# Beyond three or four: low and high resolution representations in visual short-term memory

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## Abstract

Delayed change detection tasks show that visual short-term memory (VSTM) can hold up to three or four color patches, oriented lines, or simple feature conjunctions (Cowan, 2001; Luck & Vogel, 1997). These findings are the basis for 'fixed-capacity' models, which imply that humans store "a high-resolution representation of a subset of the [displayed] objects and retain no information about the others" (Zhang & Luck, 2008). However, besides detailed representations of a few items, subjects also remember the spatial relations among stimuli (Jiang, Olson, & Chun, 2000) and depth information (Xu & Nakayama, 2007), suggesting that VSTM stores more information than fixed capacity models tend to assume.

In our first set of experiments, displays contained 3 to 9 Snodgrass' drawings, same number of items and same locations in memory and probe sets. Between memory (2s) and probe sets there was a mondrian mask (0.3s) and a blank screen (0.7s). Subjects indicated the number changes between the two sets. A fixed capacity model would predict perfect performance while VSTM capacity is not reached (i.e., when less than four items are presented), and random performance (uniform distribution of errors) when overloaded. For example, after viewing 6 objects, a subject whose VSTM holds 3 items will have four possible responses, and his selection should be random.

This logic was applied in three experiments, with different subjects and different number of items in each experiment. The error size (i.e., the response deviation relative to the number of presented items) was lower than predicted by fixed capacity models, and followed a gaussian, not an uniform, distribution. These findings suggest that, besides a few high resolution representations, VSTM also holds a wealth of information at lower resolution.

A second set of experiments explored the influence of 'realistic' 3D displays in VSTM capacity. Xu & Nakayama (2007) found increased sensitivity (A') when stimuli were presented in two planes in depth, but the K estimates (Cowan, 2001) were too low, possibly reflecting the difficulty of their task. We presented 2 to 8 colored spheres in 21/2D ( monocular depth cues of shadows, occlusions, and linear perspective) and in 3D (including all the cited monocular cues plus binocular disparity). The memory array (1s) was followed by blank display(1s) and the probe array remained on the screen until response. Memory and probe sets were identical except in one item that was surrounded by a 3D wire cube, and could change color in 50 % of the trials. Subjects indicated whether the cued item had the same color in memory and probe sets. Typically, VSTM capacity estimates obtained with change detection tasks in 2D, reaches a plateau at around 3 items, but there was no plateau in our experiments with 21/2D and 3D displays. These results indicate that the number of high resolution representations that VSTM can hold is much larger when stimuli include 3D cues.

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