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Brief article

Is it or isn't it: Listeners make rapid use of prosody to infer speaker meanings

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A B S T R A C T

A visual world experiment examined the time course for pragmatic inferences derived from visual context and contrastive intonation contours. We used the construction *It looks like an X* pronounced with either (a) a H^* pitch accent on the final noun and a low boundary tone, or (b) a contrastive $L + H^*$ pitch accent and a rising boundary tone, a contour that can support contrastive inference (e.g., *It LOOKS*$_{L+H^*}$ *like a zebra*$_{L\text{-}H\%}$... (but it is not)). When the visual display contained a single related set of contrasting pictures (e.g. a zebra vs. a zebra-like animal), effects of *LOOKS*$_{L+H^*}$ emerged prior to the processing of phonemic information from the target noun. The results indicate that the prosodic processing is incremental and guided by contextually-supported expectations. Additional analyses ruled out explanations based on context-independent heuristics that might substitute for online computation of contrast.

1. Introduction

The message a speaker intends to convey (speaker meaning) frequently includes information not made explicit in the utterance (Grice, 1975). Pragmatic inference is therefore crucial for the successful and efficient use of resources in conversation (Levinson, 2000): Listening to a speaker who made explicit everything she intended to convey would be like watching a movie in which each event unfolds in real time.

A widely held assumption in psycholinguistics is that pragmatic inference is slower and more resource-intensive than "core" aspects of sentence processing (e.g., Clifton & Ferreira, 1989). A primary example is online processing of scalar implicatures based on the English quantifier *some*. *Some* can trigger the pragmatic interpretation "some but not all", as well as the semantic interpretation "some and possibly all". Several studies find that comprehension of pragmatic *some* is significantly delayed compared to its semantic counterpart (Bott & Noveck, 2004; Huang & Snedeker, 2009, 2011). This assumption helps motivate Levinson's (2000) influential proposal that common inferences might be pre-compiled as automatically generated defaults, enabling listeners to bypass slow and resource-intensive pragmatic inference.

However, other recent studies suggest that listeners can in fact rapidly use contextually-supported expectations to facilitate pragmatic inference. For example, pragmatic *some* is computed without apparent delay when (a) it is well-supported by context and (b) accessible, more natural lexical alternatives are unavailable (Degen & Tanenhaus, in press; Grodner, Klein, Carbary, & Tanenhaus, 2010). These studies are part of a broader theoretical shift toward viewing efficient language comprehension as arising from expectations based on linguistic and non-linguistic context (e.g., Altmann & Kamide, 1999; Chambers, Tanenhaus, Eberhard, Filip, & Carlson, 2002; Chambers, Tanenhaus, &

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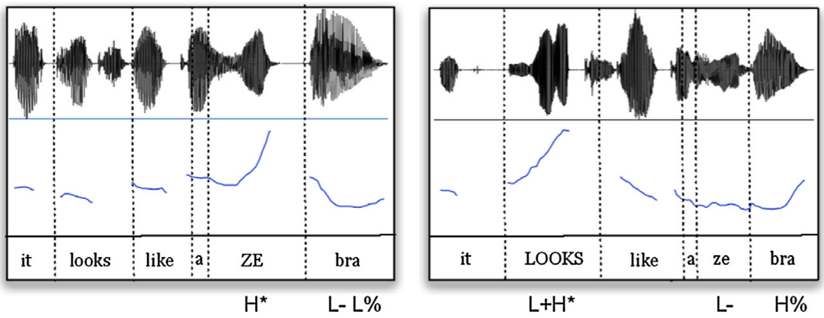


(a) Noun-focus prosody (b) Verb-focus prosody

Fig. 1. Waveforms (top) and pitch contours (bottom) for the utterance *It looks like a zebra*. The affirmative interpretation "It is a zebra" is typically conveyed by the pattern on the left (a), while the negative interpretation "It is not a zebra" is conveyed by the pattern on the right (b).

