Evaluating *each*- (but not *every*-) sentences encourages encoding individual properties

Tyler Knowlton (Maryland), Justin Halberda (Johns Hopkins), Paul Pietroski (Rutgers), Jeffrey Lidz (Maryland)

The meaning of a universally quantified sentence like *each/every circle is green* is standardly thought to express a relation between two independent sets [1], as in (1). But the same content could be represented in speakers' minds in terms of individuals and their properties, as in (2).

(1) TheX:Circle(X) ⊆ TheY:Green(Y) ≈ *the circles$_X$ are a subset of the green-things$_Y$*

(2) ∀x:Circle(x)[Green(x)] ≈ *each individual circle$_x$ is such that it$_x$ is green*

There is some evidence that speakers have a group-implicating meaning for *every*, in line with (1), but have a purely individual-based meaning for *each*, as in (2). For example, participants have been found to offer better estimates of the number of circles when asked whether *every circle is green* compared to when they were shown similar images but asked whether *each circle is green* [2]. This difference might reflect the distinction between (1-2), as only (1) calls for treating the circles as a group whose cardinality can then be estimated [3].

Here, we test another prediction of the (1-2) distinction: evaluating sentences with *each*, represented as in (2), will lead to encoding the circles' individual properties. In contrast, evaluating sentences with *every*, represented more like (1), is predicted to call for mentally grouping the circles in a way that abstracts away from the particular details of each individual.

In this novel task, we consider the individual property color. On each trial, participants were shown three circles that were different shades of blue, green, or orange (e.g., Fig. A) and asked to evaluate sentences like *each circle is green* or *every circle is green*. Colors were selected from an independently-normed set [4] so that half of the trials were "true" according to a majority of adults' empirically-determined color category boundaries. After participants responded to the first question, the circles were briefly masked (300ms). On half of the trials one circle's hue was then changed and participants were asked to evaluate whether *one circle changed its color*.

If *each* is understood as in (2) and *every* is understood more like (1), then participants who evaluated *each*-sentences should be more likely to notice when an individual circle changes its color compared to participants who saw the same pictures but evaluated *every*-sentences. This prediction of superior performance following *each* also controls for a potential confound in the results from [2]: *each*-sentences may have led to inferior cardinality estimation performance simply because *each* is less frequent than *every*, and thus requires extra cognitive effort that could have otherwise been devoted to encoding cardinality. Here though, the less frequent quantifier is predicted to result in better performance on a follow-up memory task.

In Experiment 1 (n=36), we find that this prediction is borne out. Participants were more accurate at the change-detection question if they first evaluated an *each*-statement than if they first evaluated an *every*-statement (Fig. B; $t_{33.97}=2.33$, $p<.05$). The two groups showed no significant difference in their reaction times for sentence evaluation ($t_{31.67}=0.71$, $p=.49$) or change detection ($t_{33.83}=0.08$, $p=.94$). Experiment 2 (n=36) replicated this effect using a staircased design in which the change-detection task got easier when participants failed to detect the change and harder when they correctly detected it, maintaining an average accuracy of around 70% for both conditions. Specifically, the new hue on a trial with a change was drawn from a normal distribution centered on the original color. If a participant correctly detected the change, the standard deviation of this distribution decreased, making subsequent trials harder; if they failed to detect the change, the standard deviation increased, making subsequent trials easier. We find that participants in the *each* condition had a smaller average standard deviation than those in the *every* condition (Fig. C; $t_{3022}=11.65$, $p<.001$). In both experiments, participants with an average reaction time exceeding 3 standard deviations above the mean were excluded.

These results support the hypothesis that *every* calls for abstracting away from individuals whereas *each* calls for their explicit representation. More generally, they offer a new tool for probing a specific dimension (group- vs. individual-highlighting) of meaning representations.

