Supplemental Notes

Comparisons of model parameter fits

Experiment 1

The parameter fits of the mixture model were entered into an ANOVA with the factors of condition (standard, filtered), feature (orientation, color), and articulatory suppression (with, without).

Target Responses - There was a main effect of condition, $F(1,10) = 56.6$, $p < .001$, with fewer target responses in the filtered condition. There was no main effect of feature, $F(1,10) = 2.96$, $p = .11$, and no main effect of articulation, $F(1,10) = .08$, $p = .79$. There were no significant interactions among the variables.

Swap Errors – There was a main effect of condition, $F(1,10) = 13.6$, $p < .005$, with more swap errors in the filtered condition. There was no main effect of feature, $F(1,10) = 0.65$, $p = .44$. There were more swap errors during articulatory suppression, $F(1,10) = 7.48$, $p < .05$, but this factor did not interact with condition, $F(1,10) = .003$, $p = .87$, and may have been due to the additional executive load of the articulatory suppression task (Brown & Brockmole, 2010).

Random Guesses – There was a main effect of condition, $F(1,10) = 9.01$, $p < .05$, with more random guesses in the filtered condition. There was a main effect of feature, $F(1,10) = 5.13$, $p < .05$. No interactions were significant.

Standard Deviation – There was a marginal effect of condition, $F(1,10) = 3.68$, $p = .08$, with a trend towards greater standard deviations in the filtered condition. There were no other main effects or interactions.

Experiment 2

The parameter fits of the mixture model were entered into an ANOVA with the factors of condition (standard, filtered) and feature (orientation, color). For all parameters there were no significant main effects of condition or feature, and no significant interactions (app p's > .15).

Experiment 3

The parameter fits of the mixture model (averaged across features) were entered into an ANOVA with the factors of condition (standard, filtered) and feature pairing (height-width, color-orientation).

Target Responses – There was a main effect of condition, $F(1,14) = 24.24$, $p < .001$, with lower proportion of target responses in the filtered condition. There was no main effect of feature pairing, $F(1,14) = 0.78$, $p = .4$. There was an interaction between condition and feature pairing, $F(1,14) = 7.21$, $p < .05$, with a greater cost for the filtered condition in the height-width feature pairing.

Standard Deviation – There were no main effects or interactions for standard deviation estimates.

Independent color and orientation working memory is not due to failures of feature binding

The main result of Experiment 1 was the large amount of target responses when examining response distributions for trials in which participants guessed on the other feature. One concern is that the degree of independence might be over-estimated if a significant portion of trials in the filtered condition included trials in which participants stored the probed item's features, but either accidentally reported the wrong item, or incorrectly bound the featural information across objects. To address this, we examined response distributions after excluding possible swap errors and target responses. Specifically, the filtered condition included only responses that were two or more standard deviations away from the value of any item in the sample array. Inconsistent with a misbinding account, the average absolute response error was significantly less than predicted by a uniform distribution of responses, $t(11) = 8.09$, $p < .001$ (Supplemental Figure 1).

To determine the degree of independence after removing swap errors, we conducted a bootstrap resampling analysis (Effron, 1982) that fit the group level standard and filtered response distribution (of each feature) as a mixture model (Bays, Catalao, & Husain, 2009; Zhang & Luck, 2008) (it was impossible to model individual participant data since the exclusion criterion only left 38.25 trials from each participant on average). For each resample, twelve participants were selected with replacement from the tested population. These participants were used to generate a single, group response distribution for the standard and filtered conditions of each feature. The SI value was .68, and was significantly above zero in 100% of the 1,000 resamples. Thus, the group level bootstrap resampling analysis converges with the non-uniform group response distribution in ruling out a misbinding explanation for the independence between color and orientation working memory.

Analysis excluding canonical feature values of color and orientation

Could independent failures of color and orientation be due to the fact that some features are easier to remember than others? Perhaps feature values with canonical feature values such as vertical or horizontal orientations or colors like pink and green are always remembered, even when participants don't remember the other feature. To explore this possibility, analyses were conducted that removed trials where the probed item had a canonical feature value.

