case in the present experiments. Similarly, Kjelgaard and Speer (1999) found no evidence of processing disruption in early closure sentences when the syntactic boundary was marked prosodically. In the written modality, the presence of a comma after the subordinate verb also disambiguates early and late closure sentences (e.g., Mitchell 1987).

One issue is whether the nature of the self paced listening task influenced the results. For example, the nature of self paced listening may have resulted in a slower presentation rate for the sentences, which may have affected syntactic parsing operations. In addition, features of the stimulus related to the self paced listening paradigm may have reduced the strength of the boundary cues. For example, segmentation may have interfered with the prosodic cues by decreasing the perceptibility of pitch breaks between words. A related factor is the use of pauses to communicate prosodic boundaries. In the present study, pauses in the recorded stimuli were minimized because they were felt to be most susceptible to disruption by self paced listening. However, as discussed above, there is evidence that segmentation did not distort sentence processing. Also of note, the results from Experiment 1 were largely consistent with previous studies of early closure ambiguities in the written modality (e.g., Van Gompel and Pickering 2001; Staub 2007). In addition, pilot studies confirmed that listeners were sensitive to the prosodic cues after segmentation, though the effectiveness of the cue was somewhat reduced. Thus, it is possible that stronger cues, such as protracted pauses following the subordinate verb, would eliminate the processing disruptions observed in stimuli produced with subject-biased prosodic contours.

This consideration raises the issue of the strength of the prosodic boundaries in the present experiments relative to those in Blodgett (2004) and Kjelgaard and Speer (1999), which used similar sentence structures. One critical difference was the relative duration of the pauses following the subordinate verb and ambiguous noun phrase in the subject- and object-biased prosodic conditions. Carlson et al. (2001) suggested that the relative strength of prosodic boundaries in a sentence is more important during parsing than the strength of any particular boundary. In Blodgett (2004) and Kjelgaard and Speer (1999) there was a large difference between the pauses following the subordinate verb and the ambiguous noun phrase. For early closure stimuli with subject-biased prosodic contours and intonational phrase boundaries, pauses following the subordinate verb and ambiguous noun phrase (respectively) were approximately 300 vs. 10ms in Blodgett and 500 vs. 30ms in Kjelgaard and Speer. In contrast, pauses following the subordinate verb and ambiguous noun phrase in both prosodic conditions in the present experiments were less than 50 ms (See Table 4). Such differences raise two issues, both of which require further study.

The first is whether all intonational cues act in a similar fashion. The extent to which different prosodic cues (pitch change, pause length, etc) determine perceived strength of a prosodic boundary is unexplored. The second is the naturalness of the cues used in existing studies. Although they were not outside the range of possible intonational phrase boundaries, the duration of the boundaries in Blodgett (2004) and Kjelgaard and Speer (1999) may have been unnatural relative to the duration of other pauses in the sentence. Blodgett (2004) and Kjelgaard and Speer (1999) may have exaggerated pause length cues to intonational boundaries, and the self paced listening technique in our studies eliminated them and may have reduced pitch cues. There is increasing evidence that, at the level of phonological segmental processing, naturally occurring acoustic cues provide information not found in artificially produced stimuli, and are used differently from such stimuli (Gow and McMurray 2004; Gow 2003). Studies in which naturally occurring cues to prosodic boundaries are used might result in new perspectives on their role.

To conclude, the results of these studies support constraint satisfaction models in which prosodic cues interact with lexical and pragmatic information early in the sentence during syntactic ambiguity resolution. Details of these interactions remain to be explored.

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Appendix

Experimental Stimuli

Items after each stimulus encode the Verb Class-Proportion of transitive or intransitive verb uses-Plausibility Rating.

Experiment 1

While the parents danced, the child sang a song with her grandmother. Intran-0.90–2.6

While the parents watched, the child sang a song with her grandmother. Tran-0.94–6.79

While the girl swims, her aunt makes lunch for everyone. Intran-0.78–1.05

While the girl visits, her aunt makes lunch for everyone. Tran-0.94–6.75

When the bear growled, the hiker called the ranger for help. Intran-0.96–1.55

When the bear attacked, the hiker called the ranger for help. Tran-0.88–6.7

When the man listened, his wife told him about her new job. Intran-0.96–2.65

When the man phoned, his wife told him about her new job. Tran-0.88–6.95

As the child coughed, the milk spilled on the kitchen counter. Intran-0.84–2.6

As the child poured, the milk spilled on the kitchen counter. Tran-0.90–6.75

As the woman laughed, the dog stole a hamburger off the table. Intran-0.98–1.7

As the woman called, the dog stole a hamburger off the table. Tran-0.79–6.65

Because the teacher fell, the boy gave her a present. Intran-0.9–1.5

Because the teacher helped, the boy gave her a present. Tran-0.88–6.8

As the baby sobbed, her sister tried to calm her with a lullaby. Intran-0.88–1.3

As the baby kicked, her sister tried to calm her with a lullaby. Tran-0.92–5.65

While the parents snored, the children played cards in the kitchen. Intran-0.98–1.15

