Color categories in macaque monkeys and their sources

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Color is often used to study cognitive processes such as memory and categorization because it is a controllable, continuous variable of behavioral relevance. Sets of colors are typically defined by color spaces presumed to be perceptually uniform. But one challenge in defining color space has been the potential confounds of language and task in paradigms designed to generate nominally uniform color space. Here we aim to understand the sources of color categories and to derive a language-agnostic color space by measuring color-discrimination behavior in macaque monkeys, a non-human primate that has the same three classes of cone types as humans and a very similar visual cortical organization to humans.

Four macaque monkeys were tested in multiple weekly sessions over several years (~220,000 trials) in an alternative forced-choice color-matching task adapted from literature with human subjects, which used biases in the task as a metric of color categories (Bae et al). The macaques learned to perform the task at above chance levels within [HOW MANY TRIALS], and their performance continued to rise over the course of several months, plateauing at ~70% (on a 4AFC, where chance = 25%).

The data were fit with a mixture model (where errors are assumed to occur from a mixture of guessing and noisy memory), which uncovered two sets of shared biases across the animals: one toward warm colors (hue angle = 13° in CIELUV, SD = 17°), and one toward cool colors (hue angle = 210° in CIELUV, SD = 13°). These results suggest that macaques monkeys have two consensus color categories that map onto human categories of "warm" and "cool". The monkeys also showed additional idiosyncratic biases, stable over time, providing evidence of individual differences in color categorization.

We next asked about the sources of the biases. One possibilities is that they reflect a cognitive origin (a true category); another possibility is that they reflect unrecognized non-uniformities in the presumed uniform color space used in the task. These possibilities make quantitatively different predictions: errors in matching the color of a cue would be biased to one side of the cue’s hue for a cognitive origin and symmetric about the cue’s hue for colorspace nonuniformity. To test these alternatives, we extended the "target confusability competition model" of Schurgin, Wixted & Brady (2020); the model output best explains the data with the non-uniformity of color space (AIC fit numbers etc). Finally, we used the behavioral results to estimate the extent of the non-uniformities in presumed uniform color space to reconstruct a color space that is perceptually uniform, uncontaminated by linguistic biases.

represented across cognitive hierarchies