Supplemental Online Material

Methods

Visual stimuli

Visual stimuli were generated using MGL (http://gru.brain.riken.jp/doku.php?id=mgl:overview), a set of custom OpenGL libraries in Matlab (Mathworks, Natick, MA). The test stimuli were sinusoidal gratings (contrast: 0.7, spatial frequency: 2 cycles/deg) in a circular aperture (size: 1.5°), presented on a gray background (24.2 cd/m^2). The edge of the aperture was smoothed so no sharp change in luminance occurred between the grating and the background. The mask stimulus was a circular aperture (size: 1.8°) containing pixel noise, with random luminance levels in a uniform distribution (0-48.4 cd/m^2). The probe stimulus was also a sinusoidal grating with the same contrast and spatial frequency as the test stimulus, except it was slightly smaller: 1.2°. The phases of the test and probe gratings were randomized on each trial. A fixation dot (0.3°) was presented in the center of the screen throughout the experiment. Stimuli were presented on a CRT monitor (1024x768 pixel, 96 Hz refresh rate, with linearized luminance levels), and observers viewed the display at a distance of 57 cm with their heads stabilized via a chinrest in a dark room.

Data analysis

The orientation recall offset was first calculated by subtracting the probe orientation set by the participant from the physical orientation of the cued grating. This value was then constrained within the [-90° 90°] interval (the maximum difference between two orientations is ±90°, i.e., orthogonal), with positive indicating clockwise and negative indicating counterclockwise with respect to the cued orientation. The distribution of the offset was fit with a mixture model (Zhang & Luck, 2008). This model assumes that on a certain proportion of trials

participants did not encode the stimulus into VSTM and simply guessed the orientation. On these trials, which occurred with a guess rate of *g*, the offset should conform to a uniform distribution over the entire range of possible offsets (i.e., [-90° 90°]). On the remaining trials (with a probability of 1-*g*), participants encoded the stimulus orientation into VSTM. Because of noise, the encoded orientation was variable and we modeled this variation around the true orientation by a von Mises distribution (circular normal):

$$p(x|\mu,\kappa) = \frac{1}{\pi I_0(k)} e^{\kappa \cos(2x-\mu)}$$

where *p* is the probability density, I_0 is the modified Bessel function of the first kind of order 0, κ is the concentration parameter which controls the variance of the circular normal, μ is the mean, and *x* is the orientation value in radians. Note the standard von Mises function has been modified for orientation such that it wraps around π, instead of 2π.

The mixture model thus has three parameters: the guess rate, *g*, the mean of the offset, μ, and the variability of the offset, κ. The model was fit to the observed offset data using standard maximum likelihood method. For data presentation, we plotted the circular standard deviation, σ, instead of the concentration parameter, κ, as the latter is inversely related to variance.

