Production Expectations Modulate Contrastive Inference

Anonymous CogSci submission

Abstract

[jd: insert] Include no author information in the initial submission, to facilitate blind review. The abstract should be one paragraph, indented 1/8 inch on both sides, in 9 point font with single spacing. The heading "**Abstract**" should be 10 point, bold, centered, with one line of space below it. This one-paragraph abstract section is required only for standard six page proceedings papers. Following the abstract should be a blank line, followed by the header "**Keywords:**" and a list of descriptive keywords separated by semicolons, all in 9 point font, as shown below.

Keywords: add your choice of indexing terms or keywords; kindly use a semicolon; between each term

Introduction

One of the most interesting features of language is its flexibility. In referring to an object, speakers must choose one of an indefinite number of possible referring expressions. *The banana*, *the yellow banana*, *the yellow, curvy fruit-thingy* for example are all utterances that can refer to the same object. At the same time, the same utterance – e.g., *banana* – can be used to refer to different kinds of objects. This flexibility poses a challenge for a listener, who needs to pragmatically infer a speaker's intended referent. Consequently, trying to understand how a listener processes these utterances and what affects their interpretation has become a central question in psycholinguistic research. [jd: last sentence too vague but maybe ok for first paragraph]

A basic fact about language is that listeners process utterances incrementally, i.e., new information is incorporated into the interpretation of the utterance as soon as it becomes available (Eberhard, Spivey-Knowlton, Sedivy, & Tanenhaus, 1995). For instance, eye-tracking experiments have shown that if a listener hears the incomplete utterance *the yellow* in a display like Figure 1a, they fixate on the yellow objects in the display even before they hear the disambiguating noun *banana* and [ek: arrive at] the final referent [ek: cite].

But listeners go beyond the information contained in the signal itself in processing language; they also take into account contextual information – including the nature of other possible referents – to draw rapid pragmatic inferences about a speaker's intention [ek: cite]. One such inference that has received much attention in recent years is the so-called *contrastive inference* (Sedivy, Tanenhaus, Chambers, & Carlson, 1999)[jd: include other references for studies on contrastive inferences]. Consider the context in Figure 1b that shows a yellow and orange banana, a yellow corncob and some other distractor item. When a listener is asked to *pick out the yellow...*, there are two eligible objects to choose from: the yellow banana and the yellow corncob. Rather than considering both yellow objects equally likely target referents, listeners often exhibit a preference, evidenced in increased looks, for the yellow object that has a contrast member of the same type but of a different color in the display (i.e., the banana) (Sedivy et al., 1999; Sedivy, 2003). When the contrast is absent, as in Figure 1a, listeners have no such preference. The effect of seeing a target preference over the competitor that is elicited by the presence of a contrast (i.e., the orange banana) is called the contrastive inference.

Broadly speaking, a contrastive inference arises because a listener expects a cooperative speaker to only produce the color modifier if it's contextually necessary for establishing reference [ek: Grice]. Observing the adjective suggests that the speaker was forced to produce it by the presence of a contrast object.

This simple Gricean account that only takes into consideration the contrastive function of the adjective predicts that contrastive inferences should arise wherever and whenever the target object occurs in the presence of a contrast object. It is surprising, then, that contrastive inferences have been found to vary substantially: While it has been replicated reliably in the size adjective domain [ek: cite], the effect seems to be less stable with color adjectives (Sedivy, 2003). Sedivy (2003) report that the contrastive inference arises in contexts where the target object has a "predictable" color (such as the yellow banana in Figure 1a) but not when it is replaced by an object with an "unpredictable" color like a cup, which comes in all sorts of colors. They suggest that these objects differ in how likely a speaker is to produce the color modifier for the object in isolation, i.e., in the absence of a contrast, a yellow banana is usually just called *a banana* while a yellow cup is often called *a yellow cup*. Sedivy (2003) suggest that the contrastive inference arises with objects that do not have the adjective in their *default description*, which makes the observation of the adjective surprising and the listener interprets the adjective contrastively.

