Prosodic Encoding of Informativity: Word Frequency and Contextual Probability Interact with Information Structure

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Abstract

This study investigates how prosody encodes the extent to which a linguistic element is informative. While most prior work has approached this question from one of the two angles, namely (i) information theory/statistical probability and (ii) discourse-pragmatics/information structure, we focus on the interaction between these two dimensions. Our results show that the prosodic marking of information-structural categories depends on statistical probabilistic factors. Specifically, the post-focus pitch reduction resulting from new-information focus and corrective focus is modulated by the focused word's frequency and contextual probability, respectively. In terms of pitch, new-information narrow focus patterns like wide focus when the focused word is lexically infrequent, although the two focus types differ when the word has high frequency. Furthermore, corrective narrow focus patterns like wide focus when the focused word is contextually improbable, although the two focus types differ when the word has low contextual probability. We discuss how these results suggest that prosody reflects speakers' expectation and surprise about the interlocutor's knowledge state. Our findings highlight the importance of integrating research from the information-theoretical perspective with research from the information-structural perspective, to improve our understanding of prosody.

Keywords: informativity, post-focus reduction, interactive design, information structure, focus, information theory

1. Introduction

It is widely accepted that prosody can encode the extent to which a linguistic element is informative. Acoustic-phonetic properties of an utterance such as f0/pitch reflect the relative informativity of its components. Most prior work has approached the prosodic encoding of informativity from one of two angles: **(i)** information structure in a discourse-pragmatic approach or **(ii)** statistical probability in an information-theoretic approach (see references cited in the remainder of Introduction).

In the discourse pragmatics and information structure tradition, acoustic prominence has been shown to be associated with linguistics elements in the *foreground*, or in *focus*, which add new information to the discourse. Elements in new-information focus, *i.e.* those parts of the utterance that are new to the discourse, are acoustically more prominent than given elements, *i.e.* those that are old to the discourse (*e.g.* Chen & Braun, 2006; Schwarzschild, 1999). More specifically, material in narrow new-information focus, where only one component of an utterance (*e.g.* the action, the patient, the location, *etc.*) is focused, receives greater acoustic prominence than material in wide new-information focus, where an entire utterance with multiple components is focused (*e.g.* Breen et al., 2010; Eady et al., 1986). It has also been shown that material in contrastive focus, to which alternatives exist in some way, is realized with greater acoustic prominence than non-contrastive material (*e.g.* Cooper et al., 1985; Couper-Kuhlen, 1984; Katz & Selkirk, 2011; Krahmer & Swerts, 2001). Existing studies across languages have investigated various types of contrastive focus (*e.g.* Vallduví & Vilkuna, 1998). We investigated one subtype, namely corrective focus, which serves to correct information conveyed previously in the discourse (see also Breen et al., 2010 and Dik, 1997).

On the other hand, **in the information theory and statistical probability tradition**, a correlation has been found between acoustic reduction and the *redundancy*, or the *predictability* of linguistic elements. Probabilistic measurements used to represent the predictability of a linguistic unit include context-independent properties such as frequency and neighborhood density (*e.g.* Munson & Solomon, 2004; Wright, 2003) and context-dependent properties such as joint probability and conditional probability (*e.g.* Bell et al., 2003; Pan & Hirschberg, 2000; van Son et al., 1998).

Are there connections between information-structural and information-theoretic approaches? As can be seen from the discussion above, these two research traditions have investigated rather different factors of informativity from distinct perspectives, despite their shared interest in informativity and prosody. A limited number of studies in the statistical-probabilistic approach have examined the effect of repeated mention (a repeated word is by definition given, not new, information) on different kinds of linguistic units (*e.g.* Aylett & Turk, 2004; Baker & Bradlow, 2009; Bell et al., 2009; Pluymaekers et al., 2005). To our knowledge, only one existing study has addressed the interaction between statistical-probabilistic and discourse-pragmatic factors: Baker and Bradlow (2009) found that word frequency influences the amount of reduction that a word undergoes when it is mentioned for a second time; high-frequency words exhibit more shortening upon second mention than low-frequency words. It remains unclear whether other kinds of statistical-probabilistic features also have an impact on the prosodic effects of discourse-pragmatic factors and whether word frequency interacts with other types of information structure in the same say.