Magnuson, 2004; Levy, 2008; MacDonald, Perlmutter, & Seidenberg, 1994; Spivey & Tanenhaus, 1998; Tanenhaus, Magnuson, Dahan, & Chambers, 2000; Tanenhaus, Spivey-Knowlton, Eberhard, & Sedivy, 1995).

Strong support for rapid contextual inferences comes also from online integration of prenominal modifiers in visual search tasks. For example, a prenominal adjective, such as *tall* in *Touch the tall glass*, facilitates reference resolution when a contrasting item (e.g., a short glass) is present (Sedivy, Tanenhaus, Chambers, & Carlson, 1999). In addition, studies on the fall-rise pitch accent ($L+H^{*}$[1]), which invites a contrastive interpretation, find evidence for online generation of pragmatic expectations based on visually represented contrasts (Watson, Tanenhaus, & Gunlogson, 2008; Weber, Braun, & Crocker, 2006). For instance, Ito and Speer (2008) find that the $L+H^{*}$ in *Hang the red ball. Now, hang the GREEN*$^{*}_{L+H}$ triggers anticipatory eye-movements to an object of the same type as the preceding referent contrasted in color (e.g., a green ball).

An important limitation of previous work is that it has primarily focused on quantifiers and prenominal adjectives highlighting color and size contrast. These words might lexically encode the scale that supports a contrastive interpretation. Moreover, in studies manipulating contrastive prosody, a member of the relevant contrast set was explicitly mentioned in prior discourse. Such linguistic mention has been shown to have a privileged role in defining focus alternatives (Kim, Gunlogson, Tanenhaus, & Runner, in preparation; Wolter, Gorman, & Tanenhaus, 2011). Additionally, the dimensions of contrast were often highlighted by visual presence of minimal pairs (e.g., a red vs. green ball). These limitations make it difficult to generalize previous findings to cases in which listeners must construct a contextually-relevant contrast set online to derive pragmatic interpretations.

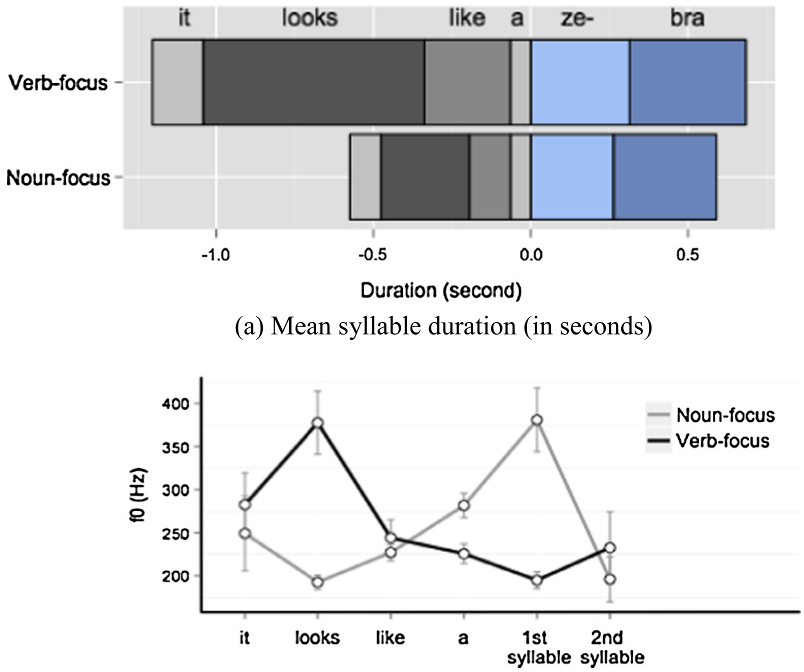
To address this, we conducted a visual world experiment (Cooper, 1974; Tanenhaus et al., 1995), using the construction *It looks like an X*, which can support opposing pragmatic interpretations depending on its prosodic realization. A canonical declarative prosodic contour, with nuclear pitch accent on the final noun (Fig. 1a, henceforth *Noun-focus prosody*), supports an affirmative interpretation without invoking contrast (e.g. "It looks like a zebra, and I think it is one"; Hansen & Markman, 2005). A prosodic contour with a contrastive $L+H^{*}$ accent on "looks" and ending with a rising L–H% boundary tone (Fig. 1b, henceforth *Verb-focus prosody*) can instead trigger a negative or contradictory interpretation (e.g. "It LOOKS like a zebra, but it's actually not one"; Kurumada, Brown, & Tanenhaus, 2012; Pierrehumbert & Hirschberg, 1990; Ward & Hirschberg, 1985).

