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Electrophysiological evidence for the interaction of prosody and thematic fit during sentence comprehension

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ABSTRACT
This study investigated the interaction of prosody and thematic fit/plausibility information during the processing of sentences containing temporary early closure (correct) or late closure (incorrect) syntactic ambiguities using event-related potentials (ERPs). Early closure sentences with congruent and incongruent prosody were presented where the temporarily ambiguous NP was either a plausible or an implausible continuation for the subordinate verb (e.g. "While the band played the song/beer pleased all the customers."). N400 and P600 components were examined at critical points in each condition. The CPS was examined in sentences with congruent prosody. Prosodic and thematic fit cues interacted immediately (N400–P600) at the implausible NP (*beer*), when it was paired with incongruent prosody. Incongruent prosody paired with a plausible NP (*song*) resulted in garden-path effects (N400–P600) at the critical verb (*pleased*). These findings provide strong evidence that prosodic and thematic fit/plausibility cues interact to aid the parser in syntactic structure building.

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Event-related potentials (ERPs); sentence processing; prosody; thematic fit

Introduction

In this paper we describe a study examining how prosody and plausibility are used to resolve structural ambiguities during on-line sentence processing. Consider:

1. While the band played the song pleased all the customers.

Moving "left-to-right", (1) contains a temporary syntactic ambiguity where the verb *played* is optionally transitive and thus it is initially unclear whether the subsequent NP (*the song*) is the direct object of *played* (e.g. " … the band played the song") or the subject of the main clause (e.g. "the song pleased all the customers"). Many studies have found that in the absence of a comma or prosodic information to help aid the parse, late closure structure is initially preferred (where *the song* is the direct object of *played*) over early closure structure (where *the song* is the subject of the main clause) (Frazier & Rayner, 1982; Pauker, Itzhak, Baum, & Steinhauer, 2011; Staub, 2007). When subsequent information is encountered (e.g. the verb *pleased*), listeners/readers realise they have been "garden-pathed" – led down the garden path and misanalysed the sentence. This is likely due to the simpler syntactic structure present in late closure sentences. Yet, if the sentence is presented aurally, the addition of a pause after the word *played* can disambiguate the subsequent temporary syntactic ambiguity by signalling the presence of a syntactic boundary (Nicholas Nagel, Shapiro, & Nawy, 1994; Schafer, Speer, Warren, & White, 2000; Speer, Warren, & Schafer, 2003; Warren, Schafer, Speer, & White, 2000). Prosodic boundaries congruent with syntactic structure have been found to enhance processing, while incongruent boundaries obstruct processing (Bögels, Schriefers, Vonk, Chwilla, & Kerkhofs, 2010, 2013; Carlson, Frazier, & Clifton, 2009; Kjelgaard & Speer, 1999; Nicholas Nagel et al., 1994; Pauker et al., 2011; Pynte & Prieur, 1996; Schafer et al., 2000; Steinhauer, Alter, & Friederici, 1999).

Prosodic cues in sentence processing

Prosody is the stress, timing, and intonation in speech and can be described using pitch, amplitude and duration measures. A prosodic break, or intonational phrase boundary, can be indicated by a pause, lengthening of the word preceding the pause, as well as a boundary tone at the pre-pause word. The impact of prosody on sentence processing has been investigated using both behavioural and ERP measures, and studies using behavioural methods suggest that the syntactic structure of a

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sentence is immediately influenced by prosodic cues (DeDe, 2010; Ferreira, Anes, & Horine, 1996; Kjelgaard & Speer, 1999; Marslen-Wilson, Tyler, Warren, Grenier, & Lee, 1992; Speer, Kjelgaard, & Dobroth, 1996). Moreover, prosodic breaks tend to occur at major syntactic boundaries (Cooper & Paccia-Cooper, 1980; Nicholas Nagel et al., 1994; Price, Ostendorf, Shattuck-Hufnagel, & Fong, 1991).

ERPs studies have also found evidence of prosody-driven garden-path effects. There are three language-related ERP components that are of particular interest in auditory sentence processing: the Closure Positive Shift (CPS), the N400, and the P600. Each component reflects a different aspect of sentence processing. Steinhauer et al. (1999) first described the CPS component, which is elicited in spoken sentences at prosodic phrase boundaries and is characterised by a large positive-going waveform with a bilateral distribution and a duration of about 500–700 ms (Steinhauer, 2003; Steinhauer et al., 1999). It is sensitive to pauses in speech along with other types of acoustic boundary markers such as constituent lengthening and boundary tones (Steinhauer, 2003), and is believed to reflect the decoding of intonational phrasing. In ERPs the N400 is sensitive to semantic processing integration difficulty (Brown & Hagoort, 1993; Hagoort, Baggio, & Willems, 2009) (see Kutas & Federmeier, 2011 for a review), and the P600 is elicited by syntactic violations (Osterhout & Holcomb, 1992, 1993). The P600 may reflect syntactic reanalysis processes (Friederici, 2011), syntactic integration difficulty (Kaan, Harris, Gibson, & Holcomb, 2000), or possibly the effort and time required to build the syntactic structure of the sentence (Hagoort, 2003). A biphasic N400–P600 complex is often found in garden-path sentences at the disambiguation point because garden-path effects can interfere with both lexical-semantic integration (reflected by the N400) and syntactic integration (reflected by the P600). Several studies have found that a mismatch between prosody and syntax can lead to a prosody-driven garden path effect, which is reflected by the N400–P600 (Bögels et al., 2010; Pauker et al., 2011; Steinhauer et al., 1999).

For example, Steinhauer et al. (1999) discovered an N400–P600 complex at the disambiguation point in prosody-driven garden path sentences. Pauker et al. (2011) also found evidence of an N400–P600 complex in prosody-driven garden path sentences. Specifically, sentences that either contained a congruent/incongruent prosodic boundary, or were missing a prosodic boundary were compared. The results revealed that the insertion of an incongruent boundary resulted in an N400–P600 complex, whereas a missing boundary only resulted in a P600. Moreover, sentences missing prosodic boundaries elicited higher participant acceptability ratings relative to those with incongruent boundaries. These results suggest that in the absence of prosodic information, listeners prefer a late closure syntactic structure, similar to results from reading studies where garden-path effects are elicited when a comma is missing (Frazier & Rayner, 1982). However, when a prosodic cue was available to aid their parse, this preference was easily overridden. They proposed a Boundary Deletion Hypothesis (BDH), which states that mentally deleting a prosodic boundary is more difficult than inserting one. Support for the BDH was also found in a study by Bögels, Schriefers, Vonk, Chwilla, and Kerkhofs (2013). Pauker and Bögels conclude that while listeners may prefer the simpler late closure over an early closure structure, this preference is quickly overridden when prosodic information leads the listener to another conclusion.

Lexical-Semantic cues in sentence processing

In addition to prosodic cues, other information, such as lexical-semantic cues, may also interact with syntax during sentence processing. For example, consider (2):

2. While the band played the beer pleased all the customers.

Here, the NP (*the beer*) immediately following the verb *played* appears to constrain the initial parse; the NP is more easily integrated into the sentence as the subject of the ensuing clause (correct interpretation) rather than the object of *played* (incorrect interpretation), since people typically don't "play beer." The combination of a verb with its arguments is often called "thematic fit" because, in this case, some NPs are better continuations of particular verbs than others. Evidence suggests that the parser is sensitive to verb transitivity and thematic fit (Staub, 2007) such that processing is momentarily disrupted when a transitive-biased verb is followed by an implausible direct object. Furthermore, studies examining the effect of lexical cues suggest that the lexical-semantic content of the NP can lessen or eliminate the garden-path effect, as in (2). Here, the NP *the beer* is a poor fit as a direct object for the verb *played*, unlike *the song* in (1), and thus the preference for late closure is reduced, and so too is the garden-path effect.