1.1 Aims of the Study

As discussed above, prior work shows that the prosodic representation of an utterance depends on how informative its constituents are relative to each other. Discourse-pragmatic features, such as information structure, and statistical-probabilistic features, such as inherent frequency and contextual probability, both play a role in the prosodic encoding of informativity. It is striking that little attention has been paid to the potential interaction between discourse-pragmatic and statistical-probabilistic factors, given the considerable efforts that have been devoted to both kinds of factors separately. To shed light on this issue, we conducted a psycholinguistic production study that investigated three related questions: (i) Do discourse-pragmatic and statistical-probabilistic features interact in determining the prosodic prominence of an element, and if so, how? (ii) If statistical features do interact with pragmatic features in shaping the prosodic profile of an utterance, to what extent can statistical factors impact the prosodic effects of pragmatic factors? (iii) If the prosodic encoding of pragmatic informativity does depend on the statistical informativity of an element, do different pragmatic factors interact with different statistical factors in the same way? For example, could it be that the prosodic cues for new-information vs. corrective focus differ in whether they are sensitive to frequency vs. contextual probability?

2. Method

We conducted a production study with an interactive design. Each trial consisted of a production task (which provided the critical recordings) and a subsequent selection task (which was included to heighten participant engagement). In both tasks, participants interacted with a partner (who was a lab assistant). Sixteen native speakers of American English participated. The target sentences of interest were those spoken by the participants in the production task on target trials. The selection task was included to engage both people in the production task: Paying attention to what the other person said in the production task was necessary to successfully perform the selection task (not discussed here due to space limitations)

2.1 Production Task

Participants worked with a partner in producing sentence pairs. Each sentence pair consisted of a question asked by the partner (Sentence A) and a response given by the participant (Sentence B). As shown in the example dialogs in (1)-(3), target sentences (*i.e.* Sentence B on target trials) are transitive clauses with the following structure: a third-person plural pronoun subject (*they*), a simple past tense verb, an object, and a prepositional phrase indicating a location. The critical word we focus on is the object of each target sentence (*e.g. cars*). To investigate whether statistical factors interact with information-structural factors in shaping the prosodic profile of a sentence, we manipulated **(i)** word frequency of the target object, **(ii)** whether it was probable in the context of preceding verb and following location, and **(iii)** its information structural status, relative to the question. Thus, a within-subject design with three independent variables was implemented: (i) **word frequency** (with two levels: high or low word frequency), (ii) **contextual probability** (with two levels: high or low contextual probability), and (iii) **information structure** (with three levels: narrow corrective focus, narrow new-information focus, or wide/VP focus). There were 48 target trials; participants encountered four items in each condition. The experiment also included 48 filler trials. The dependent variable that we measured was the **pitch/f0 of a sentence**.

We manipulated the information structure of the critical nouns by means of the question asked by the partner (which was answered by the participant), as exemplified in (1)-(3).

NARROW CORRECTIVE FOCUS (1)
A: I heard that Teresa and Martha kicked dirt in the garage.
B: No, they kicked [cars]$_{FOCUS}$ in the garage.

NARROW NEW-INFORMATION FOCUS (2)
A: What did Connie and Sharon kick in the garage?
B: They kicked [cars]$_{FOCUS}$ in the garage.

WIDE/VP FOCUS (3)
A: What did Evelyn and Jacqueline do?
B: They [kicked cars in the garage]$_{FOCUS}$.