On each trial, listeners heard either Verb-focus or Noun-focus prosody in the presence of one or two pairs of visually similar animals and objects, such as a zebra and an okapi (cf. Hanna, Tanenhaus, & Trueswell, 2003). This setup allows us to ask three questions. First, can listeners construct a contrast pair based on prosodic information? Unlike prenominal modifiers, the accented verb *looks* does not semantically encode contrast; it is compatible with both affirmative and negative meanings depending on prosodic information. Moreover, the $L+H^{*}$ in the Verb-focus contour does not evoke contrast with respect to any single property of the objects (e.g. color or size). Rather, it evokes a contrast between "It LOOKS like an X" and "It IS an X", and therefore implicates "It is not an X". This allows us to investigate how listeners construct a linguistic scale that supports a complex contrastive interpretation.

Second, is prosodic information integrated incrementally? The Verb-focus contour contains two prosodic cues: the $L+H^{*}$ on *looks* and the rising boundary tone. If prosodic interpretation is incremental, $L+H^{*}$ should influence interpretation as the utterance unfolds, based on probabilistic knowledge about pitch accent patterns and boundary tones[2]. This incremental hypothesis can be contrasted with

[1] We follow the ToBI convention and use H^{*} and $L+H^{*}$ to distinguish two accent patterns (Beckman & Ayes, 1997; Beckman, Hirschberg, & Shattuck-Hufnagel, 2005; Silverman et al., 1992). L and H represent a low tone and a high tone respectively and an asterisk * indicates the tone is aligned with a pitch accent. In contrast to H^{*}, $L+H^{*}$ is usually characterized with a wider pitch range, a steeper rise in F0, and a slight declination of pitch contour before the rise.

[2] Based on Boston University Radio Corpus of American English, Dainora (2001) showed that pitch accent strongly predicted boundary tone. For example, while 39% of H^{*} pitch accents were followed by a high boundary tone, the probability increased to 59% for $L+H^{*}$ accents.



(a) Mean syllable duration (in seconds)

(b) Mean F0 of each syllable

Fig. 2. Mean syllable duration (a) and *F*0 (b) in the Verb-focus and Noun-focus conditions.

an account in which speaker meaning is computed only after the utterance-final boundary tone is encountered (Dennison, 2010; Dennison & Schafer, 2010, discussed in more detail later).

Third, does the interpretation of $LOOKS_{L+H^*}$ involve a contextually-supported inference? Levinson (2000) posited two context-independent heuristics relating linguistic form to typical pragmatic interpretation: *What is simply described is stereotypically exemplified* (Heuristic 2); and *Marked message indicates marked situation* (Heuristic 3). The marked pitch accent, $LOOKS_{L+H^*}$, might therefore simply lead to a general heuristic expectation for an atypical referent. Alternatively, listeners may make use of contextual information to guide their prosodic interpretation. If so, the presence of a uniquely identifiable contrast set (e.g., a zebra vs. a zebra-like animal) would facilitate the interpretation of $LOOKS_{L+H^*}$ by supporting the contrastive inference ("It looks like an X, but it is not one").