While the parents hugged, the children played cards in the kitchen. Tran-0.85–6.8

After the woman stood, her dress needed to be ironed for the party. Intran-0.69–1.25

After the woman packed, her dress needed to be ironed for the party. Tran-0.82–6.4

As the woman screamed, the ladder started to tip and fell over. Intran-0.88–1.3

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As the woman climbed, the ladder started to tip and fell over. Tran-0.9–6.8

After the chef sneezed, the cake needed to be decorated by his assistant. Intran-0.96–1.45

After the chef baked, the cake needed to be decorated by his assistant. Tran-0.94–6.65

As the gardener complained, the leaves blew around the yard in the wind. Intran-0.92–1.3

As the gardener raked, the leaves blew around the yard in the wind. Tran-0.96–6.95

When the sisters giggled, their mother smiled at them happily. Intran-0.92–1.35

When the sisters kissed, their mother smiled at them happily. Tran-0.82–6.65

When the musician bowed, the students admired his enthusiasm and his talent. Intran-0.92–1.95

When the musician taught, the students admired his enthusiasm and his talent. Tran-0.86–6.8

Experiment 2

After the father walked, the dog wanted to play with the ball. Intran-0.83–6.8

After the father cleaned, the dog wanted to play with the ball. Tran-0.8–6.05

When the couple dances, the tango looks very easy to learn. Intran-0.9–6.75

When the couple teaches, the tango looks very easy to learn. Tran-0.9–6.05

When the girl tripped, her friend told the teacher what happened. Intran-0.8–6.42

When the girl copied, her friend told the teacher what happened. Tran-0.88–6.45

After the salesman cheated, the woman talked about him with the manager. Intran-0.92–6.15

After the salesman helped, the woman talked about him with the manager. Tran-0.88–6.85

While the boys fought, the girls played soccer in the park. Intran-0.69–6.4

While the boys watched, the girls played soccer in the park. Tran-0.94–6.85

As the artist studied, the model sat on the couch with a book. Intran-0.86–6.9

As the artist painted, the model sat on the couch with a book. Tran-0.9–6.4

When the woman swims, the river seems more beautiful than ever. Intran-0.78–5

When the woman visits, the river seems more beautiful than ever. Tran-0.94–5.95

After the lion escaped, the trainer held a press conference at the zoo. Intran-0.73–5.89

After the lion attacked, the trainer held a press conference at the zoo. Tran-0.88–6.65

Before the farm grew, the potatoes were planted in the fields near the house. Intran-0.73– 5.45

Before the farm sold, the potatoes were planted in the fields near the house. Tran-0.98–5.6

When the woman screamed, the name sounded familiar to her friend. Intran-0.88–5.95

When the woman called, the name sounded familiar to her friend. Tran-0.78–6.05

As the child hopped, the fence tore a huge hole in his pants. Intran-0.9–6.35

As the child climbed, the fence tore a huge hole in his pants. Tran-0.9–6.75

After the pirates sank, the treasure was found hidden in a cave. Intran-0.84–6.3

After the pirates lost, the treasure was found hidden in a cave. Tran-0.92–6.3

When the robot exploded, the bomb destroyed the building near the embassy. Intran-0.92–5.4

When the robot guarded, the bomb destroyed the building near the embassy. Tran-0.98–5.7