It remains unclear *how* and *when* prosody interacts with other types of non-syntactic information – for example, thematic fit – to influence "garden-path" effects. Only a few studies have examined the interaction of prosodic and lexical cues in sentence processing (Blodgett, 2004; DeDe, 2010; Itzhak, Pauker, Drury, Baum, & Steinhauer, 2010; Pynte & Prieur, 1996; Snedeker & Yuan, 2008). For example, Snedeker and Yuan (2008), used the visual world eye tracking method to examine the effects of lexical and prosodic cues with sentences containing ambiguous prepositional phrases (PP) (e.g. "You can feel the frog with the feather."). Here the PP can either be attached to the VP (*feel*), indicating the feather is an instrument with which to *feel* the frog, or to the NP (*the frog*), indicating the frog is holding a feather. The location of the prosodic break (intonational phrase break after the verb (*feel*) – biased toward the NP interpretation, or an intonational phrase break after the noun (*frog*) – biased toward the VP interpretation) and the type of verb (biased toward the NP interpretation, biased toward the VP interpretation, or no bias) were manipulated. Snedeker and Yuan found evidence that both of these cues interacted early in sentence processing and are used to resolve structural ambiguities.

Itzhak et al. (2010) examined the interaction of prosodic and plausibility cues in an ERP study where participants were presented with sentences that either had early closure structure (e.g. [While Billy was playing] [the game seemed simple]) or late closure structure (e.g. [While Billy was playing the game] [the rules seemed simple.]) with correct prosody. They were also presented with a garden path condition that had early closure structure with no prosodic cue to aid the parse. Additionally, the transitivity of the subordinate verb was manipulated to either have a transitive or intransitive bias. Their results revealed a larger P600 in transitively biased compared to intransitively biased verb in the garden path condition with no prosodic cue, which suggested that plausibility immediately influences structural parsing decisions. Moreover, a CPS (sensitive to intonational phrase boundaries) was elicited in transitively biased, but not intransitively biased garden path sentences, even though no prosodic boundary was present. This particular result indicates the combination of a preference for late closure structure and transitivity probabilistic cues caused the parser to mentally insert a prosodic boundary. CPS effects were also reliably generated in the late and early closure conditions at each prosodic break. Therefore, their results imply that prosodic cues override other forms of information and significantly aid comprehension, yet in the absence of overt prosodic cues, lexical-semantic information can influence covert prosodic phrasing (e.g. the elicitation of a CPS component). While Itzhak *et al.* explored the influence of lexical-semantic information in the form of transitivity bias, we were interested in exploring how other forms of plausibility information would impact sentence processing. Specifically, we conducted an ERP study examining the influence and interaction of prosody and thematic fit on sentence processing.

Current study

The current experiment seeks to understand the role of prosodic and lexical-semantic (thematic fit) cues during the processing of garden-path sentences using event-related brain potentials. Consider the sentences in Table 1.

Each sentence has early closure underlying syntactic structure but contains a temporary syntactic ambiguity because the first verb in each sentence (*played*) is optionally transitive, thus it has the option of taking a direct object or not. Thematic fit was manipulated such that the NP following the optionally transitive verb was either a plausible (Pr + TF + and Pr−TF +) or implausible (Pr + TF− and Pr-TF−) direct object. Prosody was also manipulated to either be congruent (pause after the verb *played*) or incongruent (pause after the NP *song/beer)* with the syntactic structure. These manipulations yielded a 2 (Sentence Type: plausible thematic fit, implausible thematic fit) × 2 (Prosody: congruent, incongruent) design as shown in Table 1.

Questions and predictions of current study

Question 1: were participants sensitive to intonational phrase boundaries? – predictions at the prosodic break. This question was addressed with two comparisons. First, waveforms were compared at the offset of the subordinate verb (*played*) in Pr + TF + vs. Pr−TF + sentences, which corresponded to the onset of the prosodic break in Pr + TF + sentences but not Pr−TF + sentences. Next, waveforms were also compared at the offset of *played* in Pr + TF− vs. Pr−TF− sentences, corresponding to the onset of the prosodic break in Pr + TF− sentences. Based on previous research we predicted that participants would perceive the prosodic break in each comparison, as evinced by a CPS component in Pr + TF + and Pr + TF− sentences.

Table 1. Example experimental sentences.

Sentence	Prosody (Pr)	Plausibility / Thematic Fit (TF)	Condition
[While the band played] [the song pleased all the customers.]	Congruent (+)	Plausible (+)	*Pr + TF +*
[While the band played] [the beer pleased all the customers.]	Congruent (+)	Implausible (−)	*Pr + TF−*
[While the band played the song] [pleased all the customers.]	Incongruent (−)	Plausible (+)	*Pr−TF +*
[While the band played the beer] [pleased all the customers.]	Incongruent (−)	Implausible (−)	*Pr−TF−*

Note: Brackets depict the prosodic contour of each sentence.

Question 2: does the parser use plausibility cues to predict syntactic structure? – predictions at ambiguous NP (song/beer). To answer this question, pairwise comparisons were conducted between sentences with congruent prosody (Pr + TF + vs. Pr + TF−), and sentences with incongruent prosody (Pr−TF + vs. Pr−TF−), at the onset of the temporarily ambiguous NP (*song/beer*). Analyses comparing all four sentences were also conducted. Recall that *the beer* in Pr−TF− sentences is a poor thematic fit for the subordinate verb, *played*, and this poor thematic fit may provide a plausibility cue to aid syntactic processing. The poor thematic fit between *played* and *the beer* in Pr−TF− sentences may trigger syntactic reanalysis at the ambiguous NP – before the disambiguation point at the critical verb *pleased*. We predicted this would be the case, and thus expected to find a biphasic N400–P600 complex at the ambiguous NP in Pr−TF− sentences compared to Pr−TF + sentences. The N400 effect in Pr−TF− at the ambiguous NP (*the beer*) would confirm that incongruent prosody caused the parser to initially attempt to parse the structurally ambiguous NP as the direct object of the verb played, but did not consider the NP the beer to be a good thematic fit with played. Hence, the presence of an N400 in this comparison would indicate semantic integration difficulty in Pr−TF− because *the beer* is an implausible direct object for the subordinate verb played. The presence of a P600 effect in Pr−TF− sentences compared to Pr−TF + sentences at the ambiguous NP would indicate that the poor thematic fit between *played* and *the beer* in Pr−TF− triggered syntactic reanalysis. We did not expect to find significant differences between the sentences with congruent prosody (Pr + TF + vs. Pr + TF−).

Question 3: does incongruent prosody result in garden-path effects at critical verb? – predictions at critical verb (Point of disambiguation). We examined prosodic garden-path effects due to incongruent prosody as indicated by the N400–P600 complex at the point of disambiguation (*pleased*) across all four conditions. The presence of an N400–P600 complex in the conditions with incongruent (Pr−TF + and Pr−TF−) relative to congruent prosody (Pr + TF + and Pr + TF−) would indicate that incongruent prosody yielded a garden-path effect. Recall that the good thematic fit between the subordinate verb, *played*, and the NP, *the song*, in Pr + TF + and Pr−TF + sentences does not provide the listener with a strong plausibility cue to help predict structure. However, the poor thematic fit between the subordinate verb, *played,* and *the beer* in Pr + TF− and Pr−TF− sentences is a strong plausibility cue that the NP *the beer* likely is not a direct object of *played*. Any differences in the N400–P600 complex between sentences with incongruent prosody and a plausible NP, Pr−TF +, compared to the sentences with incongruent prosody and an implausible NP, Pr−TF−, would indicate that plausibility information immediately interacts with syntactic structure building.

We expected to find a classic garden path effect at the critical verb, *pleased*, as indicated by the presence of the N400–P600 complex in Pr−TF + sentences compared to sentences with congruent prosody. However, because we expected to find a P600 at the ambiguous NP, *beer*, in Pr−TF− sentences, we did not anticipate finding an additional N400–P600 complex downstream at the critical verb.

Materials and methods

Participants

We tested 25 college-age students (19 females, mean age = 21 years) who were right-handed monolingual speakers of American English. As indicated by self-report, all of the participants had not experienced substantial exposure to a second language before the age of twelve. They also indicated they had normal or corrected-to-normal visual and auditory acuity, and were neurologically and physically stable at the time of testing with no history of psychiatric illness, drug or alcohol abuse, or other significant brain disorder or dysfunction.

Materials

Four types of experimental sentences were investigated in this study:

[While the band played] [the song pleased all the customers.] (Pr + TF +)

[While the band played] [the beer pleased all the customers.] (Pr + TF −)

[While the band played the song] [pleased all the customers.] (Pr − TF +)

[While the band played the beer] [pleased all the customers.] (Pr − TF −)

Sentences with congruent prosody (Pr + TF + and Pr + TF−) were recorded using naturally produced early closure prosody, and the following filler sentences were recorded using naturally produced late closure prosody:

3a. [While the band played the song] [the beer pleased all the customers.]