2. Methods

2.1. Participants

Twenty-four University of Rochester undergraduates who were native speakers of American English and had normal (or corrected-to-normal) vision and normal hearing were paid $10.

2.2. Stimuli

Sixteen imageable high-frequency bi-syllabic nouns with initial stress were embedded in the sentence frame *It looks like an X*. A native speaker of American English recorded two tokens of each item with Noun-focus and Verb-focus prosodic patterns. Fig. 2(a) and (b) summarize duration and mean *F*0 values for each pattern. The speaker also recorded 44 filler items in which descriptions of target objects were embedded in one of four carrier phrases: *It looks like an X* (eight sentences)[3]; *Can you find X?*; *See, it has X*; *Show me the one with X* (12 sentences each). The filler items in constructions other than *It looks like an X* unambiguously referred to a single displayed picture. This was done to reinforce the assumption that the adult speaker is generally cooperative and not intentionally vague in her instructions. We avoided explicit naming (e.g., *It's a butterfly*). Such statements bias listeners to interpret *It looks like an X* as "It's not an X" because that speaker would otherwise have simply said *It's an X* (Kurumada et al., 2012).

We formed contrast pairs for each target noun by selecting visually similar but comparatively infrequent items (e.g. pairing zebra with okapi). Based on Kurumada et al. (2012), we expected Noun-focus prosody to bias responses toward the more prototypical member of each pair (e.g., zebra), and Verb-focus prosody to bias responses toward the less prototypical member (e.g., okapi)[4]. All the visual and audio stimuli are listed in Supplementary Materials.

[3] These filler stimuli were also recorded with the two prosodic contours (i.e., Noun-focus and Verb-focus prosody, 4 instances each) and included to mask the display characteristics of the target trials. They were always associated with a display with a contrast pair and two nameable singletons, which were not included in the analysis.

[4] We normed the current set of visual and audio stimuli using an online survey platform. 70 participants were asked to select the picture described by the speaker. Noun-focus items elicited more responses to the prototypical target (72%) than Verb-focus items (30%).

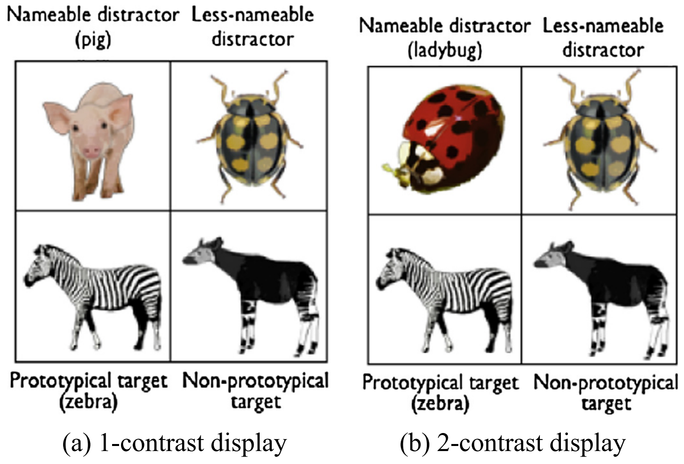


Fig. 3. Sample visual displays for the 1-contrast trials (a) and the 2-contrast trials (b).

We constructed 60 four-picture visual displays (16 critical trials and 44 filler trials). Half of critical trials were associated with *1-contrast* visual displays (one target pair and two unrelated singleton pictures, one nameable and one less-nameable; Fig. 3a) and half had *2-contrast* displays (one target pair and one distractor pair; Fig. 3b). Likewise, 12 fillers had 1-contrast displays, 12 had 2-contrast displays, and 20 had displays consisting of a target pair and two nameable singletons[5]. Picture names in each display began with different segments. Eight lists were constructed by crossing item presentation order (forward vs. backward), location of prototypical and non-prototypical items in the display, and prosodic contour (Noun-focus vs. Verb-focus). Each list began with three examples to familiarize participants with the task.