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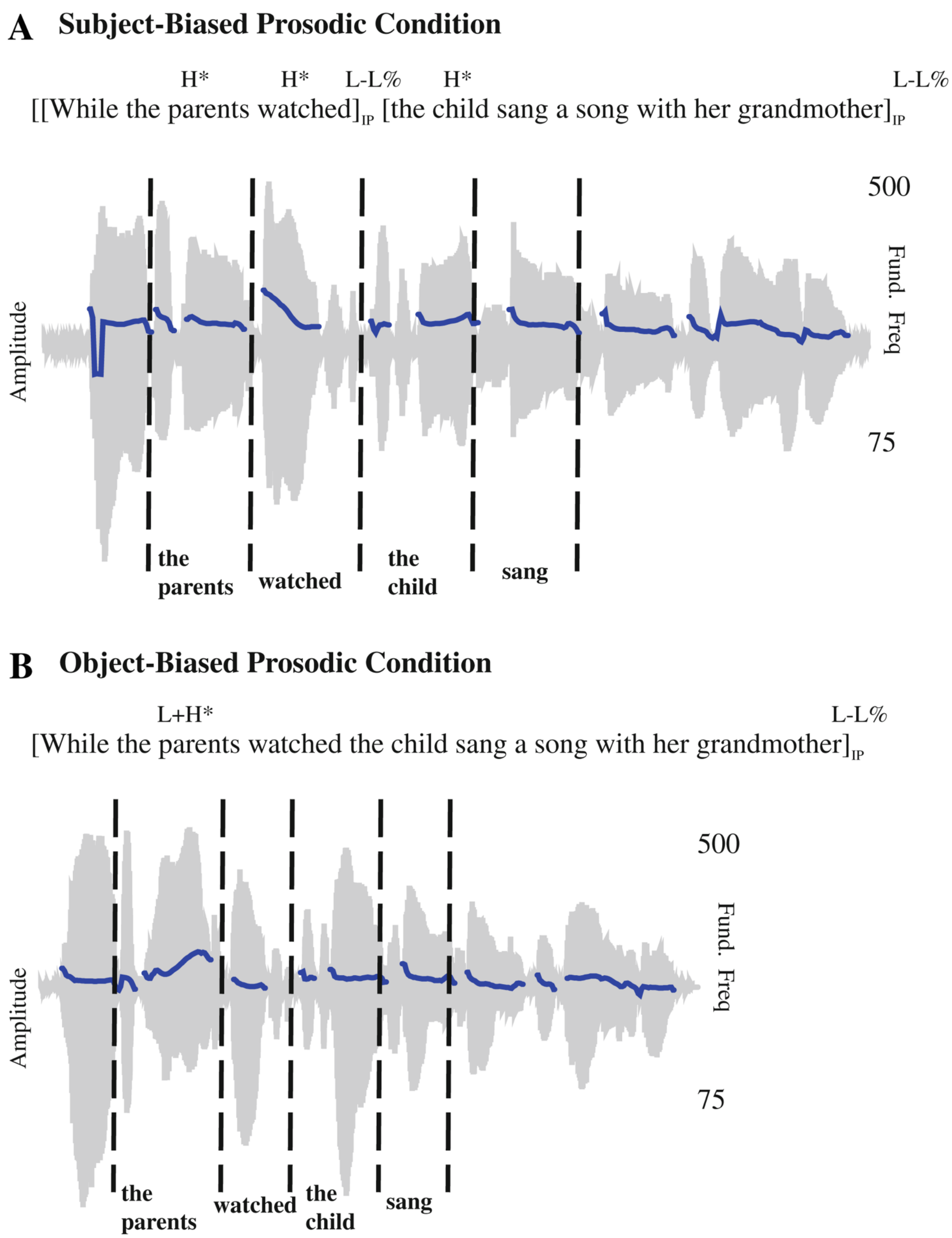

Fig. 1.

Examples of prosodic conditions: spectrogram and fundamental frequency.