3b. [While the band played the beer] [the song pleased all the customers.]

Sentences with incongruent prosody (Pr−TF + and Pr−TF−) were formed using a waveform editor (Adobe Audition) to cut the initial portions of (3a–3b) up to the end of the pause following the ambiguous NP ("*the song/the beer* (pause)") and spliced to replace everything before the onset of the critical verb *pleased* in sentences with congruent prosody (Pr + TF + and Pr + TF−). Thus sentences with incongruent prosody (Pr−TF + and Pr−TF−) were formed from the sentence segment "While the band played the song/beer (pause)" (from 3a–3b), and the segment "pleased all the customers" from sentences with congruent early closure prosody (Pr + TF + and Pr + TF−).

Additionally, sentences (3a–3b) served as fillers in this experiment. The inclusion of these two types of filler sentences ensured that listeners heard sentences with late closure syntactic structure, and prosody, paired with a temporarily ambiguous NP that was either a good thematic fit (*song* in 3a) or a poor thematic fit (*beer* in 3b) for the first verb (*played*). The filler sentences (3a–3b) were also formed via cross-splicing where we obtained two different recordings of each filler sentence and replaced the dependent clause ("*While the band played the song/beer* (pause)") of one repetition with the subordinate clause of the other repetition.

Creating the four experimental sentences allowed us to determine whether prosody can bias listeners toward a specific parse even when the lexical cues (whether the NP is a plausible or implausible direct object for the subordinate verb) conflict with the argument structure of the verb. NPs were counterbalanced across the different verbs used in our materials. Sixty of each type of experimental sentence (Pr + TF +, Pr + TF−, Pr−TF +, Pr−TF−) and filler sentence (3a–3b) were created yielding 60 sentence frames of 6 sentences each for a total of 360 sentences (240 experimental sentences and 120 filler sentences). All sentences were recorded at a regular rate of speech (4–6 syllables/second) in a soundproofed environment. The 360 sentences were split into two experimental lists. Both lists were presented to participants in one data collection session, and the order in which the lists were presented was counterbalanced across subjects. Each participant heard each of the 360 sentences once, and each sentence frame was repeated six times.

Acoustic measurements

To confirm that each condition's prosody varied as expected in their acoustic properties, we conducted word duration and pitch analyses. We anticipated significantly longer durations at the clause final word relative to its non-clause final counterpart (e.g. we expected *played* to be longer in Pr + TF + where it is the clause final word, than in its counterpart sentence, Pr−TF +, where it is not the clause final word). We also anticipated the temporarily ambiguous NP, *the song/beer,* to be longer in Pr−TF + and Pr−TF− sentences, where *song/beer* is in a clause final position relative to Pr + TF + and Pr + TF−, where the ambiguous NP is clause medial. Moreover, we expected to find a congruent pause after the subordinate verb (*pleased*) in the conditions with congruent prosody (Pr + TF + and Pr + TF−) but not in those with incongruent prosody (Pr−TF + and Pr−TF−). Similarly, we predicted there would be an incongruent pause after the temporarily ambiguous NP in conditions with incongruent prosody (Pr−TF + and Pr−TF−), but not in conditions with congruent prosody (Pr + TF + and Pr + TF−). The data were subjected to a 2 × 2 ANOVA with Prosody (Congruent, Incongruent) and Plausibility/Thematic Fit (Plausible, Implausible) as factors.

We also conducted pitch analyses and anticipated significantly lower fundamental frequency ($F_ø$) measures at the clause final word compared to the same word in the counterpart sentence at a different position in the clause. These expectations were based on pitch analyses from similar experiments (Kjelgaard & Speer, 1999). Therefore, we expected *played* to have a lower $F_ø$ in Pr + TF + sentences, where it is the clause final word, compared to Pr−TF + counterpart sentences, where *played* is in a clause medial position. Similarly, we expected the ambiguous NP *the song/beer* to have a significantly lower $F_ø$ in Pr−TF + and Pr−TF− sentences, where it is the clause final word, compared to Pr + TF + and Pr + TF− sentences, where it is in a clause initial position (the beginning of the main clause). We did not expect to find differences at the critical verb. We compared $F_ø$ measures at the first verb (*played*), the ambiguous NP (*song/beer*), and the critical verb. The data were analysed with a 2 × 2 ANOVA with the factors Prosody (Congruent, Incongruent) and Plausibility/Thematic Fit (Plausible, Implausible).

The results revealed in Table 2 corresponded with our predictions. We found evidence of significant pre-boundary lengthening of the first verb followed by a pause in conditions with congruent prosody relative to those with incongruent prosody, as indicated by a main effect of prosody at the subordinate verb (*played*) (F (1, 239) = 138.2, $p < .001$) and the congruent pause (F (1, 239) = 1151.4, $p < .001$). Similarly our results revealed significant

Table 2. Mean duration measurements for each condition in milliseconds (ms).

	Mean Durations (ms)				
	Subordinate Verb (*played*)	Congruent Pause	Temporarily Ambiguous NP (*song/beer*)	Incongruent Pause	Critical Verb (*pleased*)
Congruent Prosody					
Plausible NP (*Pr + TF +*)	521.8 (10.6)	206.0 (8.9)	475.9 (11.98)	–	384.1 (15.6)
Implausible NP (*Pr + TF–*)	515.4 (12.1)	223.4 (8.7)	478.9 (13.9)	–	384.2 (15.1)
Incongruent Prosody					
Plausible NP (*Pr–TF +*)	357.6 (12.7)	–	604.8 (13.1)	294.0 (10.2)	369.8 (15.8)
Implausible NP (*Pr–TF–*)	391.4 (13.4)	–	651.9 (16.6)	319.8 (10.4)	373.1 (16.1)

Note: Parentheses contain standard error values.

pre-boundary lengthening of the ambiguous NP (F (1, 239) = 116.3, $p < .001$) followed by a pause (F (1, 239) = 1776.3, $p < .001$) in conditions with incongruent prosody relative to those with congruent prosody, as signified by a main effect of prosody at both points in the sentence. The duration of the critical verb did not differ significantly between conditions.

Furthermore, our pitch analyses revealed support for our predictions, as we discovered evidence of pitch differences at the clause final word due to Prosody (See Table 3). Specifically, the mean $F_ø$ at the subordinate verb was significantly lower in conditions with congruent prosody relative to those with incongruent prosody (F (1, 239) = 14.9, $p < .001$). The mean $F_ø$ at the temporarily ambiguous NP was significantly lower in conditions with incongruent relative to congruent prosody (F (1, 239) = 156.8, $p < .001$). No significant differences were found at the critical verb.

Procedure

The participants were fitted with an electrode cap and were presented with sentences over headphones while sitting in a comfortable chair in a dimly lit sound-attenuated room. Simultaneous with the onset of each word in a sentence, a code specifying the condition of the word was sent to the computer digitizing the electroencephalography (EEG) data. This allowed for precise time-locking of the EEG with word onset across the various conditions. For each trial the start of the sentence was accompanied by a fixation cross in the centre of the screen, which disappeared 1000 ms post-sentence offset and was replaced by a question mark signalling the participant to make an acceptability judgment about the sentence they just heard by button press (Figure 1). Once the response was made the experiment advanced to the next trial. Before the experiment began, each participant was presented with a block of 10 practice items to familiarise them with the procedure.

Table 3. Mean fundamental frequency ($F_ø$) measurements for each condition.

	Mean Minimum $F_ø$ (Hz)		
	Verb 1 (*played*)	Ambiguous NP (*song/beer*)	Critical Verb (*pleased*)
Congruent Prosody			
Plausible NP (*Pr + TF +*)	161.0 (4.5)	202.9 (4.3)	170.2 (2.9)
Implausible NP (*Pr + TF–*)	160.3 (5.0)	189.9 (5.5)	166.7 (3.7)
Incongruent Prosody			
Plausible NP (*Pr–TF +*)	214.3 (3.3)	146.3 (3.0)	171.6 (2.9)
Implausible NP (*Pr–TF–*)	214.3 (4.5)	144.7 (2.8)	170.0 (3.9)

Note: Parentheses contain standard error values.

