Supplemental Materials: Using contrastive inferences to learn about new words and categories

Claire Augusta Bergey and Daniel Yurovsky

S1 Experiment 1

S1.1 Unique target display trials

In Experiment 1, half of the trials were filler trials in which the target had both a unique shape and unique value of the critical feature. We expected participants to mostly choose the unique object when directed to "Find the toma" in these trials, and to even more strongly prefer the target when directed to "Find the blue toma" (as it is the only object with the correct feature). These were included as filler trials to keep participants from cluing into the intended inference in contrastive display trials, and they provide a sanity check that people are making sensible selections in the task.

To analyze these trials, we asked whether participants chose the target more often than expected by chance (33%) by fitting a mixed effects logistic regression with an intercept term, a random effect of subject, and an offset of $logit(1/3)$ to set chance probability to the correct level. The intercept term was reliably different from zero for both color ($\beta = 6.64$, $t = 4.1$, $p < .001$) and size ($\beta = 2.25$, $t = 6.91$, $p < .001$), indicating that participants consistently chose the unique object on the screen when given an instruction like "Find the (blue) toma" or "Find the (big) toma," across utterances with and without an adjective.

To test whether the utterance type (with or without an adjective) and feature type (size or color) affected people's referent choices, we fit a mixed effects logistic regression predicting target selection from feature type, utterance type, and their interaction with random effects of participants. Use of an adjective in the utterance increased target choice ($\beta = 3.85$, $t = 3.52$, $p < .001$), and feature type (color vs. size) was not statistically related to target choice (β = -0.48, t = -1.1, $p = .269$). The two effects had a marginal interaction (β = -2.24, t = -1.95, $p = .051$). Participants had a general tendency to choose the target in unique target display trials, which was strengthened if the audio instruction contained the relevant adjective. These effects did not significantly differ between color and size adjectives, which suggests that participants did not treat color and size differently in these baseline trials, though the marginal interaction suggests that use of an adjective may strengthen their tendency to choose the unique object more powerfully in the size condition.

S1.2 Additional analyses

In addition to the analyses reported in the main text, we ran a pre-registered linear mixed effects model predicting target choice from the presence of an adjective in the utterance, the adjective type (size or color), and the display type (unique target display or contrastive display) (Table S1). People were more likely to choose the target if there was an adjective in the utterance ($\beta_{adjective} =$

