

Prosodic phrasing is central to language comprehension

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Words, like musical notes, are grouped together into phrases by their rhythmic and durational properties as well as their tonal pitch. This ‘prosodic phrasing’ affects the understanding of sentences. Many processing studies of prosody have investigated sentences with a single, grammatically required prosodic boundary, which might be interpreted strictly locally, as a signal to end the current syntactic unit. Recent results suggest, however, that the global pattern of prosodic phrasing is what matters in sentence comprehension, not just the occurrence or size of a single local boundary. In this article we claim that the impact of prosodic boundaries depends on the other prosodic choices a speaker has made. We speculate that prosody serves to hold distinct linguistic representations together in memory.

Prosody matters

It matters how a sentence is spoken. Linguists and psycholinguists, to say nothing of everybody’s grandmother, have known this for a long time. The sentence ‘*Steve or Sam and Bob will come*’ means one thing if it is said with a distinct pause (a prosodic phrase boundary) after *Steve*, and quite another thing if the boundary appears after *Sam* [1], [2]. We will concentrate here on how prosodic phrasing (grouping) affects syntactic processing.

Prosody, like most aspects of language, is automatically processed by listeners at a level below their conscious awareness. Listeners ‘hear’ not only the actual acoustic input, but also expected properties determined by the analysis of the input imposed by the grammar of their native language. In fluent speech, actual pauses occur only at the boundaries of prosodic phrases, although naïve listeners usually believe there are pauses between linguistic units (such as words and sentences) even when there is no period of acoustic silence [3]. Speakers of a language like French, in which stress predictably occurs on the final syllable of a word, find it difficult to hear the placement of a stress that English speakers hear with no difficulty [4].

Every language uses prosodic grouping and prosodic prominence, although different languages use them in very different ways [5]. In the most widely used system for

describing English prosody (ToBI; see Box 1), words are grouped into smaller prosodic units (intermediate phrases, or ‘ips’) and larger ones (intonational phrases, or ‘IPhs’). High and low pitches are associated with emphasis and with the ends of prosodic units. The popularity of this representational system, together with the current availability of techniques for digital processing of acoustic signals, have stimulated an explosion of research into how listeners use prosody to understand spoken language.

Prosodic processing research can be placed on a continuum. At one extreme is the view, often implicit, that there is no real grammar of prosody and no syntax–prosody mapping constraints. Such approaches tend to emphasize the strategic use of prosody, for example, assuming that a pause might be inserted at some location in a sentence for the specific purpose of avoiding ambiguity [8,9]. Approaches like this might treat prosodic events as local cues to syntactic structure, with a prosodic boundary signaling when to close off a clause [10,11]. At the other extreme is the view that the grammar dictates only one permissible pronunciation for a sentence in any given discourse context, including the phonological size (ip versus IPh) of prosodic boundaries [12]. Our approach attempts to reconcile the existence of syntax–prosody mapping constraints [13,14] with the considerable variability observed in naturalistic data [15], including optionality in the presence and size of prosodic boundaries.

Whereas earlier research typically investigated the processing of sentences with a single large prosodic boundary (e.g. [1,16,17]), and so is consistent with the belief that a prosodic boundary provides a strictly local cue to syntactic structure, our research indicates that it is often the relation between boundaries (their position and relative size) that is important [7,18,19]. Our approach emphasizes that the syntactic significance of each prosodic boundary in a sentence is assessed by listeners who assume that the speaker pronounces the sentence by coherently implementing the grammatical constraints on prosody.

In what follows, we first provide an overview of prosodic research, and then discuss the findings from our own studies. Finally, we speculate that the prosodic representation of the sentence is the essential skeleton that holds different syllables together and indexes an item across representation types (phonological, syntactic, semantic),

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Box 1. ToBI prosodic analysis

The most widely-used system of prosodic analysis is ToBI ('Tone and Boundary Indices') [6], many aspects of which are based on the pioneering work of Pierrehumbert (PhD thesis, MIT, 1980). Pierrehumbert and the ToBI system analyze English prosody using only two pitch targets, H (high) and L (low). The primary prosodic units are pitch accents, which indicate the prominence of particular words in a phrase, and prosodic phrases, which show the grouping of words.