Behavioural data analysis

The percentage of accepted sentences in each condition were computed from the subject acceptability ratings. Next, the accuracy of responses was defined and compared across conditions using a subject-based repeated measures ANOVA with the factors Prosody (Congruent, Incongruent) and Plausibility/Thematic Fit (Plausible, Implausible). An "Acceptable" rating was considered an accurate response for Pr + TF + and Pr + TF– sentences, and an "Unacceptable" rating was an accurate response for Pr–TF + and Pr–TF– sentences.

EEG recording procedure

The EEG was recorded from 29 active tin electrodes at the scalp (Electrode-Cap International). Additional electrodes were attached below the left eye (VE, used to monitor blinks), to the side of the right eye (HE, to monitor horizontal eye movements), over the right mastoid bone, and the left mastoid bone (A1, reference electrode). The eye electrode impedances were maintained below 10 kΩ, with the remaining electrode impedances maintained below 5 kΩ. The EEG signal was amplified by a Neuroscan Synamp RT system using Curry data acquisition software. Recording bandpass was DC to 200 Hz and the EEG was continuously sampled at a rate of 500 Hz throughout the duration of the experiment. ERPs were averaged from artefact free trials time-locked to critical target word onset with a 1300 ms epoch.

ERP data analysis

ERPs were time-locked to critical points in each sentence (details will be provided in the Results section). All EEG

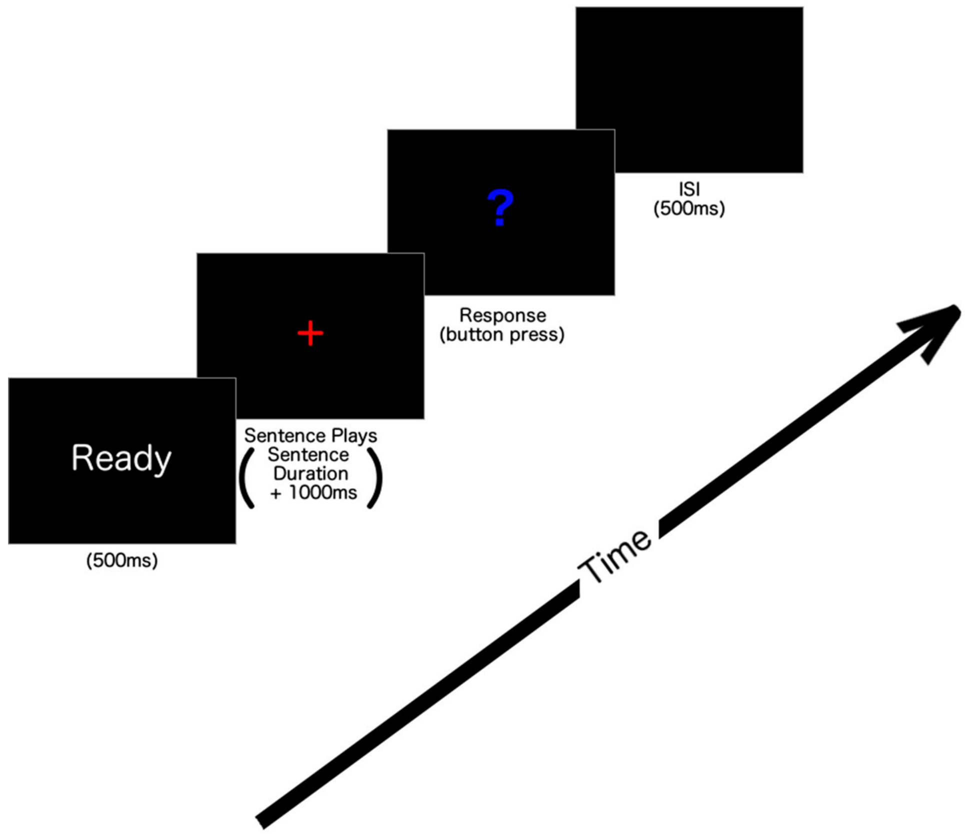

Figure 1. Schematic of one trial. Participants were presented with the word "Ready" in the centre of the screen to signal the beginning of a new trial. Next, a red cross was presented in the centre of the screen, which corresponded with the sentence playing. The red cross remained on the screen throughout the sentence duration up to 1000 ms after the sentence ended. A blue question mark was presented to signal that the participant could make their acceptability response by button press. The question mark disappeared once a response was selected.

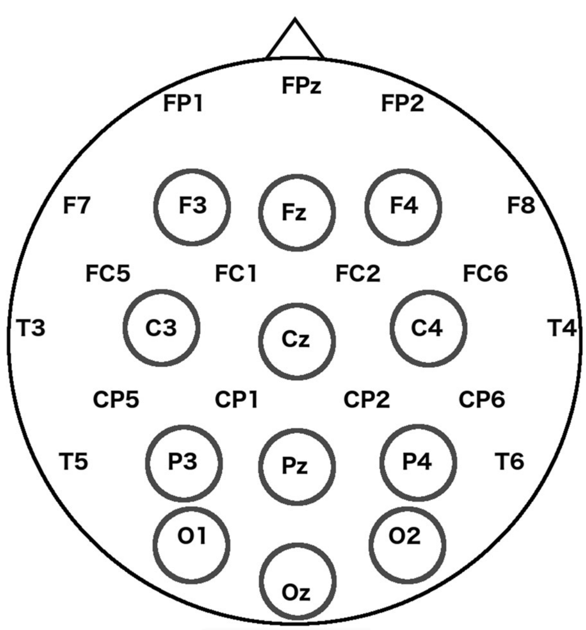

Figure 2. Electrode map. The circled electrodes indicate the 12 electrodes used in data analysis.

trials with eye-blinks, eye-artefacts, and muscle movement artefacts were rejected from analysis (3.93% of trials on average). Participants with rejection rates above 20% were rejected. We excluded one participant's data for exceeding this rejection rate. Our ERPs were averaged from the trials remaining after artefact rejection and were bandpass filtered at .03–15 Hz (FFT-FIR filter). A subset of 12 of the 29 scalp sites (Figure 2) were selected to be included in data analyses. Average waveforms were produced and analyses were conducted at three points in the sentence: (1) the prosodic break in conditions with congruent prosody (Pr + TF + and Pr + TF–) compared to those with incongruent prosody (Pr–TF + and Pr–TF–); (2) the ambiguous NP, *beer/song*, between all four conditions; and (3) at the critical verb, *pleased* between all four conditions. The analyses in the first comparison at the prosodic break contained two levels of Prosody (Congruent vs. Incongruent). The analyses at the ambiguous NP *song/beer,* and the critical verb *pleased* contained factors of two levels of Prosody (Congruent vs. Incongruent), two levels of Plausibility (Plausible vs. Implausible), and two levels of Time (Early vs. Late). Time was included in the analysis in order to investigate any latency differences between N400 and P600 effects in the four experimental sentences, where the N400 epoch was split into an early (300–500 ms) and a late time window (500–700 ms), and the P600 epoch was also split into an early (700–1000 ms) and a late time window (1000–1300 ms). Each analysis also contained three levels of Laterality (left, midline, right), and four levels of Anteriority (frontal, central, parietal, occipital). When interactions warranted follow up analyses in the analyses of intonational phrase boundaries (Question 1), pairwise comparisons were conducted between Pr + TF + vs. Pr–TF + sentences (plausible NP comparison), and between Pr + TF– vs. Pr–TF– (implausible NP comparison). When interactions necessitated follow up analyses in the analyses at the ambiguous NP (Question 2) and the critical verb (Question 3), pairwise comparisons were made between Pr + TF + vs. Pr + TF– (congruent prosody comparison), and Pr–TF + vs. Pr–TF– (incongruent prosody comparison). Pairwise comparisons were conducted within both early and late time windows when interactions included Time as a factor for Questions 2 and 3.

Mean voltages were calculated in several time windows (see details in Results section) and were analysed using separate repeated measures analyses of variance (ANOVAs). The Geisser and Greenhouse (1959) correction was applied to all repeated measures with more than one degree of freedom in the numerator in order to address violations of sphericity.

Results

Results of behavioural data

Recall that we examined the accuracy of responses in each condition, where "Acceptable" was the correct response for Pr + TF + and Pr + TF– sentences, and "Unacceptable" was the correct response for Pr–TF + and Pr–TF– sentences. Both conditions with congruent prosody had similar acceptance ratings. Pr + TF + sentences had an 84% acceptability rating and Pr + TF– sentences an 85% acceptability rating, while both incongruent prosody conditions Pr–TF + and Pr–TF–, had very low acceptability ratings (13% and 10% respectively). These results demonstrate that our prosodic manipulation was successful. These analyses show that participants were relatively accurate at identifying each condition as acceptable or not. No significant differences were found in accuracy between conditions as our analyses did not reveal any significant main effects or interactions (all $F < 1.3$). Thus, the participants were able to identify the acceptability of each condition equally well.