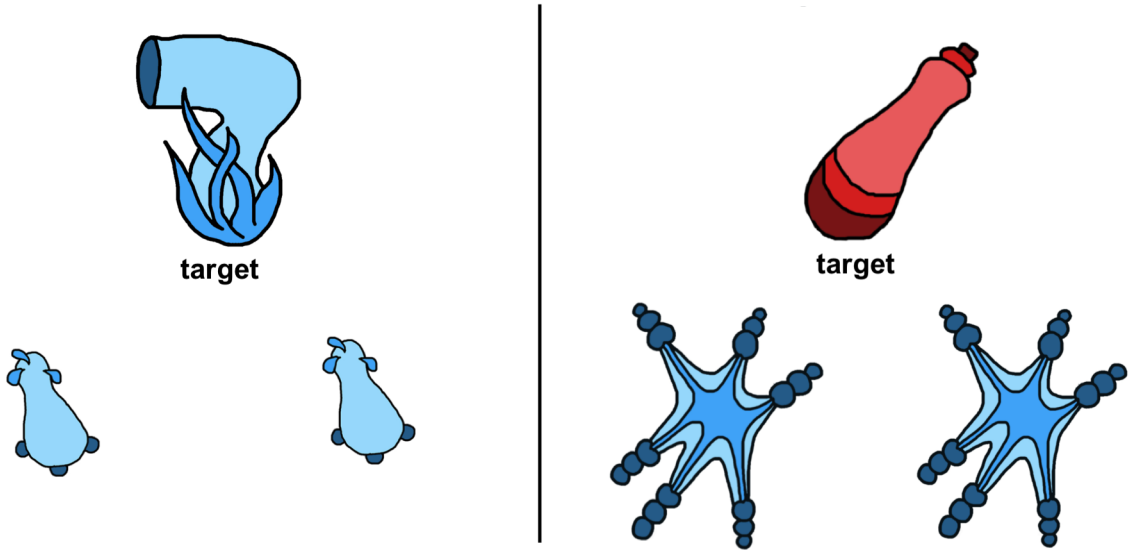


Figure S1: On the left: an example of a unique target display trial in which the critical feature is size. Here, the participant would hear the instruction, e.g., "Find the toma" or "Find the big toma." On the right: an example of a unique target display trial in which the critical feature is color. Here, the participant would hear the instruction "Find the toma" or "Find the red toma." In each case, the target has both a unique shape and critical feature (size or color). Target labels are provided for clarity and were not shown to participants.

2.21, $t = 7.18$, $p = < .001$), and were more overall likely to choose the target on unique target trials ($\beta_{unique} = 3.81$, $t = 10.68$, $p = < .001$). There was an interaction between the presence of an adjective and the type of adjective, such that people were especially likely to choose the target when there was a size adjective in the utterance ($\beta_{adjective*size} = 0.95$, $t = 2.18$, $p = .029$). There was a three-way interaction between the presence of an adjective, the type of adjective, and the search type such that the contrastive strength of size over color was stronger in the contrastive trials than the unique target trials ($\beta_{adjective*size*unique} = -3.06$, $t = -2.61$, $p = .009$).

Table S1: Full model of target choice from Experiment 1. Model specification is chose_target ~ utterance_type * adjective_type * display_type + (1 + utterance_type | subject).

term	estimate	z-value	p-value
intercept	-2.07	-7.94	$< .001$
utterance type: adjective (vs. no adjective)	2.21	7.18	$< .001$
adjective type: size (vs. color)	-0.17	-0.46	.646
display type: unique target (vs. contrastive)	3.81	10.68	$< .001$
adjective * size	0.95	2.18	.029
adjective * unique target	1.32	1.22	.223
size * unique target	-0.17	-0.37	.709
adjective * size * unique target	-3.06	-2.61	.009

Figure S2 shows referent choice in both the unique target display trials and the contrastive display trials. Unique target displays had one unique referent (the target) and two identical distractors that differed from it both in shape and the critical feature. Contrastive displays had a target, a