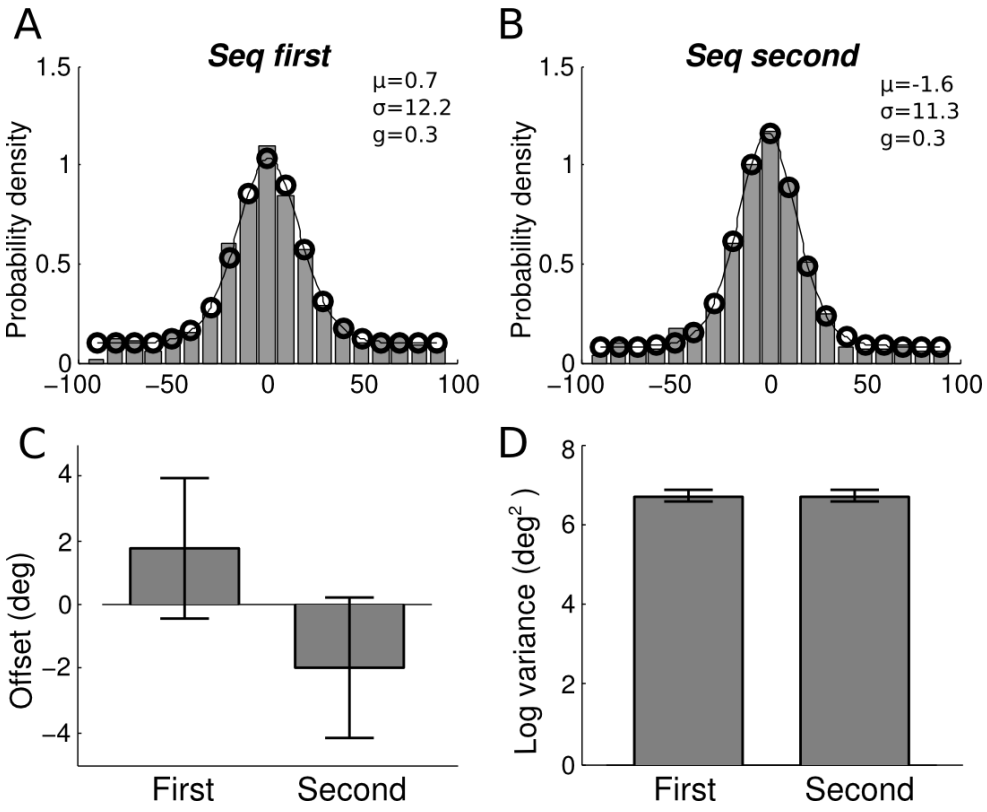

Figure S1. Performance for the first and second stimulus in the sequential condition. **A.** Aggregate offset data and model fit when the first stimulus was cued. **B.** Aggregate offset data and model fit when the second stimulus was cued. **C.** Average mean offset of the recalled orientation for the first and second stimulus. **D.** Average log variance for the first and second stimulus. Error bars in C and D are ±1 within-subject s.e.m. There was no significant difference between the first vs. second stimulus in either mean (paired t-test, $p > 0.1$) and log variance ($p > 0.5$).

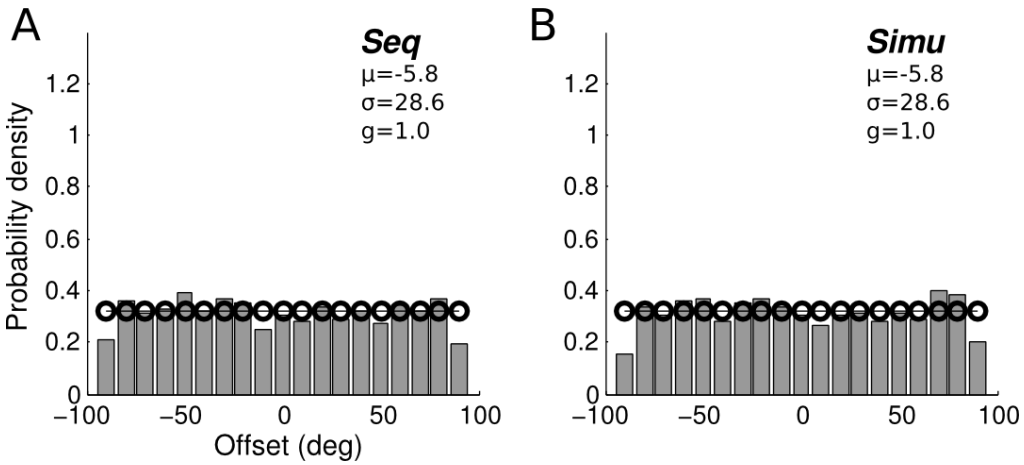

Figure S2. The aggregate distribution in the offset of the recalled orientation with respect to the uncued stimulus in the sequential (A) and simultaneous (B) conditions. No apparent peak was observed at 0, and the mixture model fit suggested that both distributions were essentially uniform distributions (note the guess parameter, *g*, is 1). Thus there was no evidence that subjects sometimes mistakenly reported the orientation of the uncued stimulus.