ERP results

Question 1: were participants sensitive to intonational phrase boundaries? – onset of the prosodic break in conditions with congruent prosody– CPS effects

Recall we predicted participants would be sensitive to intonational phrase boundaries. We included two comparisons examining CPS effects at the onset of the prosodic break in congruent prosody sentences (Pr + TF + and Pr + TF–), corresponding to the offset of the subordinate verb (*played*), compared to the same point in sentences with incongruent prosody where there was not a pause. First we compared sentences with a plausible NP (Pr + TF + vs. Pr–TF +), and next we compared sentences with an implausible NP (Pr + TF– vs. Pr–TF–).

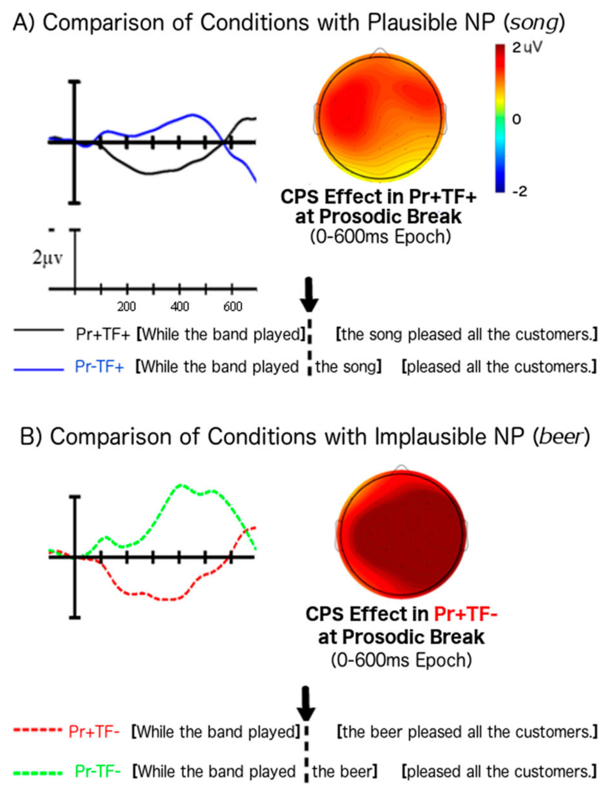

Figure 3. CPS effects at the Prosodic Break in Sentences with Congruent Prosody. Grand Average ERPs at subordinate verb (played) offset corresponding to prosodic break in sentences with congruent prosody (Pr + TF + and Pr + TF–). A) CPS at prosodic break in Pr + TF +, compared to Pr–TF + sentences without a prosodic break at this point and B) CPS at prosodic break in Pr + TF–, compared to Pr–TF– sentences without a prosodic break at this point. The voltage maps show topographical distribution of CPS effects across the scalp based on the difference waveforms (congruent – incongruent prosody) ([Pr + TF +] – [Pr–TF +] in A; [Pr + TF–] – [Pr–TF–] in B) in the 0–600 ms epoch. In both comparisons the prosodic break elicits a significant CPS effect. Waveforms were low pass filtered at 5 Hz for presentation purposes only.

We anticipated finding a CPS effect in both comparisons. A 100 ms pre-stimulus baseline was used to investigate for CPS effects in the 0–600 ms epoch.

Pr + TF + vs.Pr − TF + Plausible NP Comparison.

Visual inspection of Figure 3(A) reveals a CPS effect in Pr + TF + with a broad distribution across the head that returns to baseline at about 600 ms. Analyses in this epoch showed a main effect of Prosody (F (1,24) = 11.39, p = .003) as well as interactions of both, Prosody × Anteriority (F (3, 72) = 4.03, p = .047) and Prosody × Anteriority × Laterality (F (6, 144) = 3.76, p = .01). These interactions indicate the CPS effect is larger in left hemisphere and midline anterior sites.

Pr + TF - vs.Pr − TF − Implausible NP Comparison.

Evidence of a CPS effect was also found in Pr + TF− sentences. The results depicted a main effect of Prosody (F (1,24) = 43.66, p < .001), and an interaction of Prosody × Laterality (F (2,48) = 8.53, p = .002), which indicated that the right-lateralized CPS had a broad distribution across the scalp (Figure 3(B)). Note that the CPS effect in this comparison looks larger than the Pr + TF + vs. Pr−TF + comparison. This is presumably due to the N400 in Pr−TF− sentences at the onset of *beer*, which occurs during the second half of the CPS epoch.

Question 2: does the parser use plausibility cues to predict syntactic structure? – onset of temporarily ambiguous NP (song/beer)

In order to determine whether the parser uses plausibility cues to predict syntactic structure we compared ERPs at the onset of the temporarily ambiguous NP (*song* vs. *beer*). We examined the 300–700 ms epoch for N400 effects, and included Time as a factor in our analyses where this epoch was divided into early (300–500 ms) and late (500–700 ms) N400 windows. The 700–1300 ms epoch was examined for P600 effects, and similarly was divided into early (700–1000 ms) and late (1000–1300 ms) P600 windows. As was described in the previous section, there were waveform differences early in the ERPs, which likely resulted from the large positive CPS component at this point in the congruent sentences. Although this difference makes comparisons in an omnibus ANOVA difficult, in order to compensate we used a 200 ms post-stimulus baseline interval, which helped equate the differences across this portion of the waveforms, and we also performed separate pairwise comparisons between congruent prosody sentences (Pr + TF + vs. Pr + TF−) and between incongruent prosody sentences (Pr−TF + vs. Pr−TF−). These waveform differences resulted from the large positive CPS component at this point in sentences with congruent prosody that was not present at this point in sentences with incongruent prosody, as described in the previous section. Results from the omnibus ANOVA are also reported.

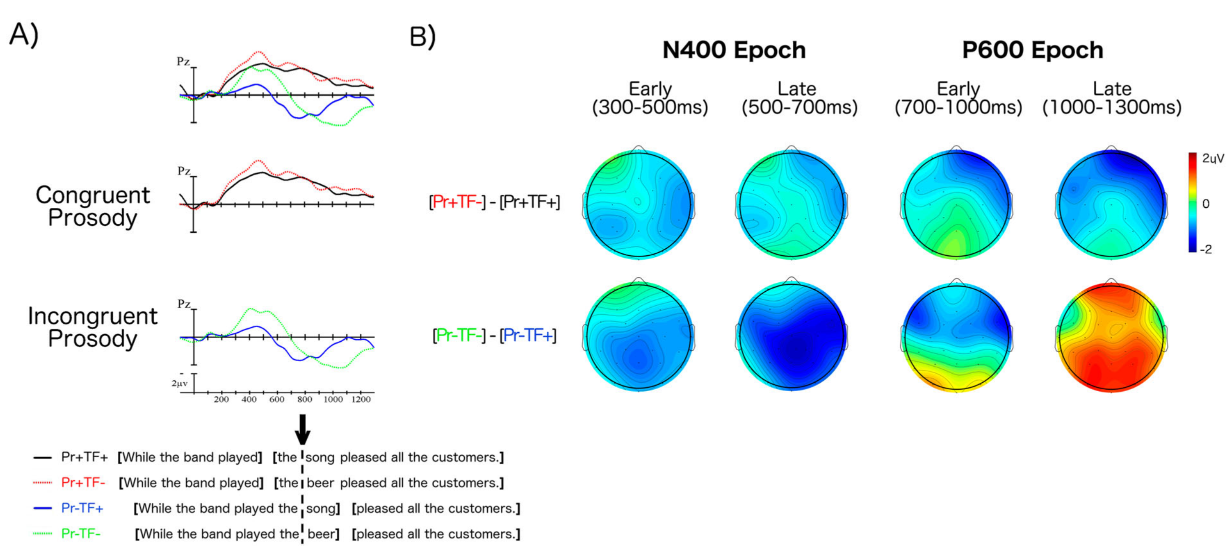

Figure 4. Grand average ERPs at the temporarily ambiguous NP (song/beer). A) Grand average ERPs at Pz sites comparing all four experimental sentences, sentences with congruent prosody (Pr + TF + vs. Pr + TF−), and sentences with incongruent prosody (Pr−TF− vs. Pr−TF +). B) Voltage maps of N400 early (300–500 ms) and late time windows (500–700 ms), and P600 early (700–1000 ms) and late time window (1000–1300 ms). Voltage maps depict difference waves as indicated in the figure. Waveforms were low pass filtered at 5 Hz for presentation purposes only.