In the interim, contrastive inferences have been shown to be modulated by multiple factors. First of all, its occurrence seems to be dependent on the expectations of informativity [ek: elaborate] (Aparicio, Xiang, & Kennedy, 2016; Apari-

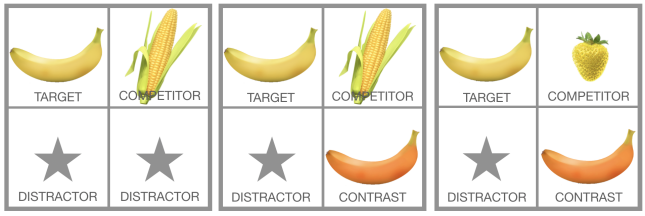

Figure 1: This is a figure. [ek: label with A and B]

cio, Kennedy, & Xiang, 2018; Sedivy, 2003). However informativity alone cannot account for [ek: ...]. Other studies indicate that adjective semantics also matter, such that the contrastive inference arises with color adjectives, relative adjectives and maximum standard absolute adjectives, but not with minimum standard absolute adjectives (Aparicio et al., 2018). Furthermore the effect only arises when the listener considers the speaker as a reliable speaker who does not violate communicative norms (Grodner & Sedivy, 2011).

In this paper, we provide a novel account of contrastive inference that has the potential to unify the above properties by reducing them to listeners' expectations about the speaker's contextual probability of producing the pre-nominal adjective.[jd: nice, just clean up the sentence a little] In so doing, we follow recent research highlighting the importance of listeners' generative model of the speaker in generating pragmatic inferences (Degen, Hawkins, Graf, Kreiss, & Goodman, 2019)[ek: cite more][jd: eg Hawkins et al under review but also some of the more cogsci-y papers in domains other than semprag, eg kleinschmidt?]. We propose to formalize the relevant listener-side reasoning within the Rational-Speech Act (RSA) framework (Frank & Goodman, 2012; Goodman & Frank, 2016), a state-of-the-art computational framework that models pragmatic inference as the result of listeners performing Bayesian inference on their speaker model and their prior beliefs about likely meanings, thereby giving the speaker model a central role in the inference. It provides a way to quantitatively assess the probability that a listener with prior beliefs and expectations about the speaker assigns to possible referents after observing partial sentences of the form *Click on the yellow*. This shifts the focus away from specific cognitive and linguistic factors that influence contrastive inference onto listener's production expectations (and their prior beliefs).

For this investigation it is important to distinguish between two concepts: *contrastive inference* and *target preference*. The target preference quantifies to what extend the listener prefers the target over the competitor interpretation in any given context. For example, if they consider both to be equally likely referents, the target preference would be 50%. Even though a contrastive inference can lead to a preference of the target over the competitor, this does not need to be the case. A contrastive inference occurs when the presence of the contrast increases the target preference. That means there can be a contrastive inference even if there is no target preference in the contrast condition, simply because there was a target dispreference in the contrast-absent condition.

In this paper we will first show how the RSA account can make the same predictions about the basic contrast effect as for instance the default description (Sedivy, 2003) [jd: somewhat clumsy sentence]. But the RSA account also makes new predictions about the context that *should* affect contrastive inference and final target preference. We report a free production study we conducted to elicit modifier probability estimates. For the quantitative evaluation of the model's inference predictions, we compare it to empirical data which we elicited using an incremental decision task.

Accounts of contrastive inference [ek: Model section]

[ek: "Likelihood" and "probability" are all scrambled up here. Don't forget to fix that!]

In the literature, different factors have been considered to give rise to contrastive inference which indirectly put more or less relevance onto the speaker.