If contrastive accent is interpreted incrementally with respect to visual context, we should observe both an overall increase in fixations to the contrast set shortly after processing $LOOKS_{L+H^*}$ and earlier gaze shifts to the non-prototypical target with 1-contrast displays, compared to 2-contrast displays. With a single contrast pair, pragmatic inference based on $L + H^*$ is sufficient to identify the target. However, context-independent heuristics would not predict an effect of display type. The atypical prosodic contour (Verb-focus prosody) should shift gaze to the atypical visual representations (i.e., non-prototypical target and less-nameable distractor) with similar time-course, irrespective of contrast-set membership.

2.3. Procedure

Participants were presented with a cover story involving a mother and child looking at a picture book. The mother commented on objects and animals to help the child identify them. Each trial began with presentation of the display. After one second of preview, participants heard a spoken sentence over Sennheiser HD570 headphones and clicked on the referent that best matched the sentence. Eye movements were monitored using a head-mounted SR Research EyeLink II system sampling at 250 Hz, with drift correction procedures performed every fifth trial.

3. Results

Our primary analyses focused on three dependent measures: picture choice, proportion of fixations to alternatives within the display, and mouse-clicking response times. Variables were assessed with multilevel generalized linear regression models utilizing the *lmer* function within the *lme4* package in R (Bates, Maechler, & Bolker, 2011; R, 2010).

3.1. Picture choices

Participants selected the correct target on 96% of the (unambiguous) filler trials. Participants selected the prototypical target picture on 65.6% of critical trials with Noun-focus prosody, but only 25.5% of trials with Verb-focus prosody. Thus, participants developed contrastive inferences based on Verb-focus prosody.

3.2. Eye-movements

Figs. 4 and 5 plot proportions of fixations to prototypical vs. non-prototypical pictures in 1-contrast and 2-contrast displays, respectively. With 1-contrast displays, Verb-focus prosody elicited more fixations to the non-prototypical target prior to the onset of the final noun. This indicates that the prosodic information, together with the lexical information, was processed incrementally. With 2-contrast displays, fixations to non-prototypical targets in response to the Verb-focus prosody and prototypical targets in response to Noun-focus prosody began to increase about 200 ms after noun-onset.

[5] Filler items with a contrast pair and two nameable singletons were included to mask the fact that the target trials always contained an equal number of visually typical and atypical pictures. This was done to discourage a task-specific strategy of encoding the pictures in terms of their visual typicality prior to hearing the recorded utterance.

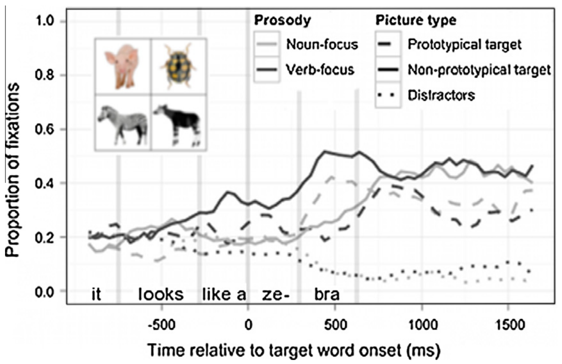


Fig. 4. Proportions of fixation to pictures in response to Noun-focus (gray lines) and Verb-focus prosody (black lines) in 1-contrast displays. The *x*-axis indicates duration with respect to the onset of the final noun.

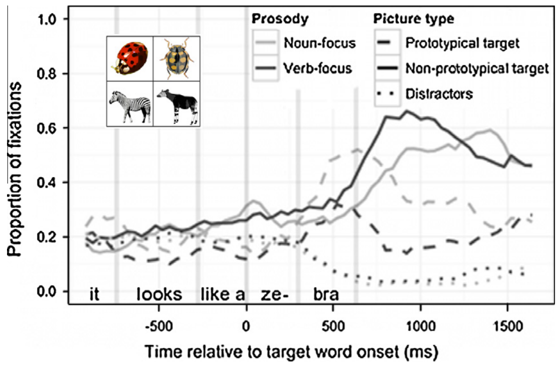


Fig. 5. Proportions of fixation to pictures in response to Noun-focus (gray lines) and Verb-focus prosody (black lines) in 2-contrast displays. The *x*-axis indicates duration with respect to the onset of the final noun.