Pitch accents can be relatively high (H*) or low (L*), and might also include leading pitch targets (e.g. L+H*). Accents usually align

with the main stress of a prominent word. There are two levels of prosodic phrasing. Intermediate phrases (ip) are the first prosodic units above the prosodic word; each ip must include at least one pitch accent and ends with a phrase tone (H-, L-). Intonational Phrases (IPh) must contain at least one ip and end with a boundary tone (H%, L%). A useful tool for prosodic analysis is the pitch track, which visually indicates the fundamental frequency contour of an utterance, and can include prosodic and lexical annotations, as shown in Figure 1.

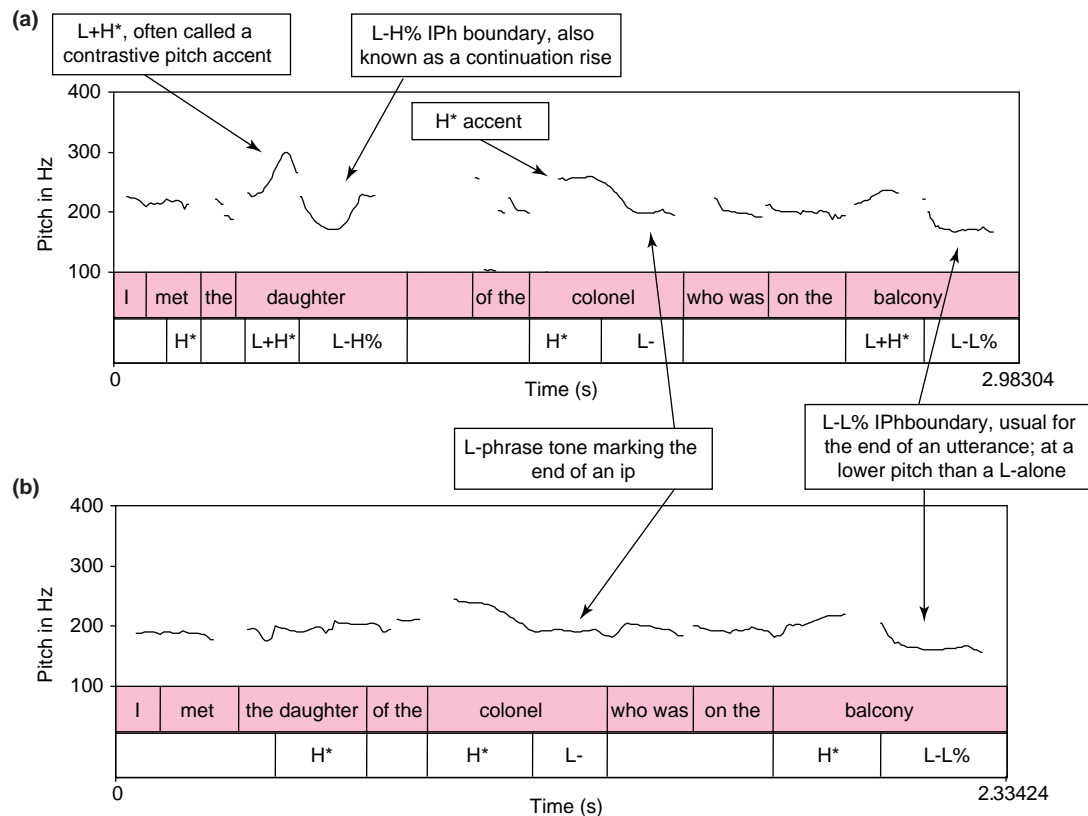


Figure 1. Sample pitch track. The sentence (from [7]) is shown in two prosodic versions. (a) The first contains two Intonational Phrases (IPhs) and three intermediate phrases (ips). At least one word within each phrase is accented. This prosody makes attachment of the relative clause (*who was on the balcony*) to the immediately preceding noun (*colonel*) relatively more likely than if the largest prosodic boundary in the sentence separated that noun from the relative clause. (b) The second prosodic version has the same post-*colonel* boundary, but now it is larger than any previous boundary, so high attachment is favored.

thereby permitting an utterance to be retained in memory while it is processed.

Where prosody is used

Some aspects of prosody are obligatory. In a language like English, most content words must be spoken with stress on a particular syllable. Some syntactic structures require prosodic boundaries in particular locations, such as the end of an initial subordinate clause (*After it rained, ...*), or flanking an appositive structure (*Lance Armstrong, the cyclist, ...*) or a parenthetical aside (*Lance, as you know, ...*). Other aspects of prosody are not obligatory, but a matter of the speaker's preference or style. For example, whether the speaker places a prosodic break before the bracketed subordinate clause in *Ramona left*

[*before the party started*]' is not dictated by the grammar; a break is possible but not required.