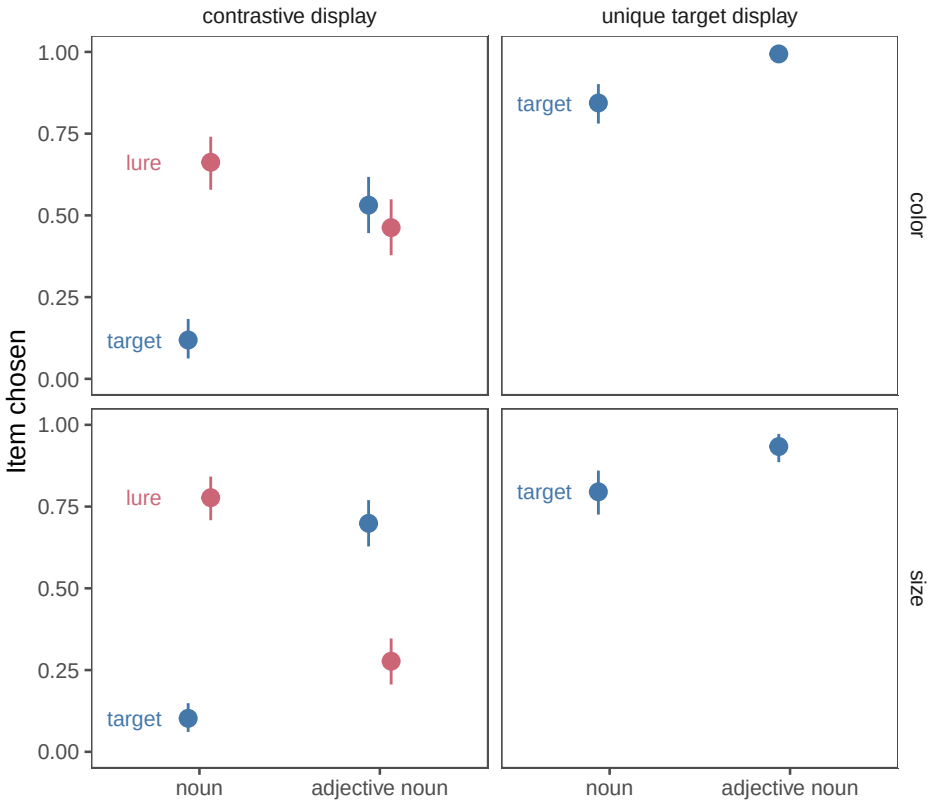


Figure S2: Referent choice in both the contrastive display trials and the unique target display trials.

contrastive pair which matched the target in shape but had a different critical feature, and a lure which matched the target on the critical shape but differed from it on the critical feature.

S1.3 Modeling Experiment 1 with continuous semantics

Degen, Hawkins, Graf, Kreiss, & Goodman (2020) capture asymmetries in description of size and color by positing that different features have different semantic strength. They posit that color has stronger semantics than size, such that "red table" is a better literal description of a small red table than "small table" is. Under these assumptions, RSA using these continuous semantics explains people's tendency to mention color more often than size in a variety of tasks. Can continuous semantics explain the asymmetry we find between color and size in Experiment 1?

In Experiment 1, we found that people more consistently choose the target using contrastive inferences about size than color. We incorporated their continuous semantics into our RSA model of referent choice, which reasons over possible lexicons, and allowed the semantic values of color and size to vary (rather than fitting feature-specific alpha values). In Figure **??** we show the resulting model predictions. This model predicts the overall inference that people choose the target more often when there is an adjective in the utterance. However, the model's fit of the color–size asymmetry, when fitting all the data, is off: it overpredicts people's contrastive inferences about color. Further, the estimated continuous semantics parameters are not in the expected direction: the semantic strength of size is 0.92, and the semantic strength of color is 0.8.

However, when we examine only the *adjective noun* condition, a continuous semantics model can

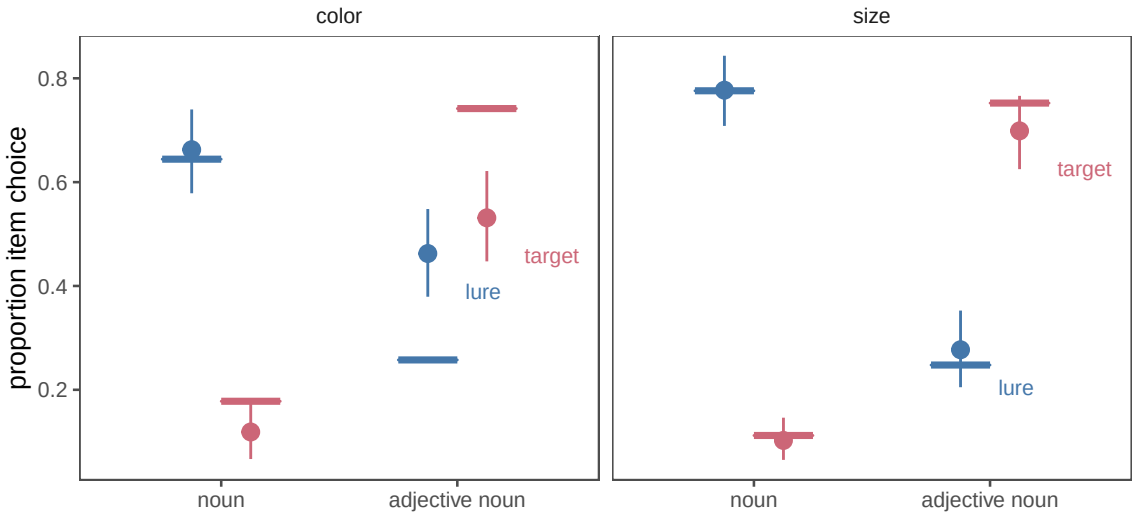


Figure S3: People's choice patterns in Experiment 1, with model predictions from a model with continuous literal semantics.