Sedivy et al. (1999) for instance only considers a very limited speaker model. As mentioned above, a contrastive inference only arises when the modifier is not a component of the object's *default description*. It therefore only assumes speaker considerations as to the creation of the default descriptions for objects and is completely independent of the context the target is presented in. Other research has extended this account and found that the size of the contrastive inference can vary (Aparicio et al., 2018)[ek: Rubio-Fernandez]. [ek: Figure out how much they really consider the speaker here... actually not much]

A Rational-Speech Act account gives the speaker a central role in the predictions, since the listener P_{L_1} determines the most likely intended referent r by directly reasoning about the speaker's possible utterances u for each object in the display C.

$$P_{L_1}(r|u,C) = \frac{P_{S_1}(u|r,C) * P(r|C)}{\Sigma P_{S_1}(u|r_i,C) * P(r_i|C)} \quad (1)$$

For now we will make the simplifying assumption that listeners have a uniform prior $P(r|C)$ over all objects in the display. Then the RSA model predicts a direct relationship between the production probabilities P_{S_0} and the listener's distribution over possible referents P_{L_1}.

$$P_{L_1}(r|u,C) \propto P_{S_1}(u|r,C) \quad (2)$$

However so far in the literature, RSA has been mainly applied to the analysis of full utterances [ek: Reuben]. To receive RSA predictions for an incomplete reference such as *the yellow...*, we take P_{S_0} to simply be the underlying probability of color mention for each referent in the display. Now we can turn to the qualitative predictions this account makes.

First, we consider the context in Figure 1a. Upon hearing the modifier *yellow*, the pragmatic listener P_{L_1} will consider

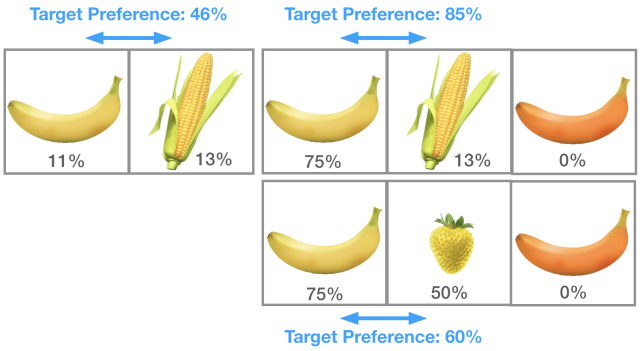

Figure 2: This is a figure. [ek: very preliminary so far, but I think we need a figure with the example numbers, otherwise it gets to confusing. And it might be too much info for the first figure; But there is probably a way to make it more efficient – ideas?]

how likely a speaker is to include this modifier in their referring expression **for each object in the display**. Since only the target (yellow banana) and the competitor (corncob) are yellow, we will assume that the production probabilities of *yellow* for the other objects in the display are 0. This only leaves the target and the competitor as potential referents.[1]

If the contrasting banana is absent, speakers are unlikely to include the color modifier when referring to the target banana [ek: number, 11%] and they are equally unlikely to do so for its competitor, the corncob [ek: number, 13%]. The pragmatic listener will therefore not be able to prefer one potential referent over the other.

The presence of the orange banana will not affect the listener's expectations about modifier production for the competitor (corncob). However, since the modifier is now necessary for a unique identification, the speaker is much more likely to use the modifier [ek: number, 75%]. Here, the pragmatic listener then predicts the yellow banana to be the more likely target over the competitor [ek: 75% (target modifier production probability) vs 13% (competitor modifier production probability); normalized 85% target preference], resulting in a target preference. Compared against the contrast absent context [ek: 11% vs 13%: normalized 46% target preference], there is a clear increase in target preference which corresponds to the generally reported case of contrastive inference.

In contrast to previous accounts of contrastive inference, the modifier production probabilities are expected to drive the contrastive inference and target preference. Since the contrastive inference is the difference in target preference between conditions and the target preference depends on the modifier production probabilities of the target and the competitor, the competitor takes on a central role. This raises the question what happens if we change the modifier production probabilities for the competitor. [ek: Westerbeek] showed that speakers are more likely to include the color modifier for objects in isolation when they appear in an atypical than in a typical color [ek: see also RF 2016]. For example the yellow strawberry in Figure 1b receives a higher modifier production probability [ek: number, 50%] than the corncob competitor in Figure 1a. The target preference in this context is only now [ek: 60%]. This predicts a change in the size of the contrastive inference, dependent on the nature of the color competitor used in the display.