Norming study: The contextual probability of target words was estimated through a norming study. Native speakers of American English performed a fill-in-the-blank writing task, where they saw sentences composed of a personal name, a verb, a blank, and a location (*e.g. Brittany kicked _____ in the garage.*) and filled in the blank with one or two words. There were 63 items in total; 66 to 70 responses were collected for each item. Four verb-location contexts and eight objects were ultimately selected for the target sentences in the main study. We chose the target words for the high-probability conditions from the two of the top three most popular objects given a verb-location context (*e.g. kicked cars/cans in the garage*). Target words in the low-probability conditions in the main study never occurred as responses for a given context in the norming study (*e.g.* no one completed *kicked _____ in the garage* with '*books*' or '*shells*'). Another four objects were selected to be the 'incorrect' objects in the questions (Sentence A's) eliciting corrective focus (ex. 1). They were words that were not frequently elicited in the norming study but did occur at least one in a given context (*e.g. kicked dirt in the garage*), and thus had a contextual probability between the high-probability and low-probability target words.

Word frequency of the target objects was determined according to the SUBTLEXus database (Brysbaert & New; 2009). The 'incorrect' objects in questions that elicited corrective focus (ex. 1) had a word frequency between the high-frequency and low-frequency target words for a given context. All the verbs, objects and prepositions were monosyllabic, and the locations were short noun phrases with the definite article.

2.2 Predictions

When it comes to pitch/f0, prior work found that elements in narrow focus are prosodically more prominent than those in wide focus, and this prosodic encoding of narrow focus appears as emphasis on the narrowly focused component and reduction in the material preceding and following it. More concretely, in declarative sentences, narrow focus results in higher mean and maximum pitch on the stressed syllable in the focused element (*e.g.* Breen et al., 2010) and lower pitch in the post-focus material (*e.g.* Cooper et al., 1985) and the pre-focus material (*e.g.* Japanese: Hwang, 2012). Pre-empting our results somewhat, we note here that prosodic prominence for narrow focus mostly manifested itself as post-focus reduction in our data (a sudden and substantial drop in pitch after the focused component, see Cooper et al., 1985 for related work). Therefore, in the remainder of this section, we present our predictions in terms of pitch movement that comes after the object (*i.e.* the narrowly focused word) in a sentence.

As discussed in the Introduction, we hypothesized that the prosodic cues for pragmatic informativity would be obscured when statistical informativity was high (low frequency and predictability). In other words, *prosodic effects of information structure may be weakened when there are other factors demanding prosodic prominence*. We also tested whether the prosodic effects of pragmatic informativity could disappear entirely when multiple sources of high statistical informativity were present (*i.e.* low word frequency and low contextual probability), and whether different pragmatic factors (*i.e.* corrective focus and new-information focus) could react differently to different statistical factors.

Based on existing findings (*e.g.* Cooper et al., 1985 and Baker & Bradlow, 2009), we expected that when *the narrowly focused words are high frequency and/or highly contextually probable*, we will be able to detect prosodic reflexes of information structure, such that post-focus reduction in the narrow corrective focus condition and the narrow new-information focus condition results in a pitch drop after the object that is faster and deeper than the wide-focus condition. When *the narrowly focused words are low frequency and/or low contextual probability*, we predicted that the prosodic distinctions between narrow and wide focus might be weakened or even entirely absent. In other words, fast and deep pitch dropping after the object might be observed in only one or even neither of the two narrow-focus conditions. If these predictions turn out to be correct and prosodic effects of information structure are indeed weakened when there are other factors also demanding prosodic prominence, we can then also look into whether word frequency and contextual probability influence corrective focus and new-information focus in different ways.

3. Data Analysis and Results

Pitch measurements were first obtained in terms of fundamental frequency (f0) (STRAIGHT: Kawahara, de Cheveigne & Patterson, 1998; VoiceSauce: Shue, Keating, Vicenik & Yu, 2011). Raw f0 values were smoothed (*smoothn* in MATLAB: Garcia, 2010) and converted into a semitone scale using the algorithm $69+12*\log_2(f0/440)$. Finally, the data were normalized by subject using the z-standardization to factor out the individual differences in pitch ranges.