explain the general pattern. We confirmed this by fitting the model to only the *adjective noun* trials, and found the expected pattern of semantic values: for size, 0.92, and for color, 0.8. The model seems to be fitting the data in the *noun* condition at the expense of estimating people's inferences in the *adjective noun* condition, which causes the fitted semantic strength parameters to be misaligned with the findings in Degen et al. (2020). Thus, although the continuous semantics model in its current form does not fit our data well, we think it is possible this is due to the pattern of responses in the *noun* condition, and potentially also the overall noisy pattern of guessing in this highly ambiguous task. Adapting a continuous semantics model to account for the response pattern in this task is a potentially promising way to integrate the findings of Degen et al. (2020) with ours.

S2 Experiment 2 Additional Analyses

S2.1 Experiment 2 Prevalence Judgments

The full regression of prevalence judgments, also reported in the main text, is in Table S2.

Table S2: Full model of prevalence judgments from Experiment 2. Model specification is percentage ~ adjective_type * utterance_type * context_type + (utterance_type | subject).

term	estimate	z-value	p-value
intercept	52.16	22.40	$< .001$
adjective type: size (vs. color)	4.73	1.46	.146
utterance type: adjective (vs. no adjective)	-10.22	-3.37	.001
context: within-category contrast display (vs. between-category contrast)	3.92	1.63	.104
context: same feature display (vs. between-category contrast)	-1.48	-0.62	.537
size * adjective	0.04	0.01	.993
size * within-category contrast display	-1.37	-0.41	.684
size * same feature display	-0.60	-0.18	.859
adjective * within-category contrast display	-1.58	-0.46	.644
adjective * same feature display	2.13	0.63	.532
size * adjective * within-category contrast display	-1.39	-0.29	.770
size * adjective * same feature display	-1.59	-0.33	.739

S3 Experiment 3 Additional Analyses

The full regression predicting Experiment 3 prevalence judgments, also reported in the main text, is shown in Table S3. The regression predicting Experiment 3 prevalence judgments among only adjective utterances and no adjective utterances (excluding alien utterance trials), also reported in the main text, is shown in Table S4.

In addition to the regressions reported in the manuscript, we report two pre-registered, targeted regressions to test the effect of utterance type to more specifically in case these effects were unclear in the maximal models. First, we filtered to adjective and no adjective trials and fit a linear mixed effects model predicting prevalence judgment by utterance type with a random slope of utterance type by subject (Table S5). Participants' prevalence judgments were significantly lower when an adjective was used in the utterance (β = -9.17, t = -7.09, $p = < .001$). Second, we included all trials in a linear mixed effects model predicting prevalence judgment by utterance type with a random slope of utterance type by subject (Table S6). Utterances without an adjective resulted in significantly higher prevalence judgments than alien utterances (β = 7.76, t = 4.91, $p = < .001$), and utterances with an adjective did not result in significantly different prevalence judgments than alien utterances (β = -1.42, t = -0.91, p = .363).

Table S3: Regression predicting prevalence judgments from utterance type, context type, and adjective type in Experiment 3. Model specification is percentage ~ utterance_type * context_type * adjective_type + (utterance_type | subject).

term	estimate	z-value	p-value
intercept	47.77	20.73	$< .001$
utterance type: no adjective utterance (vs. alien utterance)	7.48	2.80	.005
utterance type: adjective (vs. alien utterance)	-0.64	-0.24	.808
context type: within-category contrast (vs. between-category)	-2.70	-1.23	.220
adjective type: size (vs. color)	4.44	1.33	.185
no adjective utterance * within-category contrast display	5.57	1.79	.073
adjective utterance * within-category contrast display	5.77	1.86	.064
no adjective utterance * size	-5.09	-1.32	.189
adjective utterance * size	-6.56	-1.72	.086
within-category contrast display	1.24	0.39	.696
no adjective utterance * within-category contrast display * size	-0.32	-0.07	.944
	-2.21	-0.49	.623