Table 1
Summary of final linear regression model of mean logit-transformed log-odds ratios of fixations to target pictures vs. all pictures, in the region between 200 ms following the offset of *looks* and 200 ms following the onset of the target word. The final model included random intercepts and slopes for prosody and display type by participants and prosody, display type, and trial number by items.

	β	SE	t	p
Intercept	−0.34	0.28	−1.20	n.s.
Prosody = Verb-focus	0.84	0.37	2.30	<0.05
Display-type = 2-contrast	0.32	0.43	0.75	n.s.
Trial-number	−0.15	0.15	−1.00	n.s.
Prosody:display-type	−1.14	0.52	−2.20	<0.05
Display-type:trial-number	0.72	0.23	3.18	<0.005

Table 2
Summary of final linear regression model of mean log-odds ratios of fixations to non-prototypical target pictures vs. fixations to both target pictures, in the region between 200 ms following the offset of *looks* and 200 ms following the onset of the target word. The final model included random intercepts and slopes for prosody and display type by participants and prosody, display type, and trial number by items.

	β	SE	t	p
Intercept	−0.92	0.15	−6.02	<0.0001
Prosody = verb-focus	0.26	0.12	2.12	<0.05
Display-type = 2-contrast	0.03	0.13	0.26	n.s.
Prosody:display-type	−0.21	0.12	−1.76	<0.1

Because 200 ms is a conservative estimate of the earliest linguistically-mediated saccades in a four-picture display (Salverda, Kleinschmidt, & Tanenhaus, 2014), we focused on the region beginning 200 ms after the offset of *looks* and ending 200 ms after the onset of the target word. Within this window, the effect of the contrastive accent can plausibly be observed with minimal influence from the segmental information of the final noun.

If the prosodic contours are interpreted with respect to visually-represented contrasts, the contrastive accent on *looks* should trigger more fixations to contrast-set members in 1-contrast trials. Linear mixed-effects regression was used to examine the effects of prosody condition (Noun-focus vs. Verb-focus), display type (1- vs. 2-contrast), and trial number on logit-transformed log-odds ratios of fixations to either member of the target contrast set (e.g., the zebra and okapi) vs. all pictures[6]. The main effect of prosody and the interaction between prosody condition and display type were significant (Table 1): participants made anticipatory eye-movements to the contrast set upon hearing the contrastive accent on *looks* when the visual context allowed them to uniquely identify one.

The second set of models examined effects of prosody condition, display type, and trial number on logit-transformed log-odds ratios of fixations to non-prototypical targets vs. fixations to both target pictures. The results are summarized in Table 2. Prosody condition was significant, suggesting that the contrastive accent biased participants to fixate non-prototypical targets. Trial number and its interactions did not contribute significantly to model fit, making it unlikely that participants developed an association between prosody conditions and picture-types as a task-specific strategy.

Subsequent models analyzed the display types separately. In 1-contrast trials, there was a significant bias toward the non-prototypical target with Verb-focus prosody (β = .95, t = 3.07, p < .005). However, prosody condition was not a significant predictor in 2-contrast trials, in which participants were overall more likely to look at the non-prototypical target[7]. Fig. 6 plots mean fixation proportions to all the target and distractor pictures averaged across the same window of analysis. If participants were simply associating atypical prosody with atypical visual representations (e.g., Levinson's heuristics), Verb-focus prosody should

[6] Fixation ratios were transformed using the empirical logit function (Cox, 1970) with the number of observations set to the number of 50-ms time intervals within the analysis window. To minimize the risk of over-fitting the data, fixed effects were removed stepwise and each smaller model was compared to the more complex model using the likelihood ratio test (Baayen, Davidson, & Bates, 2008). Maximal random effects were used; in the event of convergence failure, random slopes were removed stepwise starting with the highest-order interaction terms with the least variance (Barr, Levy, Scheepers, & Tily, 2013).