Fig. A: Example trial

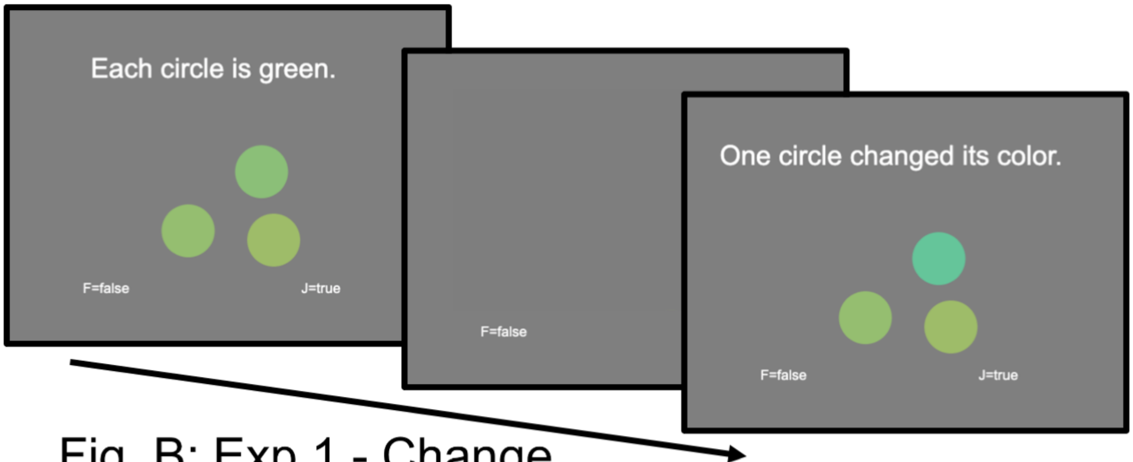


Fig. B: Exp 1 - Change detection accuracy

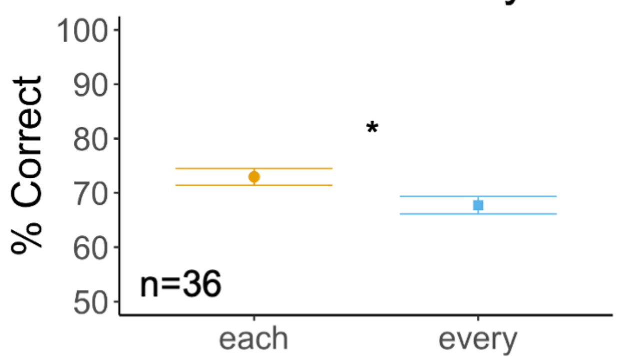
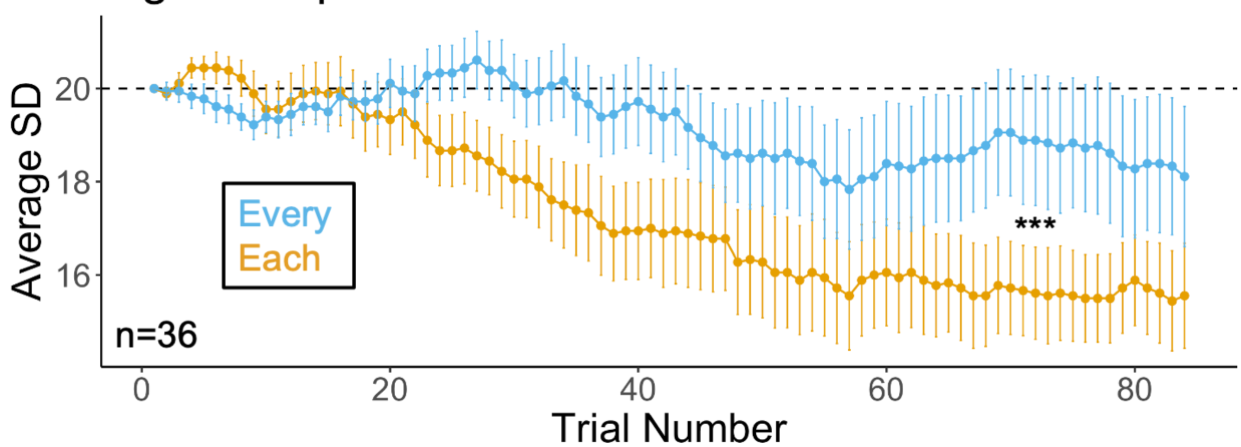


Fig. C: Exp2 - SD of new color distribution



References

[1] Barwise & Cooper (1981) *Generalized quantifiers and natural language*

[2] Knowlton, Pietroski, Halberda, & Lidz (2019) *The mental representation of universal quantifiers: evidence from verification*

[3] Ariely (2001) *Seeing sets: representation by statistical properties*

[4] Bae, Olkkonen, Allred, & Flombaum (2015) *Why some colors appear more memorable than others: a model combining categories and particulars in color working memory*