Table S4: Regression predicting prevalence judgments from utterance type, context type, and adjective type only among adjective and no adjective utterances (excluding alien utterances) in Experiment 3. Model specification is percentage ~ utterance_type * context_type * adjective_type + (utterance_type | subject).

term	estimate	z-value	p-value
intercept	55.24	23.76	$< .001$
utterance type: adjective (vs. no adjective)	-8.12	-3.46	.001
context tyep: within-category contrast (vs. between-category)	2.87	1.34	.180
adjective type: size (vs. color)	-0.66	-0.20	.845
adjective utterance * within-category contrast display	0.19	0.06	.949
adjective utterance * size	-1.47	-0.43	.665
within-category contrast display	0.92	0.30	.766
no adjective utterance * within-category contrast display * size	-1.90	-0.43	.665

Table S5: Regression predicting prevalence judgments from presence of an adjective in the utterance (excluding alien language utterances) in Experiment 3. Model specification is percentage ~ utterance_type + (utterance_type | subject).

term	estimate	z-value	p-value
intercept	56.59	38.00	$< .001$
adjective utterance (vs. no adjective utterance)	-9.17	-7.09	$< .001$

Table S6: Regression predicting prevalence judgments from utterance type in Experiment 3. Model specification is percentage ~ utterance_type + (utterance_type | subject).

term	estimate	z-value	p-value
intercept	48.83	33.18	$< .001$
no adjective utterance (vs. alien utterance)	7.76	4.91	$< .001$
adjective utterance (vs. alien utterance)	-1.42	-0.91	.363

S4 Combined Analyses of Experiment 2 and 3

Given that many participants failed the memory check in Experiments 2 and 3 (which was our pre-registered exclusion criterion), we yielded data from fewer participants than expected in our pre-registrations. This means that the analyses of Experiments 2 and 3 may be underpowered to detect subtle effects of context or feature type. Since Experiments 2 and 3 had very similar procedures, we can conduct an exploratory combined analysis comparing the conditions they shared.

Combining data from Experiment 2 (N = 193) and Experiment 3 (N = 197) yields a total sample of 390 participants in this combined analysis. Only trials from the conditions that Experiments 2 and 3 share are included in this analysis: two types of referential context (within-category context and between-category context), two types of feature (size and color), and two types of utterance (adjective noun and noun only).

We fit a mixed effects linear regression on the combined data with the same specification as the full models we used for Experiments 2 and 3 in the main text: effects of utterance type, context type, and critical feature and their interactions, and a random slope of utterance type by subject. This model revealed a significant effect of utterance type ($\beta_{adjective}$ = -9.04, t = -4.68, $p < .001$): people inferred that a feature was rarer when it was mentioned, consistent with our findings in each experiment separately. Participants' inferences did not significantly differ between color and size adjective conditions (β_{size} = 2.01, t = 0.85, p = .396). This is also consistent with findings from each experiment. There was a significant effect of context, with people making overall slightly higher prevalence judgments in the within-category context (β_{within} = 3.39, t = 2.1, p = .036), which was not found in either experiment separately. However, there was not a significant interaction between context and utterance type ($\beta_{within*adjective}$ = -0.74, t = -0.32, p = .748), consistent with findings from each experiment. That is, people did not modulate the size of their typicality inferences (the difference between the adjective noun and noun utterance types) based on context type, though there was a baseline difference in prevalence judgments between context types.

Overall, these results are consistent with what we found in Experiments 2 and 3, with the exception of finding an overall difference in prevalence judgments between context types. However, we did not find an interaction between context type and utterance type, which would demonstrate that participants are trading off between referential utility and typicality when making these inferences. This exploratory combined analysis suggests further research is necessary, as even when combined our data are not definitive about whether potential trade-offs are small or nonexistent.