Listeners use obligatory aspects of prosody to identify the words and syntactic phrasing of an utterance (e.g. [1,12,15] and many others). For example, they do not postulate a word that straddles a prosodic boundary [20]. Sentences with temporarily ambiguous initial subordinate clauses (e.g. *When Roger leaves the house is dark*) have been studied by several investigators (e.g. [1,12,16,21]). In Kjelgaard and Speer's study, an analysis of the initial clause in which *'the house'* is taken as the direct object of *leaves* (a 'late closure' analysis) was blocked when an intonational phrase boundary was inserted after the verb (*leaves*). The intonational phrase boundary, indicated by longer verb duration and a pause plus characteristic pitch movements, appeared to guide the

syntactic analysis of the sentence, playing a very early role in processing. Event-related potentials (ERPs) showed an immediate effect of a prosodic boundary in a study of German sentence processing [22]. These data too indicate that obligatory elements of prosodic structure guide analysis of the syntactic structure of an utterance. This would be expected either if the listener treated prosodic events as local cues, or treated an utterance as a phonologically structured input whose analysis is constrained by the mapping between syntax and prosody.

Optional prosodic boundaries and the rational speaker hypothesis

Although some aspects of prosody are tightly linked to the lexical and syntactic structure of an utterance, there is also considerable optionality in how a sentence can be prosodically phrased [15,19]. We have investigated the effect of optional prosodic boundaries on the attachment of phrases, and found results that are inconsistent with a purely local mechanism. The effect of an optional prosodic boundary – indicated by (#) – in ‘*John said Susan telephoned (#) after the party*’ depends on the global prosodic pattern [7,18]. In particular, if the prosodic boundary at (#) is the only prosodic boundary in the sentence, or if it is a larger phonological category ($IPh > ip > 0$) than relevant earlier boundaries, then the prosodic boundary favors high attachment of the final phrase as a modifier of *said*. However, if the boundary at (#) is missing or is smaller than relevant early boundaries, then the prosody will favor low attachment of the *after*-phrase as a modifier of *telephoned*.

In syntactic terms, these results make sense: if the prosodic boundary at (#) is smaller than a boundary before *telephoned* or *Susan*, the speaker is indicating prosodically that the *after*-phrase is part of this larger syntactic constituent (i.e. part of the verb phrase *telephoned after...* or the clause *Susan telephoned after...*). But if the prosodic boundary at (#) is larger than a boundary before those constituents, then the speaker’s prosody indicates that the *after*-phrase is not part of the preceding syntactic constituent. In general, a prosodic boundary is relevant to the informativeness of a later boundary if it intervenes between distinct potential attachment sites (i.e. a boundary after *said* is relevant to (#) because it appears between *said* and *telephoned*) [7].

We claim that the speaker is using prosody in an internally consistent, rational, fashion, and that the listener assumes such rationality in interpretation. If the speaker intends a structure where a constituent contains the *after*-phrase, she will not insert a prosodic boundary that separates the *after*-phrase from the rest of its constituent without good reason. Conversely, a speaker who intends a larger syntactic boundary at some early position will not capriciously place a larger prosodic boundary at the (#)-position. Listeners can interpret the pattern of prosodic boundaries as conveying information about syntactic boundaries when analyzing spoken input. This proposal was introduced as the ‘rational speaker hypothesis’ in [18].

Our results show that listeners’ use of optional prosodic boundaries in a wide variety of ambiguous syntactic

structures matches the predictions of the rational speaker hypothesis [18]. The structures included the sentence types in (1–4): in (1), *with very large houses* may modify *women* (a ‘low attachment’, referring to point of attachment in the sentence’s syntactic tree structure) or *old men and women* (a ‘high attachment’); in (2), *in-laws* may attach low to *Sharon* or high to *Johnny and Sharon*; in (3), *son* may attach low to *the Pharaoh* or high to *the daughter of the Pharaoh*; and in (4), *who was on the balcony* could attach low to the *colonel* or high to *the daughter of the colonel*.