To investigate when a listener with a generative speaker model should draw a contrastive inference, we need to manipulate and elicit how likely a listener can expect a modified over an unmodified referring expression for each object in the display. To evaluate the performance of the model and to gain information about the prior of the objects, we need comprehension data that informs us which object is considered the most likely target referent.

Experiment 1: Modifier Production in an Interactive Reference Game

Experiment 1 was aimed at obtaining modifier production probabilities for all the displays ultimately used in the contrastive inference experiment (Experiment 2). We elicited these probabilities in a free production interactive reference game. We expect that the typicality of a color for an object will affect these modifier production probabilities, i.e., presented in isolation, we expect the speaker to call a yellow banana simply *the banana*, but an orange banana *the orange banana*. We take these results as the modifier production probabilities a listener can expect for each object.

Participants

We recruited 282 participants over Amazon Mechanical Turk, who were randomly matched to form one listener-speaker chat pair (i.e., 141 pairs in total). Each participant was paid $2.30 (approximately $11-$14/hr). We restricted participation to workers with IP addresses in the US and an approval rate of previous work above 97%. We excluded 29 participant pairs because of multiple participation and for using primarily using unnatural descriptions such as *should be yellow, must have teeth to eat* for *red corn*.

Material

Each context included four items, as displayed in Figure 3. The pool of items consisted of 10 types (banana, broccoli, carrot, corn, egg, lettuce, pumpkin, strawberry, swan, tomato), each of which could occur in a typical and atypical color. For example, the broccoli could occur in its typical color green or in the atypical color red. The resulting pool contains 20 items, 10 of which are atypically colored. The number of colors is counterbalanced such as each color occurs twice as a typical and twice as an atypical instance. All items were carefully normed for color-diagnosticity (Tanaka & Presnell, 1999), typicality and nameability.

[1] All of the following modifier production probabilities for the target and competitor are the ones obtained in the production study explained below.

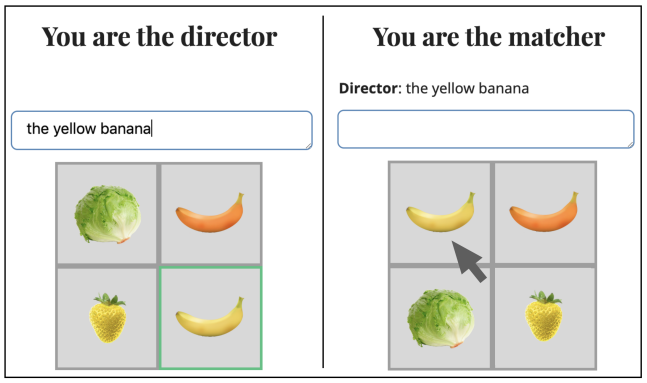

Figure 3: This is a figure. [ek: make text bigger in figure]

Design

The contexts varied in the typicality of the target, the typicality of the competitor and the presence of a contrast, resulting in eight conditions. We needed to elicit the modifier production probabilities for the target and the competitor. In contexts where the contrast is absent, this distinction is irrelevant. For example, when target and competitor are both (a)typical, it is irrelevant, which is underlyingly coded as the target. Similarly, the modifier production probability for a typical target with an atypical competitor is the same as the probability for a typical competitor in a context with an atypical target. In contrast-present contexts, the target-competitor distinction matters, which is why half of the trials had the competitor to be communicated and half of them the target.

The fillers were eight randomly created contexts where the contrast or the distractor had to be communicated. Overall, each participant saw 60 different contexts (32 critical trials) in a completely randomized order.