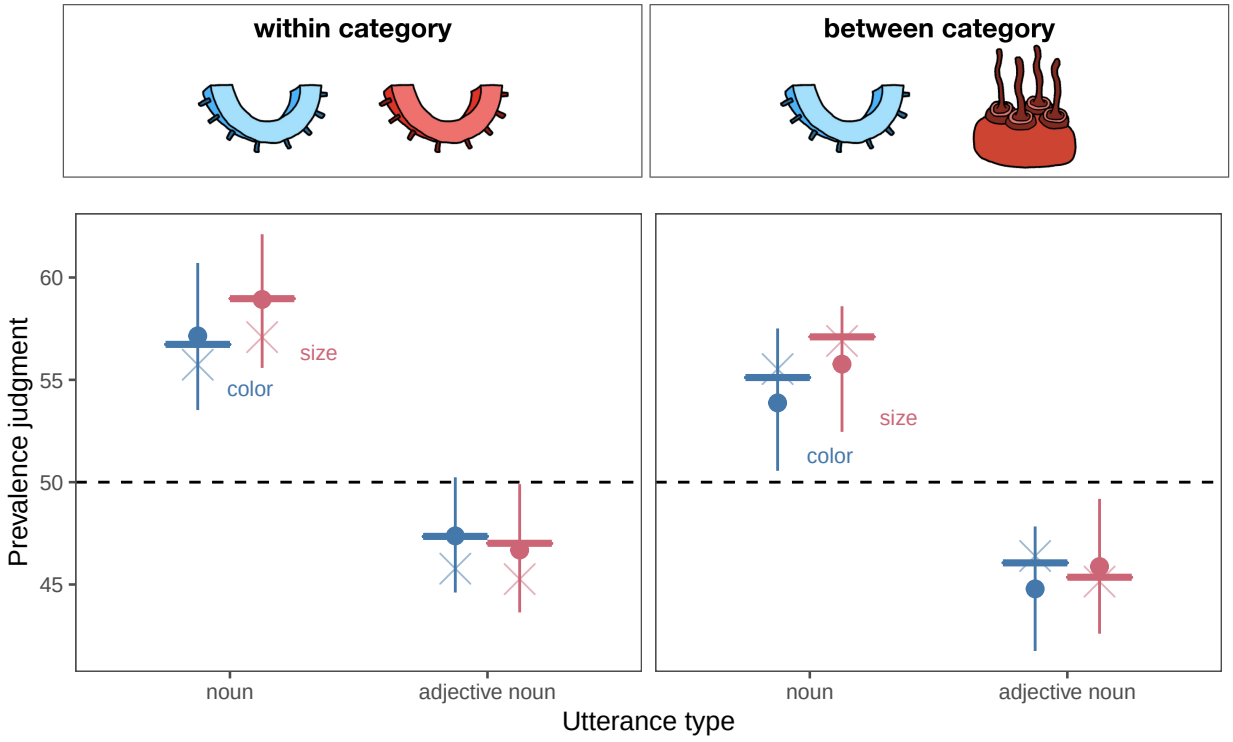


Figure S4: Prevalence judgments of combined data from Experiments 2 and 3, along with our model's predictions (marked by horizontal lines) and the predictions of a model that does not take into account referential context (marked by X shapes).

S5 Experiments 2 and 3: Comparison to a Model with No Referential Context

Our experiments set out to compare two possibilities: a *reference-first view*, on which there would be a strong tradeoff between the goals of reference and conveying typicality, and an adjective used for reference would not prompt any further inferences about typicality; and a *probabilistic weighing view*, on which conveying contrast with respect to reference and with respect to typicality would trade off in a graded way. Our data rule out the reference-first view, as there is not a strong trade-off: people still make inferences about typicality when an adjective was useful or necessary for reference. Our findings leave open the possibility that either (1) there is a weak trade-off that we do not have the power to detect in our data or (2) there is no trade-off whatsoever. Here, we compare our model with a model that does not incorporate reference to evaluate this latter possibility.

We constructed a model much like that used in Experiment 2, except that the model only considered the target object as a potential referent. This is analogous to only presenting the model with the target object and an utterance, e.g., "the [red/small] toma." The model has the same prior on the object's feature distribution and direct observation as the model with context (and as the participants in our task)—it does observe another toma with a different feature from the target, but that observation is separate from its reasoning about reference.