To investigate whether different levels of word frequency and contextual probability have different effects, quantitatively or qualitatively, on the prosodic encoding of information structure, we examined the distinctions between information-structure categories in the four conditions of word frequency and contextual probability separately: high frequency words in high probability contexts, low frequency words in high probability contexts, high frequency words in low probability contexts, and low frequency words in low probability contexts. Pitch values (*i.e.* semitones normalized by subject) of target sentences were analyzed using the Smoothing Spline ANOVA method (Gu, 2003). We divided each sentence into five intervals – pronoun '*they*', verb, object, preposition and article, and the location noun – and extracted ten data points with equal time spacing from each interval. The negative '*no*' at the beginning of a sentence in the corrective-focus conditions was not included in the statistical analyses. Mixed-effects models were conducted using the *ssanova* function in the R package *gss* (Gu, 2013). We used information structure, time, and their interaction as fixed effects and included random intercepts for subjects and items. In all statistical analyses presented in this paper, the hypotheses were tested at a significance level of $\alpha=0.05$.

Overall, the predictions outlined in Section 2.2 were borne out, as can be seen in Figures 1-4, which shows pitch contours throughout the sentences. Let us take a closer look at the middle three intervals from the verb (henceforth referred to as the **pre-object** interval) to the object to the preposition+article region (henceforth referred to as the **post-object** interval). The three information-structural categories barely differ in the pre-object and object intervals. Significant differences mostly occur in the post-object interval, where narrow corrective focus (red lines with squares) and narrow new-information focus (blue lines with triangles) have a deeper pitch fall than wide focus (green lines with circles) in some cases, depending on word frequency and contextual probability. More specifically: When the narrowly focused object is high frequency and occurs in a highly probable context (*kicked cars in the garage*), both types of narrow focus differ significantly from the object in wide focus (differences in fitted values = 0.112-0.427, 95% C.I.'s = fitted values ±0.045-0.049; Figure 1). When object is frequent but contextually improbable (*kicked books in the garage*), only new-information focus differs significantly from wide focus; corrective focus patterns with wide focus (differences in fitted values = 0.094-0.249, 95% C.I.'s = fitted values ±0.040-0.042; Figure 2). In contrast, when the object has low word frequency but high contextual probability (*kicked cans in the garage*), corrective focus differs significantly

from wide focus; new-information focus does not (differences in fitted values = 0.095-0.292, 95% C.I.'s = fitted values ±0.041-0.043; Figure 3). Finally, neither type of narrow focus differs from wide focus when the object is infrequent and contextually improbable (*kicked shells in the garage*; differences in fitted values = 0.004-0.190, 95% C.I.'s = fitted values ±0.041-0.044; Figure 4).