Procedure

Participants were randomly paired up and each was randomly assigned either to the role of a speaker or listener. They could communicate freely through a real-time multi-player interface similar to [ek: Hawkins (2015)]. The speaker was instructed to communicate a target object out of a four-object context to the listener. The target could be identified by a green border surrounding it. The speaker and the listener saw the same set of objects but in a randomized order to avoid trivial position-based references such as "the left one". After the listener clicked on the presumed target, both the speaker and listener received feedback about whether the right object had been selected.

Results

Figure 5 shows the probability of color modifier mention for the target and competitor in each condition[2].

When a contrast to the target is present (e.g., another banana), a speaker needs to include the color modifier to fully

[2]Note that some data is duplicated in the conditions where the contrast is absent (as described in *Design*)

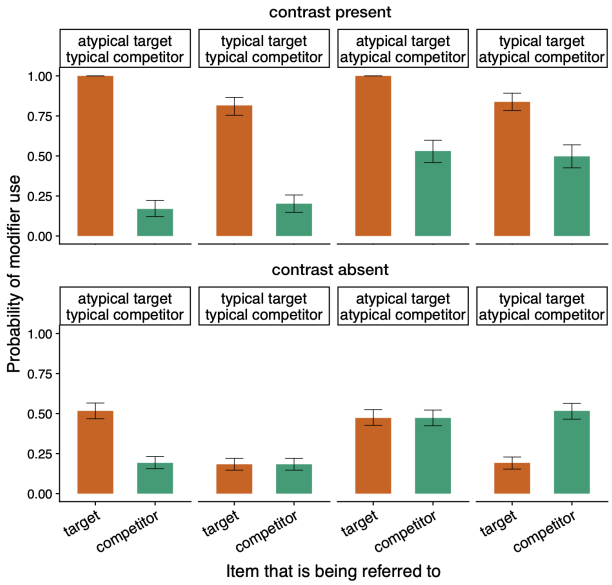

Figure 4: This is a figure. [ek: make text bigger in figure]

disambiguate the two items (see the upper row in Figure 5). When the target is atypical, speakers always used the color modifier, whereas they sometimes still used only the bare noun when the target was typical.

When the contrast was absent (see the lower row in Figure 5), speakers were more likely to include a color modifier when referring to an atypical target than a typical one [ek: stats?].

Independent of contrast, speakers were more likely to include the color modifier for an atypical color competitor over a typical one [ek: stats?].

The results of this production experiment show that the probability of a speaker's modifier use is modulated by the color typicality of the item and the presence of a contrast. Our experiment therefore successfully manipulates the modifier production probabilities a listener can expect in different contexts.

Comprehension Experiment: An Incremental Decision Task

To investigate which objects listeners consider to be the most likely referent after observing the color adjective, we conducted an incremental decision task (Qing, Lassiter, & Degen, 2018). This is an offline task to investigate a listener's belief about the intended referent while gradually unfolding the referring expression.

Participants

We recruited 239 participants over Amazon's Mechanical Turk, 121 of which saw atypical color competitors and 118 saw typical color competitors in the critical trials. Each of them was paid $1.80 for their participation (10-16/hr). We restricted participation to workers with IP addresses in the

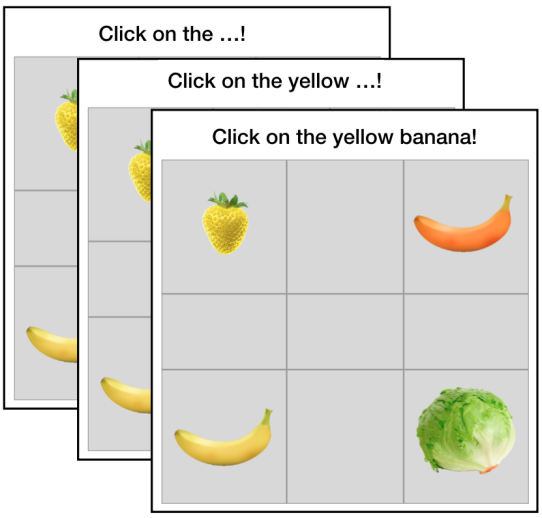

Figure 5: This is a figure.