We fit this model to the combined set of people's judgments from Experiment 2 and Experiment 3,

allowing for separate feature rationality parameters. We also re-fit the model from the text in the same way. In Figure **??**, we show the combined data from Experiment 2 and Experiment 3, along with our original model's estimates (horizontal lines) and the estimates of the model that does not take into account reference (X shapes). The model without referential context makes very similar predictions to the model with referential context. Combined with the null effects of context we find in the regressions on people's judgments, this suggests that context has either an undetectably small effect or no effect on people's typicality judgments in this task.

S6 Inferring Atypicality with Non-Fruit Novel Stimuli

The use of alien fruit stimuli in our experiments raises the question of whether people would infer that *non-fruits* are atypical when their color is remarked upon. As noted in the introduction, people remark on the colors of some kinds of objects more than others, perhaps because they more often vary in color (Rubio-Fernández, 2016). Because fruits tend to have stereotypical colors, it is possible that people would not expect the colors of fruits to be remarked upon very often, and thus have a stronger inference of atypicality for fruit than other types of objects. Here, we provide some additional data showing that people still make these inferences for categories about which they likely do not have such an expectation: block shapes.

S6.0.1 Participants.

346 participants were recruited on Amazon Mechanical Turk to perform this task. They were paid 10 cents to complete the task. Participants on average took 20 seconds to complete the single trial (not including reading the consent form).

Two participants were excluded because they repeated the task, leaving 344 participants for analysis. There were no other exclusion criteria.