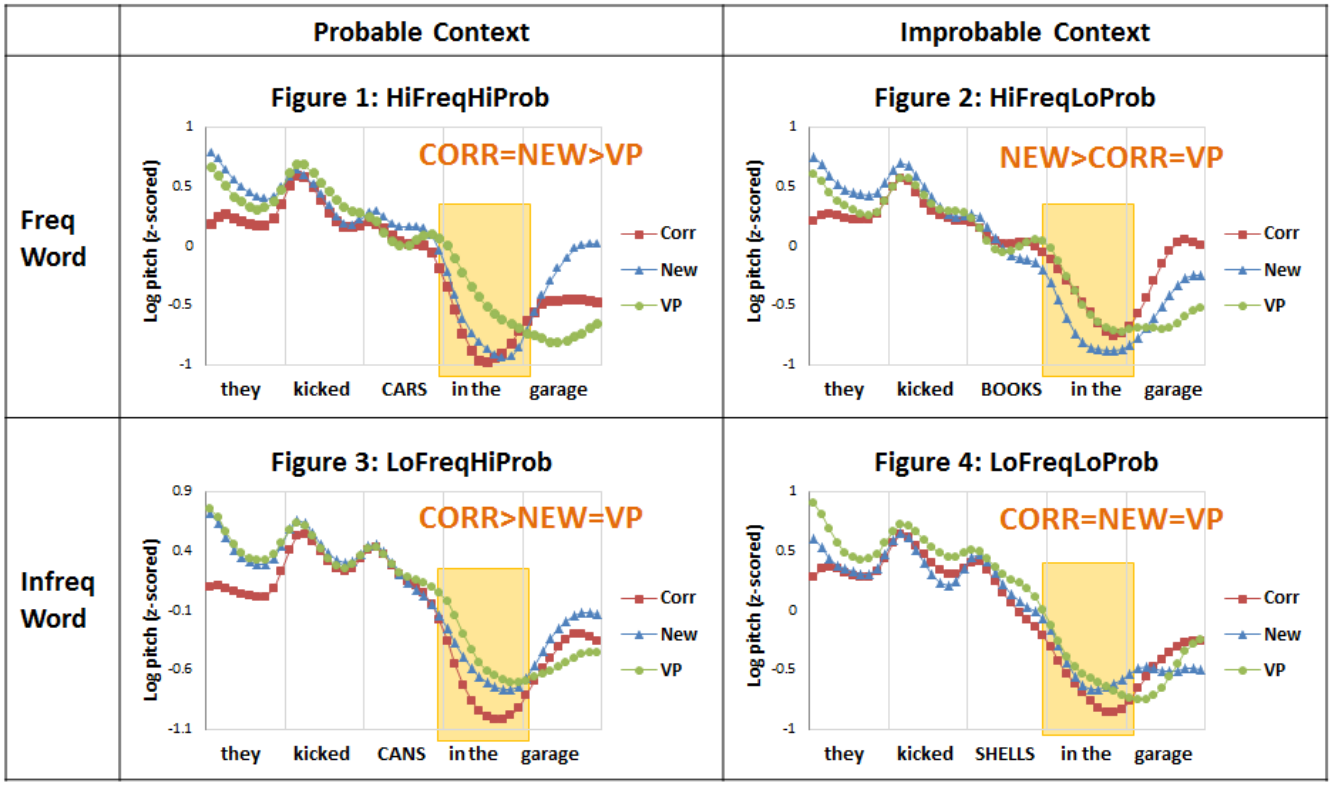

Figure 1-4: Log pitch (semitones) of target sentences, normalized by subject

4. Discussion

This study investigated the interaction between statistical and pragmatic factors in sentence prosody. Although a considerable number of studies have examined prosodic cues from either a statistical or an information-structural/discourse-pragmatic perspective, little work has been done to include these two kinds of informativity factors in one study and look into their interaction. Our results show that **the prosodic prominence associated with information structure is modulated by word frequency and contextual probability** in terms of post-focus pitch reduction. *Both types of narrow focus result in significant post-focus pitch lowering when frequent words are narrowly focused in a probable context.* In contrast, frequent words with low contextual probability lead to significant post-focus pitch lowering *only when they are in new-information focus*, and infrequent words with high contextual probability do so *only when they are in corrective focus*. When infrequent words are narrowly focused in an improbable context, post-focus pitch lowering is not significant in either type of narrow focus. This supports our general prediction that *prosodic effects of information structure are weakened when there are other factors demanding prosodic prominence*.

As a whole, these findings pose a challenge to the widespread view that narrow focus (consistently) leads to greater prosodic prominence than wide focus. In fact, prior work on information structure, taken together, suggests a prominence hierarchy: contrastive/corrective information is prosodically marked with greater prominence than plain new information (*e.g.* Breen et al., 2010 and Katz & Selkirk, 2011), and narrowly focused new information is more prominent than new information in wide focus (*e.g.* Breen et al., 2010). As discussed above, however, we did not find this hierarchy in our data. Crucially, it seems that many prior studies investigated probable contexts and did not manipulate word frequency, which may explain why the hierarchical relation has been found between corrective focus, new-information focus, and wide focus. Consider a hypothetical study that involves a mixture of high-frequency and low-frequency words that are focused in probable sentences. Based on our findings, in such a study corrective focus will have greater prominence than wide