N400 Epoch

Visual inspection of the waveforms (see Figure 4) revealed no differences between sentences with congruent prosody. Yet an N400 effect is apparent in Pr−TF− sentences compared to Pr−TF + sentences, where only Pr−TF− sentences contain a plausibility cue. Pairwise comparisons of congruent prosody sentences (Pr + TF + vs. Pr + TF−) confirmed the absence of significant differences between sentences with congruent prosody. Also, as predicted, in the comparison of incongruent prosody sentences (Pr−TF + vs. Pr−TF−), an N400 effect was elicited in sentences with a plausibility cue (Pr−TF−) as demonstrated by a main effect of Plausibility (F (1, 24) = 21.52, $p < .001$).

The comparison of all four sentence types, revealed main effects of Prosody (F (1, 24) = 19.24, $p < .001$) and Plausibility (F (1, 24) = 32.31, $p < .001$) as well as interactions of Prosody × Laterality (F (2, 48) = 15.44, $p < .001$). These results indicated that the large positivity/CPS in congruent prosody sentences in the baseline of this analysis created a confound which made it problematic to compare all four sentence types. Due to these baseline differences, the sentences with congruent prosody were more negative-going than sentences with incongruent prosody. However, as the pairwise comparisons demonstrate, differences in the N400 window were only present in the comparison of sentences with incongruent prosody.

P600 Epoch

Note that the P600 epoch corresponded with the onset of the prosodic break in incongruent prosody sentences (Pr−TF + and Pr−TF−). Thus, we anticipated finding a positivity in both of these sentences, indicating a positive CPS component that is sensitive to intonational phrase boundaries. We anticipated the plausibility cue at the ambiguous NP in Pr−TF− sentences would result in a P600 effect, so we hypothesised finding a larger positivity in Pr−TF− sentences, indicating a combined CPS and P600 component and only a small positivity in Pr−TF + sentences due to the presence of a CPS, but no P600. Visual inspection of Figure 4 revealed no differences between congruent prosody sentences, but a significant P600 effect in Pr−TF− sentences in the comparison of incongruent prosody sentences (Pr−TF− vs. Pr−TF +). Analyses confirmed these findings, and revealed no significant differences between sentences with congruent prosody (Pr + TF + vs. Pr + TF−). The comparison of sentence with incongruent prosody (Pr−TF + vs. Pr−TF−) demonstrated that Pr−TF− sentences, with a plausibility cue, elicited a significant P600 effect that was posteriorly distributed and was largest in the late window, as indicated by a significant interactions of Plausibility × Anteriority (F (3, 72) = 7.79, $p = .001$), Plausibility × Time (F (1, 24) = 12.14, $p = .002$), and Plausibility × Time × Anteriority (F (3, 72) = 4.5, $p = .033$). In order to further investigate the time course of the P600 effect, follow up analyses within the early and late time windows were conducted for incongruent prosody sentences.

Analyses in the early P600 window (700–1000 ms) revealed a significant Plausibility × Anteriority interaction (F (3, 72) = 9.13, $p = .002$), which indicated that when compared to Pr−TF + sentences, Pr−TF− sentences elicited a P600 in the early P600 window with a posterior distribution. Analyses within the late P600 window (1000–1300 ms) indicated the P600 effect had a scalp-wide distribution, which was demonstrated by a main effect of Plausibility (F (1, 24) = 5.79, $p = .024$) (Figure 4).

Additional analyses of all four sentences confirmed that incongruent prosody elicited a widespread positivity (main effect of Prosody (F (1, 24) = 32.36, $p < .001$). Interactions of Prosody × Laterality (F (2, 48) = 8.06, $p = .003$) and Prosody × Anteriority × Laterality (F (6, 144) = 5.36, $p = .002$) showed that the positivity elicited by incongruent prosody (Pr−TF + and Pr−TF−) was largest in centroparietal and occipital sites along the mid-line and right-hemisphere (Figure 4). Additionally, implausible NPs elicited more positive-going waveforms with a posterior distribution (Plausibility × Anteriority (F (3, 72) = 7.67, $p = .003$). Interactions of Prosody × Plausibility × Time (F (1, 24) = 15.47, $p < .001$), Prosody × Time Anteriority (F (3, 72) = 17.80, $p < .001$), Plausibility × Time × Laterality (F (2, 48) = 6.11, $p = .007$) were also found.

Question 3: does incongruent prosody result in garden-path effects at critical verb? – prosodic garden-path effects at critical verb (pleased)

Garden-path effects driven by incongruent prosody were examined by comparing waveforms time-locked to the critical verb (*pleased*), which was the disambiguation point in all four experimental conditions. N400 effects were examined in the 300–700 ms epoch (300–500 ms, and 500–700 ms time windows) and P600 effects in the 700–1300 ms epoch (700–1000, and 1000–1300 ms time windows). A 200 ms post-stimulus baseline interval was used to compensate for prosodic differences between sentences with congruent and incongruent prosody. If we used a pre-stimulus baseline, comparisons became difficult because the positivities at the ambiguous NP in sentences with incongruent prosody (Pr−TF + and Pr−TF−) impacted the effects of interest.[1] We hypothesised finding an N400–P600 complex in Pr−TF + sentences, which have incongruent prosody and