US and an approval rate of previous work above 97%. 27 participants were excluded because they indicated that they did the experiment incorrectly, English was not their native language, or they gave more than 20% erroneous responses[3]. 211 participants remain, 108 of which were in the atypical competitor and 103 were in the typical competitor condition.

Material

The item pool is the same as in the production study (Experiment 1).

Design

Participants completed 55 trials in total, 20 of which were critical trials and 35 were fillers. The contexts varied for each participant with respect to the presence of a contrast and the target's color typicality (within-subject manipulation). Participants were randomly assigned to see either typical or atypical competitors on critical trials (between-subject manipulation). All critical trials included color modified utterances. To avoid learning effects, we included filler trials with unmodified referring expressions and with referents other than the targets of the critical trials. The trial structure is summarized in table 1.

Procedure

This experiment is a one-player adaptation of the production study explained above and follows the design of an incremental decision task (Qing et al., 2018).

All participant were assigned the role of the listener, which means that they needed to identify which object was the target given a referring expression placed above the context. Crucially, the referring expression was only gradually revealed and participants had to choose an object each time before the trial continued. Per trial, three choices had to be made: (1) before receiving any information about the referent (i.e, after observing "Click on the"), (2) after receiving the adjective ("Click on the yellow") and (3) after receiving the full referring expression with the disambiguating noun ("Click on the yellow banana!"). The critical selections are the clicks after observing the adjective but before the disambiguating noun, since they will inform us about the inferences participants seem to draw from observing the adjective.

To center the position of the mouse after each selection, a button appeared in the center of the grid which had to be clicked to reveal the next word or to advance to the next trial.

The trials were randomized with one restriction: contexts in which a speaker's color modifier use to refer to the target is very unlikely only occurred after the 15th trial. These were contexts where there was no contrast and either both target and color competitor were typical objects, or the target was typical while the color competitor was atypical. We introduced this restriction to minimize the risk that participants perceive the "utterance generator" (speaker) as unnatural.

Before participants proceeded to the main trials, they had to complete four practice trials constructed from the speaker perspective, which were introduced to familiarize the participants with the task.

Table 1: Overview of the trial structure for the comprehension study.

trial type	number	utterance	referent
critical	20	modified	target
filler	5	unmodified	competitor (typical)
filler	5	modified	competitor (atypical)
filler	5	modified	contrast
filler	20	unmodified	distractor (typical)

Results

Figure 6 shows the proportion of object selections before reading the adjective (lighter colors) and after the adjective (darker colors), grouped by context condition. Before an adjective is observed, all items should appear equally likely to be the target, which is supported by the generally uniform distribution in all conditions. After the adjective is revealed (darker colors), only the target and competitor are legible options and we predict that the presence of the contrast and the typicality of the objects will affect the listeners' object choices.

When the contrast is present (upper row in Figure 6), there is a general preference for target over competitor selections. This preference is biggest for the case when the target is atypical and the competitor is typical and disappears for when the target is typical and the competitor is atypical.

When the contrast is absent (lower row in Figure 6) and target and competitor differ in typicality, there is a preference

[3] An erroneous response is defined as a click to a non-target object after observing the fully disambiguating noun.