focus, since the sentences are probable; new-information focus will be less prominent than corrective focus and more prominent than wide focus, because frequent words pattern with the former but infrequent words with the latter. This prediction is confirmed by a follow-up analysis that we conducted where we pooled the frequency conditions and only examined the conditions of high contextual probability. Tested at the significance level of α=0.05, the pitch fall immediately following the object was largest for corrective focus, second largest for new-information focus, and smallest for wide focus. In other words, *the common generalization that corrective focus is more prominent than narrow focus which is more prominent than broad focus may be an epiphenomenon stemming from not controlling for word frequency and using relatively probable contexts.* Our findings highlight the importance of disentangling information structure and statistical factors: To fully understand how prosody encodes informativity, it is important to integrate the work in the information-theory approach and the work in the information-structure approach (see Wagner & Watson, 2010, pp.933 for relevant discussion).

Why should the prosodic effects of statistical factors interact with information-structure in the way we observed? Our results show that the prosodic cues for correction and 'plain' new information are sensitive to probability and frequency, respectively. For corrective focus, post-focus pitch reduction appears only when the focused element is contextually probable; whereas for new-information focus, post-focus pitch reduction appears only when the focused element is lexically frequent. We suggest that these differential effects can be explained in terms of **the interaction between interlocutors**. In a corrective focus structure (ex. 1), when the correct information is contextually improbable (*e.g. kicked books in the garage*), the interlocutor's misbelief (*e.g. kicked dirt in the garage*) may not be very surprising, which perhaps motivates low pitch prominence (as low as wide focus) in the correction. Possibly for similar reasons, new information conveyed by infrequent words is realized with low pitch prominence. Compared to high-frequency words that have a large number of meanings/senses (*e.g.* Nelson & McEvoy, 2000), lexical associates (*e.g.* Reder, Anderson & Bjork, 1974), and suitable contexts (*e.g.* Adelman, Brown & Quesada, 2006), low-frequency words have been claimed to be semantically less diverse (*e.g.* Hoffman, Rogers & Ralph, 2011). In a new-information focus structure (ex. 2), when the new information is an infrequent word with a relatively specific meaning (*e.g. kicked cans in the garage*), it may not be surprising that the interlocutor has asked for the information (*i.e.* what they kicked). On the other hand, when the new information is a frequent word with a relatively 'vague' meaning (*e.g. kicked cars in the garage*), it may seem to the speaker that the interlocutor's question is *not worth asking* (and thus surprising). If these ideas are on the right track, they fit with the view that **speakers take into account the interlocutor's knowledge state**. Under this view, these interaction patterns reflect the speaker's expectations about what the interlocutor "should have known". This study adds to the body of literature regarding whether/to what extent interlocutors consider each other's knowledge and perspectives (*e.g.* Bell, 1984; Brown & Dell, 1987; Hanna, Tanenhaus & Trueswell, 2003; Keysar, Barr, Balin & Brauner, 2000; Lockridge & Brennan, 2002). Our findings suggest that people's expectation about their interlocutor's knowledge state is an important factor involved in the prosodic encoding of informativity. Future work will allow us to further test the validity of this idea.

5. Conclusions

We conducted a psycholinguistic production study that investigated how two types of informativity interact in shaping the prosody of utterances: (i) statistical informativity in terms of lexical frequency and contextual probability, and (ii) pragmatic informativity such as new-information focus and corrective focus. Our results show that lexical frequency modulates the prosodic prominence associated with new-information focus, and contextual probability modulates the prosodic prominence resulting from corrective focus. In terms of pitch cues, new-information narrow focus differs from wide focus only when the object is high frequency, and corrective narrow focus differs from wide focus only when the object has high contextual probability. We discuss how these patterns can be explained from an interaction-based perspective – speakers take into account their interlocutor's knowledge state; prosody reflects speakers' expectations/surprise about what the other person has in mind. By integrating factors that have previously been examined in separate traditions of work, this study brings new insights into the relationship between informativity and prosody.

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