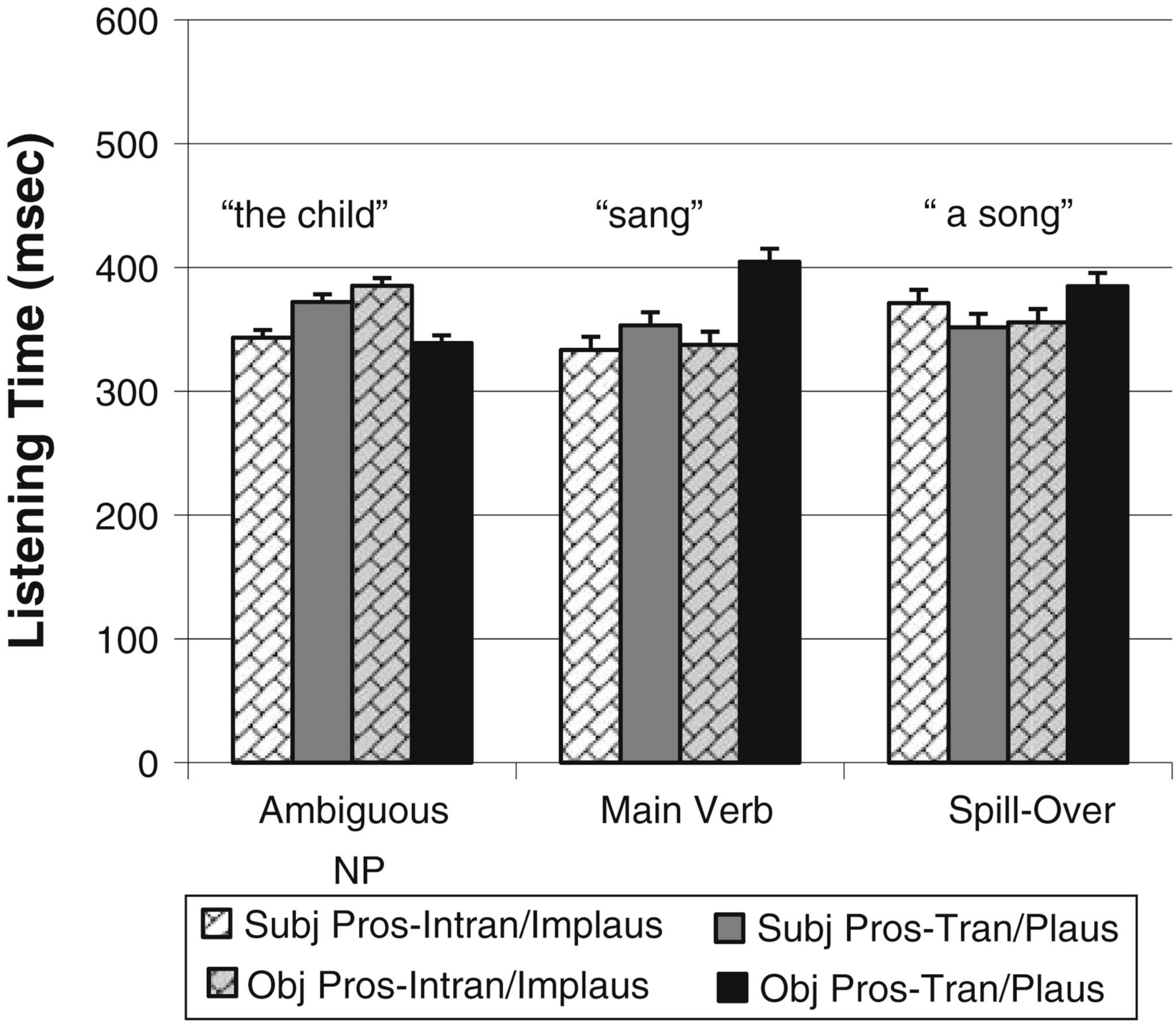

Fig. 2.
On-line listening times in critical segments in Experiment 1. *Error bars* indicate one standard error above the mean