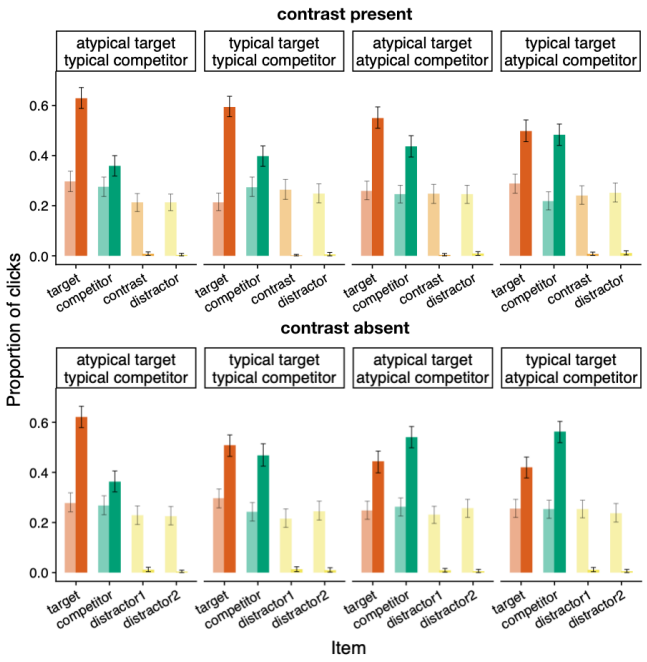

Figure 6: This is a figure. [ek: make bars and text bigger]

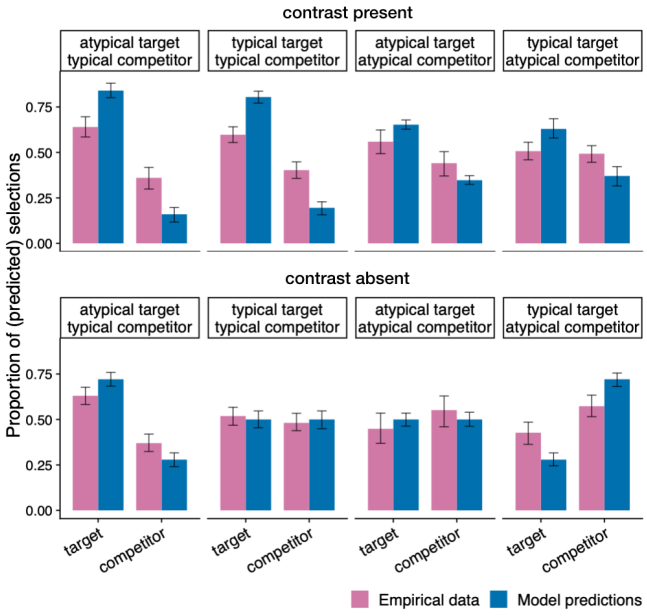

Figure 7: This is a figure.

for the item with the atypical color. When the two items share their typicality, the selection are approximately at the same rate.

These results clearly show that the color typicality of the objects in the display affect the inference listeners draw about the intended referent. An atypical competitor alone can promote the competitor over the target when the contrast is absent and even make the target preference disappear when a contrast is present. Choosing an atypical target makes the contrast-present and contrast-absent condition selections more similar, suggesting a smaller contrastive inference.

Model evaluation

To assess the relationship between the modifier production probabilities and the comprehension data in the simplest way, we will assume a flat prior over all objects in the display. The probabilities to choose the target over the competitor are then simply the normalized modifier production probabilities as shown in Equation (3), where r is the possible referent, u the utterance and C the specific context.

$$P_{L_1}(r|u,C) = \frac{P_{S_0}(u|r,C)}{P_{S_0}(u|r_{target},C) + P_{S_0}(u|r_{comp},C)} \quad (3)$$

Figure 7 shows the model predictions (in blue) and the empirical results (in purple) for target and competitor selection after observing the adjective.

The model predicts...

The model qualitatively predicts the patterns for the different context conditions. However, it generally predicts a stronger inference than borne out in the empirical data. [ek: which is why the correlation is so low]

[ek: the rsa model is a significant predictor for the comprehension data; however there are also biases: position and non-switching (see figure); in fact if we add these predictors to the model, they also become significant. In the new plots, we can see that (when the position is equal), whatever was previously clicked highly affects the outcome. Now the model underpredicts the target clicks in most conditions. The reverse is true if the competitor was clicked previously. This is something where the eyetracking data will provide more information since we expect the switching cost to be lower.]