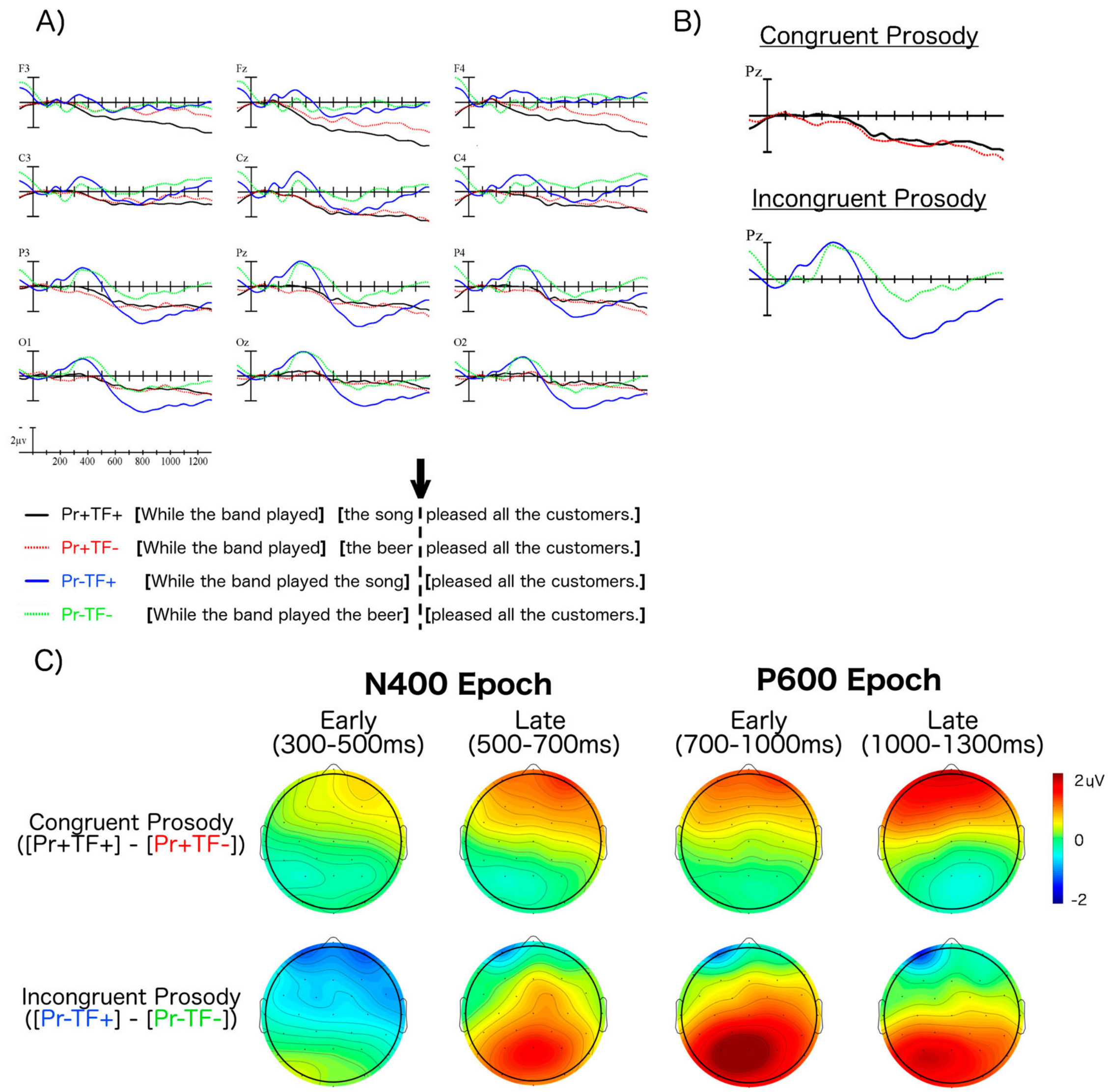

Figure 5. Grand average ERPs at the critical verb (played). A) Waveforms across 12 electrode sites used in analysis. B) Grand average ERPs at Pz sites comparing sentences with congruent (Pr+TF+ vs. Pr+TF-), and incongruent prosody (Pr–TF+ vs. Pr–TF–) C) Voltage maps of N400 early (300–500 ms) and late time windows (500–700 ms), and P600 early (700–1000 ms) and late time window (1000–1300 ms). Voltage maps depict difference waves as indicated in the figure. Waveforms were low pass filtered at 5 Hz for presentation purposes only.

no plausibility cue before the critical verb to help them predict syntactic structure. Recall that we anticipated finding an N400–P600 earlier in the sentence at the NP (*beer*) in Pr–TF– sentences, due to the presence of a plausibility cue. Thus, we did not expect to also find an N400–P600 at the critical verb (*pleased*) in Pr–TF– sentences.

N400 Epoch

As depicted in Figure 5, visual inspection of the waveforms demonstrated an N400 in both sentences with incongruent prosody (Pr–TF + and Pr–TF–) compared to sentences with congruent prosody (Pr + TF + and Pr + TF–). Yet, the N400 had a shorter duration in Pr –TF + sentences. The analyses comparing all four sentences revealed a main effect of Prosody (F (1, 24) = 6.96, $p = .014$)) where incongruent prosody elicited more negative-going waveforms. A main effect of Time (F (1, 24) = 27.33, $p < .001$) was also revealed, indicating waveforms were more negative-going in the early time window. Interactions of Prosody × Laterality (F (2, 48) = 3.66, $p = .042$) and Prosody × Anteriority × Laterality (F (6, 144) = 3.92, $p = .011$) demonstrated that the N400 to sentences with incongruent prosody (Pr–TF + and Pr –TF–) had a centroparietal distribution at midline and right-hemisphere sites. Additionally, the N400 elicited by incongruent prosody had an anterior distribution in sentences with a plausible NP (Pr−TF +), but a more posterior distribution in sentences with an implausible NP (Pr−TF−), as indicated by a significant Prosody × Plausibility × Anteriority interaction (F (3, 72) = 5.85, p = .001). Moreover, this N400 was largest in the early time window, particularly in parieto-occipital midline and right-hemisphere sites (significant interactions of Prosody × Time (F (1, 24) = 9.18, p = .006), Prosody × Time × Anteriority (F (3, 72) = 16.81, p < .001), Prosody × Time × Laterality (F (2, 48) = 7.15, p = .004), and Prosody × Time × Anteriority × Laterality (F (6, 144) = 5.48, p < .001)). Finally, the N400 elicited by incongruent prosody was largest in the early time window, particularly in Pr−TF + sentences (significant interactions of Plausibility × Time (F (1, 24) = 12.00, p = .002), and Prosody × Plausibility × Time (F (1, 24) = 7.31, p = .012)). In order to further investigate these effects, pairwise comparisons with both time windows were conducted as described below.

Recall that visual inspection revealed N400 components in both sentences with incongruent prosody, and the N400 in Pr−TF− sentences appeared to have a slightly longer duration (Figure 5). Pairwise comparisons within the early N400 window (300–500 ms) confirmed that there were no significant differences between sentences with congruent prosody (Pr + TF + vs. Pr + TF−), and no significant differences between sentences with incongruent prosody (Pr−TF + vs. Pr−TF−) within this early time window.

Pairwise comparisons in the late N400 window (500–700 ms) between congruent prosody sentences (Pr + TF + vs. Pr + TF−) revealed a small frontal negativity in Pr + TF− sentences (Plausibility × Anteriority (F (3, 72) = 4.98, p = .023)). The comparison of incongruent prosody sentences in the late N400 window (Pr−TF + vs. Pr−TF−) showed no significant effects.

P600 Epoch

Visual inspection of the P600 window (700–1300 ms) reveals a large P600 component in Pr−TF + sentences (see Figure 5). The analysis of all four experimental sentences in the entire P600 window (700–1300 ms) indicated waveforms in sentences with plausible NPs (Pr + TF + and Pr−TF +) were more positive-going than those with implausible NPs (Pr + TF− and Pr−TF−) (main effect of Plausibility (F (1, 24) = 4.45, p = .046)). Also, when compared to sentences with congruent prosody, incongruent prosody elicited a positivity that was primarily distributed at parieto-occipital midline and right-hemisphere sites (interactions of Prosody × Anteriority (F (3, 72) = 20.26, p < .001), Prosody × Laterality (F (2, 48) = 3.79, p = .043), and Prosody × Anteriority × Laterality (F (6, 144) = 8.01, p < .001)). A significant Prosody × Plausibility × Anteriority (F (3, 72) = 7.49, p = .008) demonstrated that the positivity was most prominent in sentences with incongruent prosody and a plausible NP (Pr−TF +). Furthermore, significant interactions of Prosody × Time (F (1, 24) = 13.08, p = .001), and Prosody × Time × Laterality (F (2, 48) = 9.05, p < .001), revealed the positivity elicited by incongruent prosody was more positive-going along the midline and in left-hemisphere locations. In order to further investigate these interactions pairwise comparisons were conducted within the early (700–1000 ms) and late (1000–1300 ms) P600 windows.

Analyses in the early P600 window (700–1000 ms) revealed a significant Plausibility × Anteriority interaction (F (3, 72) = 4.56, p = .030) in the comparison of congruent prosody sentences (Pr + TF + vs. Pr + TF−). This reflected the presence of a small frontal negativity in Pr + TF− sentences. The comparison of incongruent prosody sentences (Pr−TF + vs. Pr−TF−) P600 revealed a large P600 effect in Pr−TF + sentences but not Pr−TF− sentences (main effect of Plausibility (F (1, 24) = 4.73, p = .040)) in the early P600 window.

Similar to the early P600 window, a small frontal negativity was revealed in Pr + TF− sentences compared to Pr + TF + sentences (Plausibility × Anteriority (F (3, 72) = 7.54, p = .007)) in the late P600 window (1000–1300 ms). Also, the P600 effect that emerged in Pr−TF + sentences in the early time window was sustained in the late P600 window at posterior sites (Plausibility × Anteriority (F (3, 72) = 4.21, p = .043)).

Discussion

We argue that our results support an account of sentence processing where prosodic and plausibility cues interact with each other and immediately impact structure-building processes. First, we discuss the implications of our ERP results across different points in the sentence (*i.e.* at the onset of the prosodic break in sentences with congruent prosody, at the onset and offset of the temporarily ambiguous NP, and at the critical verb). Finally, we examine how these results relate to one another and what directions future research should take.

Question1: were participants sensitive to intonational phrase boundaries? – onset of the prosodic break in conditions with congruent prosody– CPS effects

In order to answer this question, two comparisons were made. The first between Pr + TF + vs. Pr−TF + sentences, and the second between Pr + TF− vs. Pr−TF− sentences:.