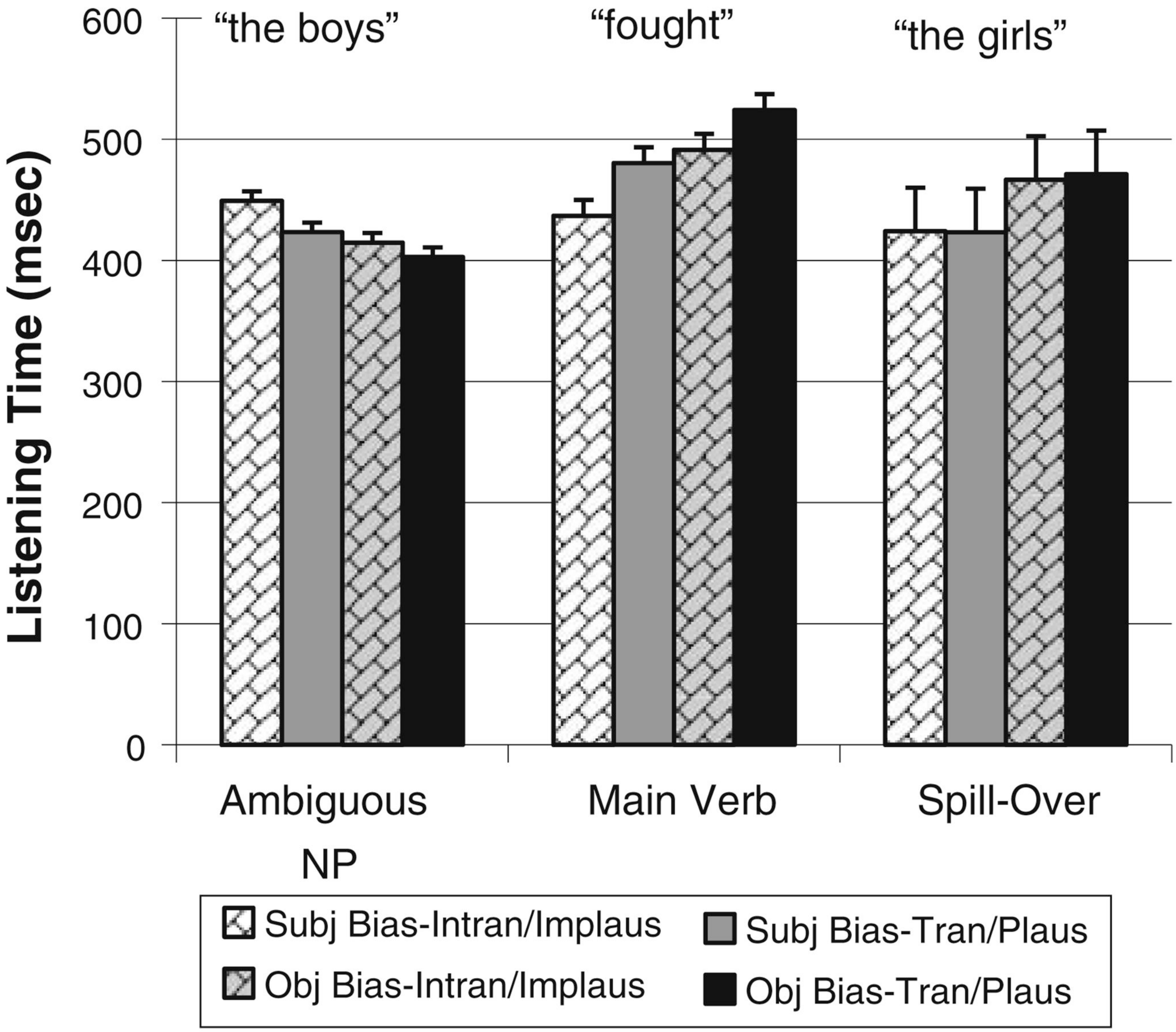

Fig. 3.
Experiment 2 listening times for critical segments. *Error bars* indicate one standard error above the mean

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Table 1

Examples of Experiment 1 and 2 stimuli and conditions

Experiment 1
Subject biased prosody-intransitive/implausible condition:
[[While the parents / danced]$^{L-L\%}_{IP}$/ [*the child / sang / a song* / in the kitchen]]$^{L-L\%}_{IP}$
*Subject biased prosody-transitive/plausible condition:**
[[While the parents / watched]$^{L-L\%}_{IP}$/ [*the child / sang / a song*/ in the kitchen]]$^{L-L\%}_{IP}$
Object biased prosody-intransitive/implausible condition:
[While the parents / danced / *the child / sang / a song* / in the kitchen]$^{L-L\%}_{IP}$
*Object biased prosody-transitive/plausible condition:**
[While the parents / watched / *the child / sang / a song* / in the kitchen]$^{L-L\%}_{IP}$
Comprehension probe:
The parents danced together.
Experiment 2
Subject biased prosody-intransitive/plausible condition:
[[While the boys / fought]$^{L-L\%}_{IP}$/ [*the girls / played / soccer* / in the park]]$^{L-L\%}_{IP}$
*Subject biased prosody -transitive/plausible condition:**
[[While the boys / watched]$^{L-L\%}_{IP}$/ [*the girls / played / soccer* / in the park]]$^{L-L\%}_{IP}$
Object biased prosody-intransitive/plausible condition:
[While the boys fought / *the girls / played / soccer/* in the park]$^{L-L\%}_{IP}$
*Object biased prosody-transitive/plausible condition:**
[While the boys watched / *the girls / played / soccer /* in the park]$^{L-L\%}_{IP}$
Comprehension probe:
The boys played soccer.