Discussion

[jd: somewhere make clear that it's not just color-diagnosticity of the target (as sedivy suggests) that matters – instead, it's that, and the color-diagnosticity of the other distractors, and their relative typicality, etc etc, which are all ultimately captured variable modifier production expectations, and *that's* the explanatory quantity]

[ek: random thought: if target is typical and contrast present – does the typicality of the contrast affect modifier production for the target? It should. So far we see that modifier mention for the typical target + contrast contexts is not at ceiling, because (maybe) "banana" is still a better description of the target than the contrast. This would probably change if the contrast was brown.]

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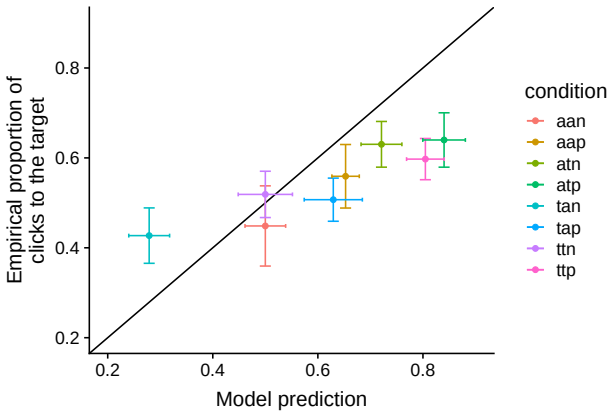

Figure 8: This is a figure.[ek: fix condition naming][jd: don't say "clicks to the target" but instead "target selection" on the y-axis and throughout the paper. clicks sounds clumsy. maybe also highlight the ttp and tap conditions visually if you use them as the motivating example at the beginning of the paper]

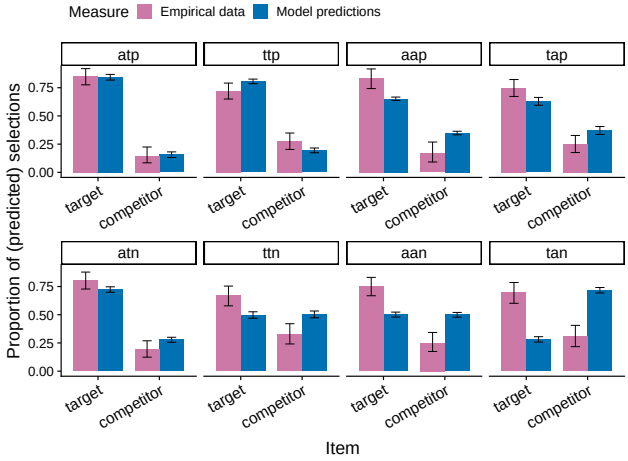

Figure 9: This is a figure.[ek: fix a lot]

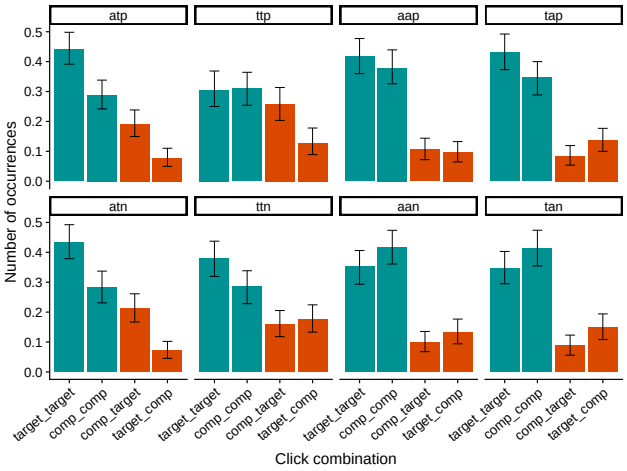

Figure 10: This is a figure.[ek: fix a lot]

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