- (1) *Who came out ahead? Old men (#1) and women (#2) with very large houses.*
- (2) *Who arrived? Johnny (#1) and Sharon’s (#2) in-laws.*
- (3) *Who was it? The daughter (#1) of the Pharaoh’s (#2) son.*
- (4) *I met the daughter (#1) of the colonel (#2) who was on the balcony.*

Each structure was heard with an intermediate phrase boundary at (#2), following a larger, same-size, or smaller boundary at (#1). What mattered was not the mere presence of a prosodic boundary before the ambiguously-attached phrase, but whether this boundary was phonologically the largest in the sentence. Figure 1 shows that the frequency of high attachment interpretations of each of these four sets of sentences consistently decreased as the size of the boundary at (#1) increased relative to the boundary at (#2). The global pattern of prosodic boundaries consistently influenced sentence analysis.

These results contrast with the predictions of the older localist views described above, as well as newer prosodic theories such as the Anti-Attachment Hypothesis [23], which suggests that a prosodic boundary can be interpreted locally as evidence that following material does not attach to the most recent potential site.

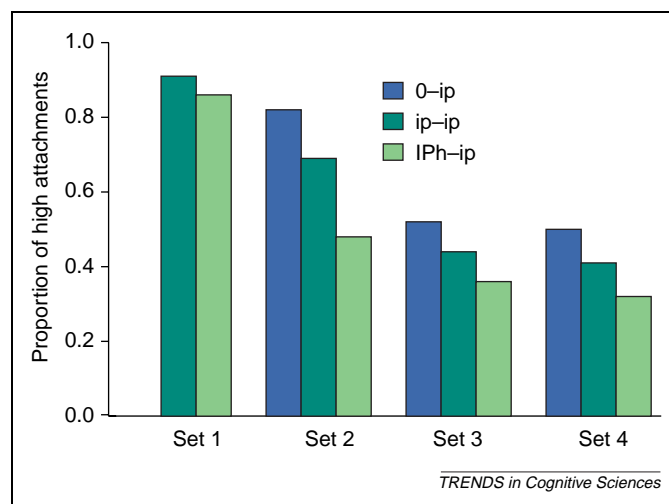


Figure 1. Proportion of high-attachment interpretation choices for the four sets of sentences illustrated in (1) to (4) in the text (data from [7], Experiments 1 and 2; note that set 1 lacked the 0-ip condition). High-attachment interpretations decreased as the earlier boundary – (#1) in (1)–(4) – became larger, compared with the later boundary (#2), which was always an ip.

Box 2. Prosody in silent reading

Prosody is not always overt. Implicit prosody is assigned even during silent reading, apparently influencing the preferred interpretation of some sentences [29]. Indeed, in German, revisions of syntactic analyses cost more in reading time if they also entail prosodic revisions [30]. Event-related potentials indicate that commas in reading give rise to the same component (a closure positive shift) as intonational boundaries do in speech [31] (see Figure 1). The locations of obligatory prosodic boundaries in speech also correspond to locations of long reading times in eye-movements, contributing to an account of 'wrap-up' – locations where readers

dwell before taking in new information [32]. Some low-level aspects of prosody, including syllable structure and the number of stressed syllables in a word, affect eye movements and reading time also [33,34].

Speech is clearly the primary system for language in hearing individuals [35]. It is not surprising that the rich structure available in prosody would be used even in silent reading. One question facing the field now is precisely how a prosodic representation is assigned, both when there is an acoustic input, as in speech, and when there is not, as in reading.