Note: Slashes depict location of segmentation for self-paced listening. Prosodic boundaries are indicated with TOBI notation (*IP* intonational phrase, *ip* intermediate phrase, *L*- low phrase accent, *L*% low boundary tone). Critical segments are in italics print. Asterisks (*) denote conditions that are repeated in Experiments 1 and 2

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Table 2

Mean (and SD) transitivity bias (proportion of transitive / intransitive uses) and plausibility ratings for Experiments 1 and 2

	Transitivity/intransitivity bias	**Plausibility rating**
Experiment 1		
Intransitive/implausible	0.02/0.90 (.05)	1.52 (.45)
Transitive/plausible	0.88/0.08 (.05)	6.63 (.32)
Experiment 2		
Intransitive/plausible	0.11/0.82 (.08)	6.24 (.51)
Transitive/plausible	0.89/0.06 (.08)	6.31 (.50)

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Table 3

Proportion acceptable judgments for auditory stimuli for Experiments 1 and 2

	Prosodic contour		
	Subject-biased	**Object-biased**	**Conflicting**
Experiment 1			
Intransitive/implausible	.93 (.05)	.90 (.07)	.15 (.10)
Transitive/plausible	.92 (.06)	.89 (.07)	.09 (.07)
Experiment 2			
Intransitive/plausible	.97 (.03)	.92 (.07)	.12 (.07)
Transitive/plausible	.94 (.04)	.93 (.06)	.14 (.08)

Table 4

Acoustic measurements of auditory stimuli for Experiments 1 and 2

	Subject-biased prosody		Object-biased prosody	
Experiment 1	**Trans-plaus**	**Intrans-implaus**	**Trans-plaus**	**Intrans-implaus**
Duration (ms)				
NP1*	540	513	616	600
Sub V*†	500	557	419	481
Ambig NP	476	477	507	491
MainV	367	363	375	387
Pause length (ms)				
SubV—Ambig NP	45	50	37	33
Ambig NP—MainV	20	17	22	25
Pitch change (Hz)				
NP1*	50.03	50.49	72.2	65.42
SubV*	86.46	85.35	42.55	52.32
Ambig NP	51.51	46.6	47.3	43.28
MainV	44.01	43.86	42.97	48.91

	Subject-biased prosody		Object-biased prosody	
Experiment 2	**Trans-plaus**	**Intrans-plaus**	**Trans-plaus**	**Intrans-plaus**
Duration (ms)				
NP1*	577	554	660	634
SubV*	621	608	490	500
Ambig NP	552	554	552	559
MainV	472	467	471	474
Pause length (ms)				
SubV-Ambig NP2	18	7	17	7
NP2-MainV	22	21	15	16
Pitch change (Hz)				
NP1*	21	19	11	15
SubV*	85	83	19	14
Ambig NP	13	6	7	6
MainV	9	7	13	12

*Main effects of prosody, $p < .05$;

†main effect of transitivity, $p < .05$

Table 5

Mean (and SD) percent of early closure interpretations in self-paced listening and whole sentence tasks—Experiment 1

Task	Subject-biased prosody	Object-biased prosody
Self-paced listening	91% (12.1)	19% (18.9)
Whole sentence	96% (8.0)	13% (20.7)

Table 6

Mean (and SD) proportion correct for comprehension questions in Experiment 1 and 2

	Subject-biased prosody		**Object-biased prosody**	
Experiment 1	Intran-implaus	Tran-plaus	Intran-implaus	Tran-plaus
	.93 (.09)	.94 (.08)	.91 (.11)	.93 (.09)
Experiment 2	Intran-plaus	Tran-plaus	Intran-plaus	Tran-plaus
	.85 (.17)	.87 (.17)	.88 (.17)	.87 (.14)

Table 7

Mean (and SD of) residual listening times for the subordinate verb (ms) for Experiments 1 and 2

	Experiment 1	**Experiment 2**
Subject-biased prosody		
Intransitive	−56.4 (33.6)*	−16.6 (59.7)
Transitive	−7.11 (42.2)	−13.0 (75.9)
Object-biased prosody		
Intransitive	15.4 (38.4)	14.6 (60.9)
Transitive	46.14 (62.3)	14.8 (62.4)

*Main effect of transitivity, $p < .05$. Note that the use of residual listening times sometimes results in negative values, as seen above. This essentially means that the raw listening times were (on average) faster than would be expected on the basis of word frequency alone

Table 8

Mean (and SD) percent of early closure interpretations in self-paced listening and whole sentence tasks for Experiment 2

	Subject-biased prosody		Object-biased prosody		Conflicting prosody	
	Tran-plaus	**Intran-plaus**	**Tran-plaus**	**Intran-plaus**	**Tran-plaus**	**Intran-plaus**
Self-paced listening	.78 (.13)	.84 (.10)	.14 (.11)	.25 (.19)	.04 (.06)	.06 (.10)
Whole sentence	.97 (.06)	.95 (.08)	.29 (.21)	.35 (.21)	.03 (.07)	.05 (.10)