Prosody-meaning mismatches in PP ambiguity: Incremental processing with pupillometry

Jesse Harris, Chie Nakamura, Bethany Sturman, & Sun-Ah Jun (UCLA)
jharris@humnet.ucla.edu

Introduction. Prosodic boundaries are inserted not only for phonological reasons (e.g., to maintain optimal phonological weight or rhythm), but also to align prosodic groups with major syntactic junctures. After initial debate regarding the impact of prosody on early sentence parsing, studies have shown that prosody can guide processing at early stages (Speer et al., 1996; Steinhauer, 2003), that subjects are particularly apt to use the location of the boundary to disambiguate structures if encouraged by the task (Schafer et al., 2000), and that listeners use prosodic boundaries to anticipate upcoming structure in the visual world paradigm (e.g., Snedeker & Trueswell, 2003). However, with the exception of EEG measures, the methods employed in these studies tend to be offline or subject to task-specific strategies. We report findings from a pupillometry study, in which pupil dilation is measured as subjects passively listen to sentences. Using familiar PP attachment ambiguities (e.g., Pynte & Prieur, 1996), we show that listeners attend to phonologically optional prosodic boundary locations that disambiguate the structure, and that a processing penalty, as indexed by increased pupil dilation, is generated when the resulting structure is implausible.

Pupillometry experiment. Twenty items (1) were constructed in a 2x2 design, crossing Prosody (Instrument, Modifier) and the noun's Plausibility as an instrument (Plausible, Implausible), so that the only truly mismatching condition was InsPros-ImplausibleNP (*The artist sketched the man % with the* ***gun***). Critical nouns (*gun* vs. *pen*) were matched for syllable length and frequency. Materials were produced at a normal speech rate by a ToBI trained native speaker of English, so that prosodic boundaries were signaled with pre-boundary lengthening and a L-L% falling tone. Follow-on material (identical within each item quartet) was spliced after the critical nouns, with 100ms of intervening computer-generated silence. Items were counterbalanced and interspersed with 40 experimental fillers and 26 non-experimental filler items. Comprehension questions were presented after half of the items (1). Subjects were presented with sentences through high-quality sound-isolating headphones, while pupil size was recorded as subjects looked at a fixation cross. The sampling rate was set to 250Hz. Prior to analysis, trials with blinks were removed, and the pupil size was averaged into 50ms bins over a 2 second period. Data were fit with a growth curve analysis (Mirman, 2014), in which polynomial terms capture continuous changes in pupillary dilation (Kushinsky 2013). The experimental conditions and their interaction received deviation coding and were added as predictors to a series of LMER models with random intercepts, to compare fit from higher-order orthogonal polynomial structures. The best-fitting model was a linear polynomial model, reported below.

Results. We analyzed the percent change for each subject and each trial from the first 50ms of silence post critical noun at each 50ms time bin to control for individual variation in pupil size. There was ***a general penalty for Instrument Implausible nouns*** that interacted with the linear polynomial term [Plausibility: β = 0.15, *SE* = 0.05, t = 2.84, p < .01; Linear x Plausibility: β = 1.19, *SE* = 0.32, t = 3.73, p < .001]. The general effect was moderated by an interaction, showing ***an increased penalty for Instrument Prosody with Implausible noun mismatches***, again interacted with the linear component [Prosody x Plausibility: β = 0.15, *SE* = 0.05, t = 2.84, p < .01; Linear x Prosody x Plausibility: β = 1.19, *SE* = 0.32, t = 3.73, p < .001]; see Figure A. Overall, the mismatching condition, in which Instrument prosody was paired with an Implausible noun, elicited greater increases in pupil size than other conditions, depicted in Figure B.

Conclusions. The results support previous studies, finding that the pupil responds to prosodic misalignment (Engelhardt et al., 2010), and additionally show that optional boundaries are understood as syntactically informative, even without encouragement by the task. Pupillometry offers a promising advance in prosody studies, in the form of a real-time measure that is simple to administer and interpret, which could be paired with more time-intensive measures, like EEG.

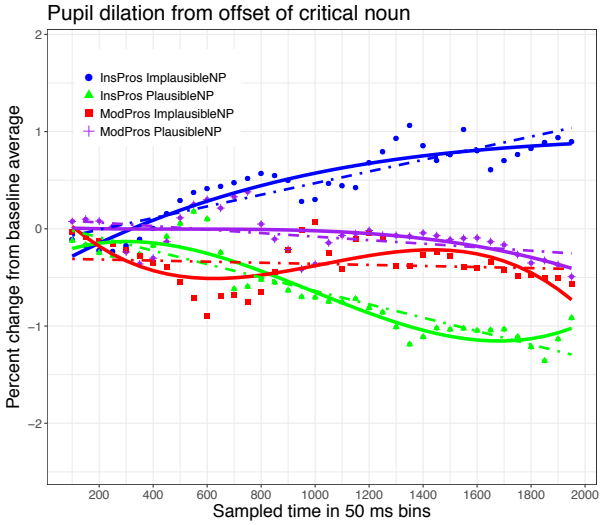
Materials. 20 quartets in a 2x2 design. Critical nouns in **bold**, prosodic boundaries (%) and identical auditory material spliced after the / symbol.

(1) a. *Instrument Prosody – Plausible as Instrument NP*
The artist sketched the man **%** with the **pen** / following the incident that morning.
b. *Instrument Prosody – Implausible as Instrument NP*
The artist sketched the man **%** with the **gun** / following the incident that morning.
c. *Modifier Prosody – Plausible as Instrument NP*
The artist sketched **%** the man with the **pen** / following the incident that morning.
d. *Modifier Prosody – Implausible as Instrument NP*
The artist sketched **%** the man with the **gun** / following the incident that morning.

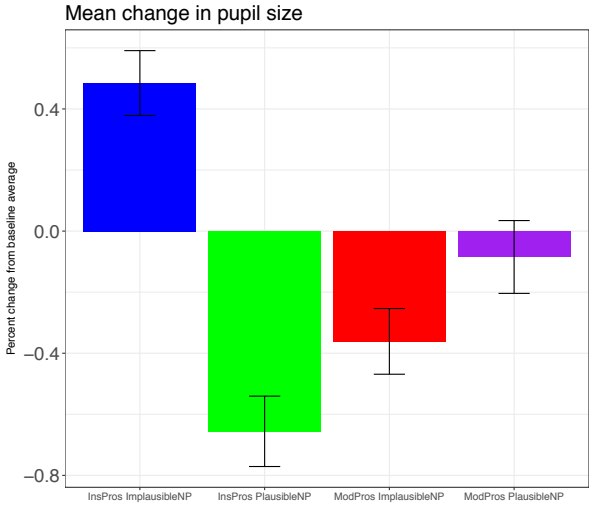
Comprehension question
What did the artist do? *Sketch someone* *Paint someone*

Figures.

A. Growth curves fit to data points recorded from offset of critical noun. Linear model showed in dashed lines; cubic in solid.



B. Means change in pupil size by condition.



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