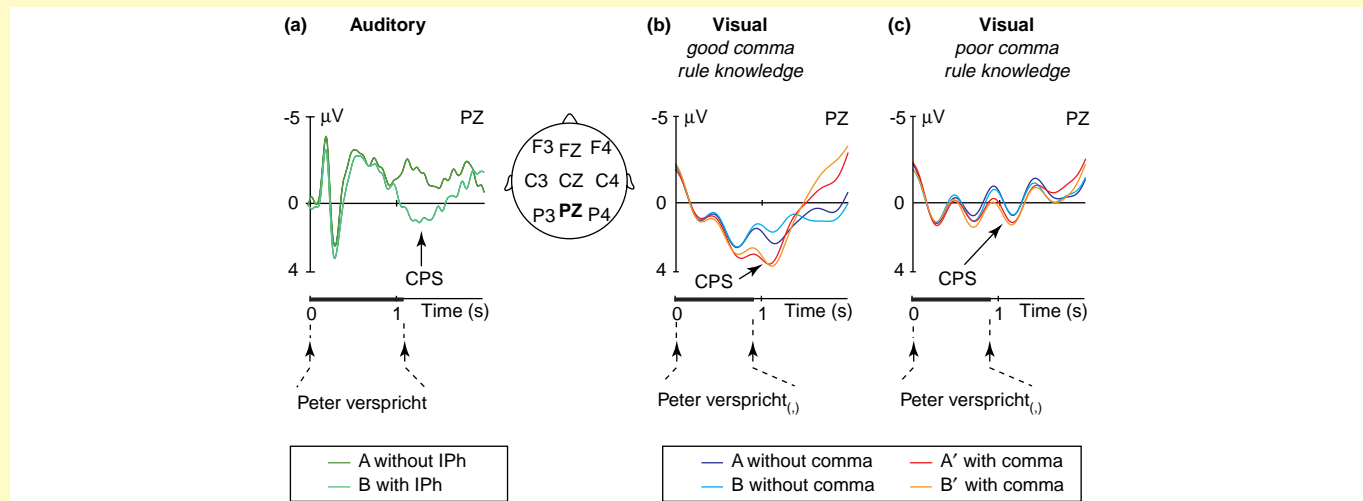


Figure 1. ERPs to auditory and visual sentences. Data are responses to the sentence: *Peter verspricht Anna zu [arbeiten/entlasten] und das Büro zu putzen* ('Peter promises [Anna to work/to support Anna] and to clean the office.'). In the auditory experiment (a), sentences of type A had no IPh after the first verb (*verspricht*), whereas an IPh was present in sentence type B. In the reading experiment, sentences were either without or with a comma after *verspricht*, to mimic the prosodic boundaries of spoken sentences (resulting in ungrammaticality for A'). The vertical line marks the sentence's onset; data extends ~1.5 s beyond the start of *verspricht*. CPS = Closure Positive Shift. Note that in German, the proper placement of commas is mandated by grammatical rules. Subjects in the experiment were categorized by their level of explicit knowledge of these rules; the subjects with 'good comma rule knowledge' (b) showed a more pronounced effect than those without (c). Data adapted from [22] (a) and [31] (b,c).

Length and the rational speaker hypothesis

Prosodic phrasing is partially determined by syntax. But it is also affected by the sheer length (in words or syllables) of syntactic phrases. Holding other factors constant, the probability of a prosodic boundary occurring at some position is an increasing function of the length of the preceding and following constituents [24–26]. According to the rational speaker hypothesis, we would expect the presence of a prosodic boundary to have a smaller impact on the chosen syntactic analysis of a sentence when its existence could be justified by long flanking constituents. We suggest that increased length of surrounding phrases should reduce the informativeness of a prosodic boundary because listeners need not assume that the syntax of the sentence motivated the boundary.

In recent work, this prediction was tested and supported in a series of experiments [27]. When two short phrases (short proper names) were conjoined as in (5), the placement of the initial prosodic phrase boundary, (#1) in (5)a,b, had a substantial effect on what interpretation listeners report for a sentence. When long phrases – either multi-syllabic proper names or definite descriptions as in (6) – replaced

these short phrases, the effect of prosodic boundary placement became much smaller.

- (5) a. *Pat (#1) or Jake and Lee (#2) convinced the bank president to extend the mortgage.*
b. *Pat or Jake (#1) and Lee (#2) convinced the bank president to extend the mortgage.*
- (6) a. *The plantation owner (#1) or the tenant farmer and the new caretaker (#2) convinced the bank president to extend the mortgage.*
b. *The plantation owner or the tenant farmer (#1) and the new caretaker (#2) convinced the bank president to extend the mortgage.*

On a local level, the same prosodic boundaries occurred in the sentences and might be expected to have the same results on interpretation. But listeners showed more nuanced behavior than a simple cue-based theory of prosodic processing would predict.

The centrality of prosody

One of the mysteries of human speech is its incredible complexity, on the one hand, and the apparent ease with which humans perceive and understand it, on the other. Unless one is simultaneously engaged in some difficult

secondary task, one is not aware that any resources are needed to understand one's native language, at least when it is spoken with normal prosody. But if each syllable is spoken with equal weight in a monotone, speech becomes difficult to understand for more than a brief agonizing period (see, for example, [28]).

