Color categories in macaque monkeys and their sources

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Categorization and memory are hallmarks of cognition, often studied with color, a controllable, continuous variable of behavioral relevance. A perennial question has been the extent to which color categorization and memory are impacted by language. The question has been very challenging to answer, not only because all human cultures have language, but also because sets of colors used to assess categorization and memory are defined by color spaces assumed to be perceptually uniform, and assumption known to be only approximately accurate. Macaque monkeys, who have the same three cone types as humans and a similar cortical organization to humans but obviously lack language, provide an opportunity not only to assess these behaviors in the absence of language, but also to evaluate underlying assumptions about the perceptual uniformity of color spaces.

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