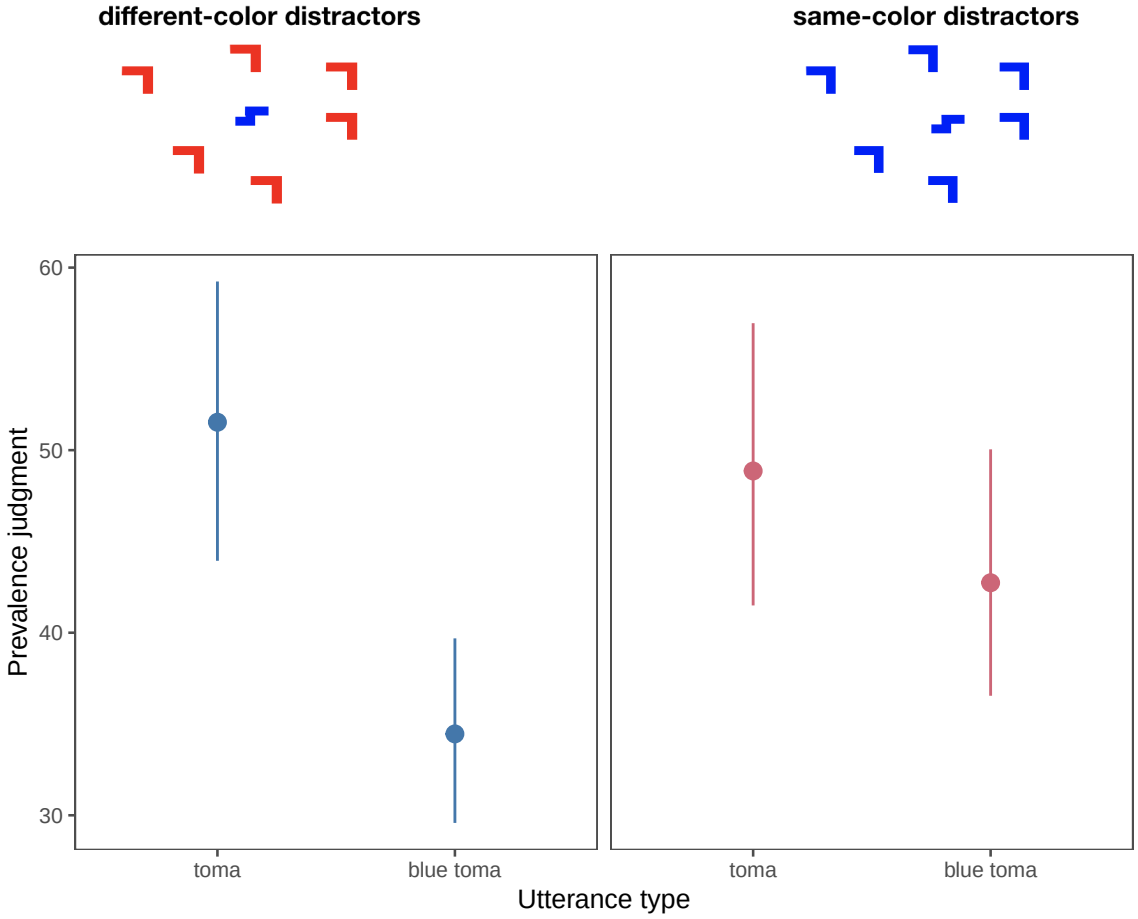
S6.0.2 Procedure

Before the main task began, participants were shown an array of colorful block shapes and told they were going to learn about shapes like these, and were given three examples of novel names these kinds of shapes might have. The object shapes, colors, and names in this introduction phase were randomly chosen and different from the ones used in the task.

In this one-trial task, participants saw a stimulus display with six identical block shapes (distractors) surrounding one unique block shape (the target) (see label in Figure **??**). They were asked to "Find the [blue] toma," with an utterance that either included a color adjective or did not. We expected that participants would click on the unique, central object, and they only moved forward in the task once they selected that object.

Two conditions of interest, utterance type (with or without an adjective) and display type (whether the distractors' color was the same as or different from the target) were varied between subjects. Additionally, several factors were randomly assigned between subjects: the name of the target (among *dax, blicket, wug, toma, gade,* or *sprock*), the target color (among red, blue, green, orange, purple, yellow, pink, tan, teal, or grey), the distractor color if different from the target (among the same set of colors), and the target and distractor shapes (among ten possible block shapes with five square components).

After selecting the target object, participants made a judgment about the prevalence of the target's color among the target's category. They were asked, e.g., "What percentage of tomas do you think are blue?" and responded on a slider scale between 0 and 100%.



S6.0.3 Results

The main question of interest is whether people infer that a color is rarer when it is mentioned than when it is not; when a participant hears "blue toma," do they infer that tomas are less likely to be blue? We fit a linear model predicting participants' prevalence judgments from the utterance type (noun or adjective noun) and context type (different-color or same-color distractors) and their interaction. There was a significant effect of utterance type, such that people's prevalence judgments were lower when there was an adjective in the utterance than when there was not ($\beta_{adjective}$ = -17.07, t = -3.65, p = < .001). There was not a significant effect of context type ($\beta_{same-color-context}$ = -2.67, t = -0.54, p = .587) or an utterance by context interaction ($\beta_{adjective-context}$ = 10.95, t = 1.61, p = .108).

S6.1 Discussion

We found that when a block object is referred to as "the blue toma" rather than "the toma," people think tomas are less likely to be blue in general. People's judgments also did not significantly differ depending on whether surrounding objects were the same color as the target. This stripped-down demonstration of the effect provides additional evidence that people infer described objects are

atypical even when they likely do not have strong expectations that the object categories have a stereotypical color (as they may with fruit). It is an open and interesting question whether people's prior expectations about a category's feature distribution would modulate or extinguish this effect. This demonstration is evidence that the effect generalizes beyond fruit; we leave a systematic investigation of that question to future work.

References

Degen, J., Hawkins, R. D., Graf, C., Kreiss, E., & Goodman, N. D. (2020). When redundancy is useful: A Bayesian approach to "overinformative" referring expressions. *Psychological Review*, *127*, 591–621.

Rubio-Fernández, P. (2016). How Redundant Are Redundant Color Adjectives? An Efficiency-Based Analysis of Color Overspecification. *Frontiers in Psychology*, *7*. http://doi.org/10.3389/fpsyg.2016.00153