Perhaps prosody provides the structure within which utterance comprehension takes place (in speech and even in silent reading: see Box 2). It might supply the basic skeleton that allows humans to hold an auditory sequence in memory [36,37]. For example, holding a string of digits such as 2543186 in memory is easier if it is structured into a prefix (254) and a suffix (3186). Why is this? Syllables organized prosodically become part of a larger structure of precedence and prominence relations. Further, predictable properties of larger structures, such as lengthened unit-final syllables, provide syllables with structural roles. Prosodic structure organizes the elements of an utterance, and the prosodic structures within a given language have many predictable properties. As expected on this view, highly constrained or even stereotyped prosodic or rhythmic patterns seem especially characteristic of language that must be held in memory, for example, nursery rhymes for young listeners, and epic poems for all listeners.

Beyond holding syllables in relation to each other, the grouping and prominence relations in a prosodic representation can help to solve the 'binding' problem in language. Vision researchers recognize that the brain must unify or 'bind' together information about numerous aspects of visual objects (shape, color, motion, location, etc.) (cf. [38]). A similar problem exists in sentences, although it is not widely discussed. A passage of speech may be divided into phonological units in one way, and divided in different ways for syntactic or

semantic analysis. For example, *corner's* is a unit (a prosodic word) in the phonological representation of '*the boy on the corner's hat*', but it is not a unit in the syntactic representation (where the possessive attaches to the entire phrase *the boy on the corner*, because the boy, not the corner, owns the hat). Similarly, *took* and *kicked* each consist of a verb stem and a past tense morpheme. In the phonology these go together. But in the syntax and the semantics, the past tense has scope over the whole sentence, not just the verb stem. The binding problem is the problem of how to identify the correspondence between the different appearances of, say, a past tense or a possessive in different representations in which it occupies very different locations. If each (level of) linguistic representation is indexed to the prosodic representation, then it would explain how a single unit (e.g. the past tense) can be identified across representational types.

Although speculative, this view would fit with the central and early role accorded to prosodic structure in some neural models [39], and it might help to explain why prosody and intonation interact with every component of grammar. The prosodic representation is the skeletal structure on which the rest of the utterance depends (see also Box 3 for future research questions).

Conclusions

We advocate an approach to prosody that tries to reconcile the existence of grammatical constraints on prosody with the enormous variability in natural pronunciations of a sentence. We view the problem in terms of the listener's assumption that the speaker is self-consistent in selecting among permissible prosodic options: that is, the listener assumes that a speaker who is using short prosodic phrases (lots of prosodic boundaries) will not omit a prosodic boundary at the largest syntactic break in the utterance for no reason. Similarly, the listener assumes that a speaker using small prosodic boundaries will not then use a large prosodic boundary at a minor syntactic break for no reason. On this view, the regularities in the pronunciation of a sentence will be higher-order patterns, rather than constraints on the absolute size of boundaries at particular positions. Prosody is therefore central to understanding spoken language, and we speculate that it might supply the basic skeleton that allows us to hold an auditory linguistic sequence in memory while the brain processes it.

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Box 3. Questions for future research

- How on-line is the use of prosody? Is the global prosodic structure updated locally? Is the relation among prosodic boundary sizes honored from the very start? Are decisions involving phrase length (especially of upcoming phrases) made quickly based on predictions [40] or are they delayed until the length of phrases becomes apparent? Are some prosodic decisions delayed, and if so, which ones?
- What are the effects of prosodic prominence? Most work on prosody has emphasized boundary effects, but prominence plays a role too [41,42]. How does prominence interact with boundaries? Do prominence and boundaries typically affect decisions about different aspects of grammar, for example, syntax versus information structure?
- How does prosodic information interact with other sources of information? What kinds of syntactic preferences can it overrule – for example, only decisions affecting the shape of the parse tree, or others as well? How does prominence interact with pragmatic factors such as the given/new status of phrases?
- Do different languages use prosody differently? For example, do languages with an obligatory syntactic position for focused phrases (e.g. Hungarian) use pitch accents differently from a language like English, where focus is typically conveyed by the presence of a pitch accent?
- How global is global? Is a listener's interpretation of a given prosodic event affected by a speaker's global style? Or just the events in semantically/syntactically relevant domains in the current utterance?

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