[7] We do not have an explanation as to why Noun-focus prosody in the 2-contrast condition triggered more looks to the non-prototypical target. Because this trend was not present in the 1-contrast condition, it is unlikely that listeners were simply fixating atypical-looking objects in the display.

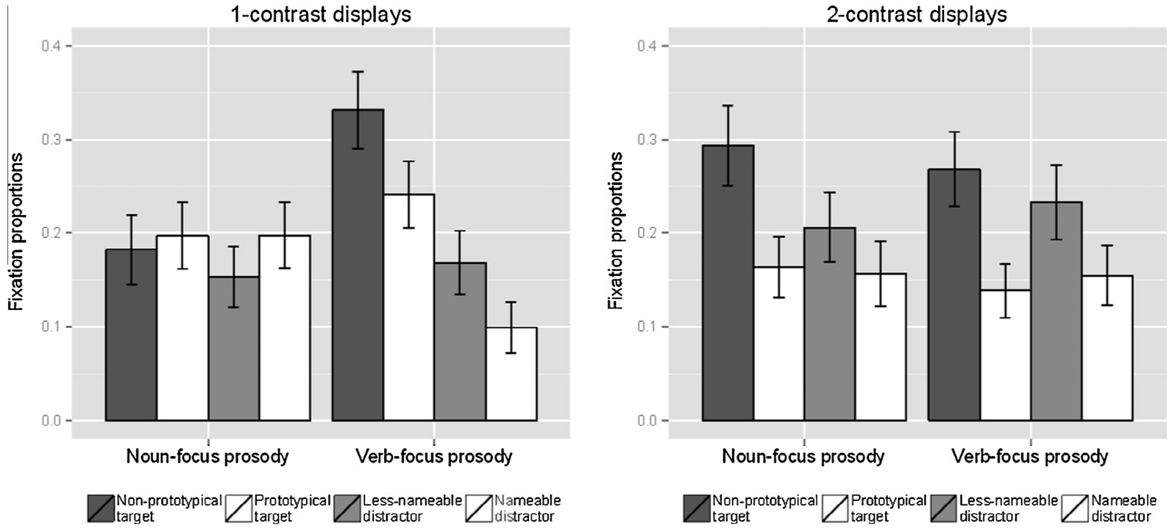


Fig. 6. Proportions of fixations to target and distractor pictures averaged across the region between 200 ms following the offset of *looks* and 200 ms following the onset of the target word.

trigger more looks to the non-prototypical target and the less-nameable distractor than to the prototypical target and nameable distractor for both display types. On the contrary, in 1-contrast trials, participants fixated the target contrast set more than the less-nameable distractor, suggesting that the interpretation was derived with respect to contrast-set membership rather than to pure visual typicality.

3.3. Mouse-clicking response times

Response times (RTs) were calculated by subtracting the time at which the utterance ended from the time at which participants selected a picture. Effects of prosody on log-transformed RTs were dependent on whether the prototypical or non-prototypical target picture was selected ($\beta = .509$, $t = 2.94$, $p < .005$). On trials with Noun-focus prosody, response times were significantly faster when a prototypical target picture was selected (mean RT = 1762 ms) than when a non-prototypical target was chosen (mean RT = 2364 ms, $\beta = .272$, $t = 3.20$, $p < .005$). On trials with Verb-focus prosody, there was a numerical trend in the opposite direction (mean RT = 2540 ms for prototypical vs. 2089 ms for non-prototypical target responses; $\beta = .201$, $t = 1.10$, $p > .10$). Overall, however, Verb-focus prosody elicited slower responses (mean RT = 2204 ms) than Noun-focus prosody (mean RT = 1969 ms, $\beta = .242$, $t = 2.09$, $p < .05$). Thus, unlike the online eye-tracking data, the final-choice RT data would have been consistent with delayed pragmatic inference.