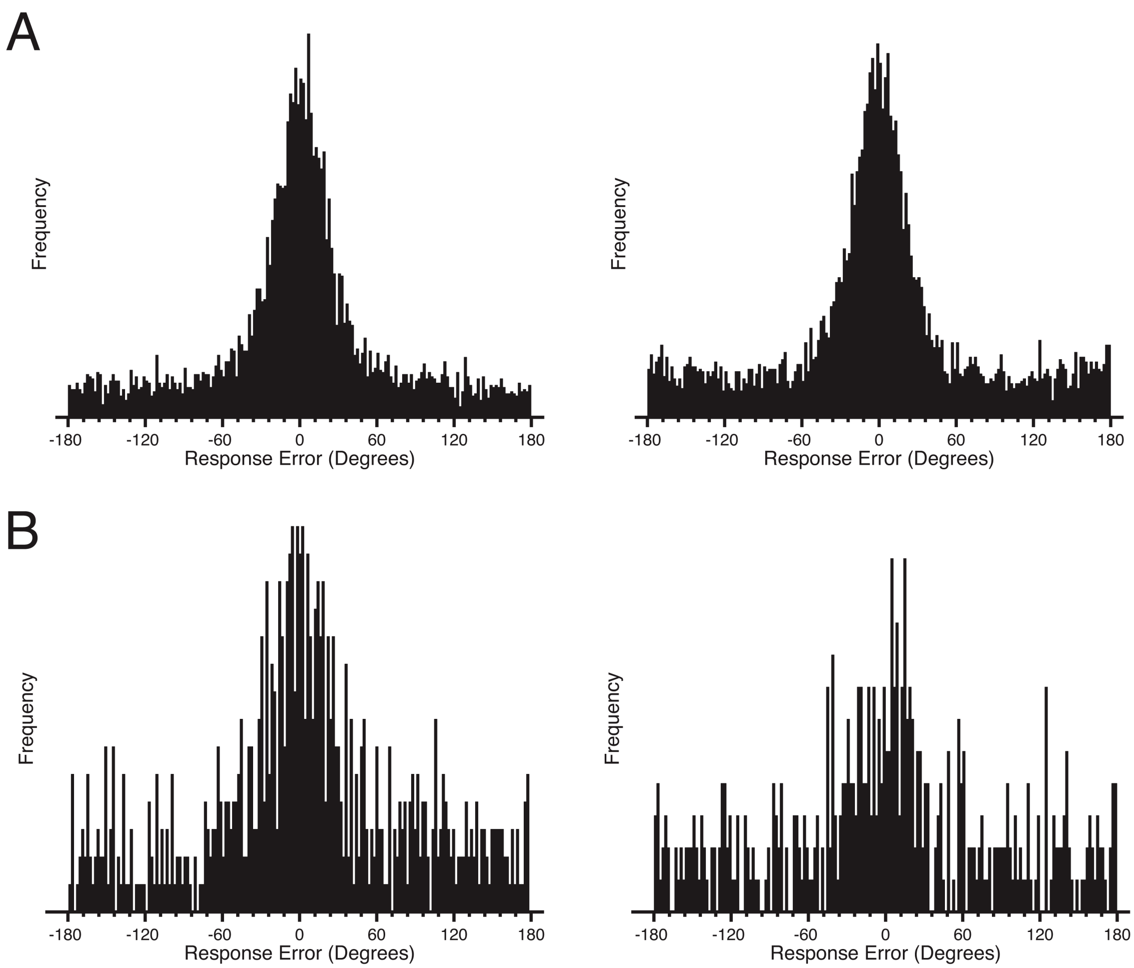
Analysis with canonical orientations excluded

Prior to analysis, all trials where the probed item had an orientation within 20° of up, down, left or right were excluded. The remaining items were used to estimate the proportion of target responses for orientation and color responses (standard condition) (51%). Responses for each feature that were two standard deviations away from the center of the target response distribution were used to generate the filtered condition for the other feature. We found an SI value of .87 that is inconsistent with the hypothesis that the results of Experiment 1 were influenced by participants always remembering canonical orientations.

Analysis with canonical colors excluded

To identify canonical colors we looked for peaks in the response frequency of color values on group level data. We observed four peaks corresponding to the colors: orange, green, pink, and blue. Prior to analysis, all trials where the probed item's color was within 10 steps of the most commonly reported color values were excluded. Mixture modeling on the remaining trials estimated that there were 51% target response trials and showed an SI of .86. The fact that neither excluding canonical orientations nor colors lowered the SI value is inconsistent with the suggestion that independence between features was influenced by the ease at which canonical feature values can be stored.

Supplemental Figures



Supplementary Figure 1: A: Response error distribution including all trials from all observers for color (left) and orientation (right) responses. B: Filtered response error distributions for color (left) and orientation (right) including only those trials where the response to the other feature was not within two standard deviations from any sample item value.

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Zhang, W., & Luck, S. (2008). Discrete fixed-resolution representations in visual working memory. *Nature, 453*(7192), 233-235.