First comparison:

[While the band played] [the song pleased all the customers.] (Pr + TF +)

[While the band played the song] [pleased all the customers.] (Pr − TF +)

Second comparison:

[While the band played] [the beer pleased all the customers.] (Pr + TF −)

[While the band played the beer] [pleased all the customers.] (Pr − TF −)

Waveforms were examined within each pairwise comparison at the offset of the subordinate verb (*played*), which corresponded to the prosodic break in sentences with congruent prosody (Pr + TF + and Pr + TF−), relative to sentences with incongruent prosody (Pr−TF + and Pr−TF−) that did not have a prosodic break at this point. We found evidence of a broadly distributed CPS effect in sentences with congruent prosody in both comparisons, indicating that the participants were sensitive to the prosodic manipulation.

Question 2: does the parser use plausibility cues to predict syntactic structure? – onset of temporarily ambiguous NP (song/beer)

Waveforms were compared at the onset of the temporarily ambiguous NPs (*song/beer*) between sentences with congruent prosody (Pr + TF + vs. Pr + TF−), and between sentences with incongruent prosody (Pr−TF + vs. Pr−TF−):

Congruent prosody comparison:

[While the band played] [the song pleased all the customers.] (Pr + TF +)

[While the band played] [the beer pleased all the customers.] (Pr + TF −)

Incongruent prosody comparison:

[While the band played the song] [pleased all the customers.] (Pr − TF +)

[While the band played the beer] [pleased all the customers.] (Pr − TF −)

We predicted that the poor thematic fit between *played* and the implausible NP *beer* in Pr−TF− sentences would elicit a significant N400 effect relative to the other conditions, signifying semantic processing difficulty. Our results confirmed our predictions as a significant N400 effect was found at *beer*. These results demonstrate that participants were sensitive to the plausibility/thematic fit manipulation.

Moving to our analyses in the P600 epoch, recall we were interested in investigating whether the combination of incongruent prosody and a plausibility cue in Pr−TF− sentences at *beer* would trigger syntactic reanalysis – signified by a P600. Additionally, the onset of the temporarily ambiguous NP (*song/beer*) coincides with the prosodic break in sentences with incongruent prosody (Pr−TF + and Pr−TF−), and typically a large positive-going CPS component is elicited at the onset of a prosodic break. Thus, we expected to find a positivity due to a CPS in Pr−TF + sentences (without a plausibility cue), and a combined CPS/P600 component in Pr−TF− sentences (with a plausibility cue). Therefore, we anticipated the combined CPS/P600 in Pr−TF− sentences would be larger than the sole CPS in Pr−TF + .

Our predictions were confirmed. Both incongruent prosody sentences elicited a positivity, however, the positivity in Pr−TF− sentences was larger with a longer latency than the positivity in Pr−TF + sentences. We interpreted these results as depicting a large combined CPS/P600 component at the ambiguous NP in Pr−TF− sentences, but only a smaller CPS component in Pr−TF + sentences (due to the onset of the prosodic break). It should be noted that the longer latency of the positivity in Pr−TF− sentences is likely due to a combination of factors, including the larger N400 in Pr−TF− vs. Pr −TF + sentences, as well as duration differences at the ambiguous NP between these two conditions, where the mean NP length was ∼ 45 ms longer in Pr−TF− sentences. However, regardless of these latency differences, the positivity is clearly larger in Pr−TF− sentences, which confirms our predictions.

The combination of incongruent prosodic contour and the plausibility/thematic fit cue at *the beer* in the Pr−TF− sentences resulted in an N400–P600 effect before the disambiguation point (*pleased*). Hence, the combination of incongruent prosody and an implausible ambiguous NP (*beer* in Pr−TF−) immediately interacted to influence sentence processing. These results are similar to the findings of Itzhak et al. (2010), who examined the impact of prosodic and plausibility cues in the form of transitivity bias. Recall their study implied prosodic cues override other forms of information and significantly aid comprehension, yet lexical-semantic information (transitivity) can influence covert prosodic phrasing by eliciting a CPS in the absence of prosodic cues. Thus, their results suggested that different forms of information interact during sentence processing, which is parallel to our interpretation. Moreover, Itzhak *et al*. proposed prosody provides the strongest cues for parsing decisions and can override syntactic preferences, including the preference for simpler late closure syntactic structure.

These findings also align with our results where congruent prosodic cues in sentences with a plausible (Pr + TF +) and implausible thematic fit (Pr−TF−) facilitated processing and prevented garden path effects. Only when incongruent prosody grouped the subordinate verb *played* and the NP *the beer* together, seemingly in the same clause ("While the band played the beer"), did sentence processing break down and require repair through N400–P600 processes. Thus, multiple forms of information, including syntactic structure, prosody, and thematic fit plausibility cues, interact throughout sentence processing – yet prosody appears to have a privileged role. Although, in future studies, it will be important to assess the impact of thematic fit without the influence of prosody to determine whether this type of plausibility cue influences covert prosodic phrasing by eliciting a CPS in the absence of prosodic cues – as transitively biased verbs did in the Itzhak *et al*. study. This would provide more evidence in support of a prosody-first account.

Question 3: does incongruent prosody result in garden-path effects at critical verb? – prosodic garden-path effects at critical verb (pleased)

When comparing our four conditions we anticipated discovering a garden-path effect at the critical verb (*pleased*) resulting from incongruent prosody in sentences without a strong plausibility cue (Pr−TF + sentences). Consider the four experimental conditions, repeated here:

[While the band played] [the song pleased all the customers.] (Pr + TF +)

[While the band played] [the beer pleased all the customers.] (Pr + TF −)

[While the band played the song] [pleased all the customers.] (Pr − TF +)

[While the band played the beer] [pleased all the customers.] (Pr − TF −)

We predicted the incongruent prosody in classic garden-path sentences (Pr−TF+) would elicit an N400-P600 effect compared to congruent prosody sentences, and this is exactly what we found.

However, in Pr−TF− sentences we anticipated that the plausibility cues would result in early syntactic reanalysis at the ambiguous NP *the beer* – before reaching the critical verb. Thus, at the critical verb we did not expect to find an N400–P600 effect when comparing Pr −TF− to congruent prosody sentences, and the presence of an N400 effect (without a P600) in Pr−TF− sentences bore out these predictions. As previously mentioned, the early P600 found in Pr−TF− sentences at the ambiguous NP *the beer* reflected an early syntactic reanalysis at *beer* so the parser did not need to engage in reanalysis at the critical verb. Our analyses suggested that the N400 effect at the critical verb *pleased* in Pr−TF− shared similar characteristics to the N400 found in Pr−TF + . Thus, even though the parser engaged in an early syntactic reanalysis in Pr−TF− sentences it is likely that the N400 effect reflected some degree of difficulty in integrating *beer* with *pleased* as a result of the incongruent prosody.

Furthermore, the lack of an N400–P600 effect in both conditions with congruent prosody (Pr + TF + and Pr + TF−) confirms that congruent prosody immediately disambiguated sentence structure for the listener in the current study, which conforms with the findings from many studies (Bögels et al., 2010, 2013; Kjelgaard & Speer, 1999; Nicholas Nagel et al., 1994; Pauker et al., 2011; Schafer et al., 2000; Steinhauer et al., 1999).

Conclusions

To conclude, the present study provides strong evidence that prosodic and lexical-semantic cues interact with each other to influence sentence processing. These results align with Snedeker and Yuan (2008) and Itzhak et al. (2010) who also discovered evidence of an interaction between prosodic and plausibility cues. The ERP method allowed us to discover the N400–P600 effect at the ambiguous NP *beer* containing a strong plausibility cue in Pr−TF− sentences, confirming that the interaction of prosodic and plausibility cues impacted sentence processing. Furthermore, the lack of a P600 effect downstream at the critical verb in the Pr−TF− sentences suggests that the typical garden-path syntactic reanalysis was not required at the critical verb in sentences containing a strong plausibility cue (Pr−TF−) before the critical verb. The N400–P600 at the ambiguous NP in Pr −TF− combined with the discovery of an N400 but no P600 effect at the critical verb *pleased* in Pr−TF− sentences suggests that syntactic reanalysis occurred at the ambiguous NP as a result of a mismatch between prosodic and lexical-semantic cues. These findings all converge to provide strong evidence that the parser is immediately influenced by the combination of prosodic and lexical-semantic information when encountering temporary syntactic ambiguities.

Note

1. We also conducted analyses with a traditional 100ms pre-stimulus baseline and the results did not fundamentally differ from the effects reported here.

Disclosure statement

No potential conflict of interest was reported by the authors.

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