4. General discussion

Contrastive accenting on *looks* elicited early eye-movements to non-prototypical targets, suggesting that listeners used prosody incrementally to develop pragmatic expectations. The results are inconsistent with a heuristic-based account in which marked prosody directs listeners' attention to visually atypical referents irrespective of contrast-set membership, which incorrectly predicts a null effect of display types. The current study also provides novel evidence that predictive pragmatic processing based on contrastive prosody is not restricted to cases where referents are contrasted along a single perceptual dimension or a member from a contrast set is overtly mentioned in the prior discourse. Together with recent studies showing rapid generation of context-bound implicatures (e.g., Breheny, Ferguson, & Katsos, 2013), the current results suggest that in constrained contexts complex pragmatic expectations can develop rapidly and incrementally.

One remaining question is how one can reconcile the apparently rapid and effortless generation of pragmatic expectations observed in the current study (see also Degen & Tanenhaus, in press; Grodner et al., 2010), with the general view that inference is slow and costly. The current results point us to two possibilities. One is that pragmatic inference consists of heterogeneous processes. The eye-movement data showed faster consideration of the non-prototypical target with Verb-focus prosody, whereas mouse-click RTs were slower. This suggests that prosodic and contextual information is integrated incrementally to generate pragmatic expectations online while pragmatic interpretations might be verified more carefully (Grodner et al., 2010).

A second possibility focuses on the role of recent experiences. As noted earlier, and in contrast to our results, Dennison (2010) and Dennison and Schafer (2010) did not observe immediate inferences with Verb-focus prosody. Their participants clicked on objects distributed among the bedrooms of two characters, as they heard instructions such as *Lisa had/HAD*$_{L+H^*}$ *the X*... If listeners made an immediate contrastive inference at HAD (i.e., Lisa HAD the bell but she no longer has it), participants should have shifted their gaze away from Lisa's bedroom. However, Dennison & Schafer did not observe such immediate effects of contrastive accent. We suspect that this is at least partly due to their within-subject prosody manipulation. They manipulated combinations of nuclear pitch accent and boundary tones, rendering some instances of $L + H^*$ incongruent with the contrastive interpretation. As the experiment progressed, participants might have adapted to the unreliability of the $L + H^*$, down-weighting it as a predictive cue for contrastive inference. In our experiment, on the other hand, $L + H^*$ is consistently followed by an L–H%.

Underlying this reasoning is an emerging view in psycholinguistics that listeners rapidly adapt to statistical properties in the input (e.g., Clayards, Tanenhaus, Aslin, & Jacobs, 2008; Farmer, Brown, & Tanenhaus, 2013; Fine & Jaeger, 2013; Fine, Jaeger, Farmer, & Qian, 2013; Jaeger & Snider, 2013; Kamide, 2012). Listeners integrate recent experience to flexibly adjust their expectations for future input, which allows them to navigate the variability and uncertainty ubiquitous in natural language (see Dell & Chang, 2013; Kleinschmidt & Jaeger, submitted for publication). Adaptation has so far been demonstrated in online phonetic and syntactic processing, and has been used to argue that language processing is consistent with rational inference. We have reported preliminary evidence for adaptation effects in prosodic interpretations (Kurumada et al., 2012), and are currently investigating how the reliability of prosodic input affects the online pragmatic processing of prosodic contours.

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Appendix A. Supplementary material

Supplementary data associated with this article can be found, in the online version, at http://dx.doi.org/10.1016/j.cognition.2014.05.017.

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