The Capacity for Spatial Updating in Visual Short-term Memory

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Introduction

The object file framework of Kahneman et al. (1992) holds that memory for an object's surface feature properties (such as color) is bound to a spatial index marking the object's location. When an object moves, the spatial index is automatically updated, and the bound properties come to be associated with the new location.

In one influential account of spatial updating (Pylyshyn, 2004), the ability to update bound properties of an object should be limited only by spatial tracking capacity. The binding of properties to indexes should be maintained automatically as long as an object is successfully tracked.

However, participants are often quite poor at recalling non-spatial properties associated with successfully tracked objects (Pylyshyn, 2004; Horowitz et al., 2007)

Present Study

In the present study, we sought to determine participants' capacity for updating the association between object location and remembered object properties.

On the assumption that memory for object properties draws upon the visual short-term memory (VSTM) system, we created a hybrid VSTM-updating paradigm that required participants to remember the colors associated with moving objects.

In addition to testing updating capacity, we tested whether updating occurs in an object-based fashion, consistent with accounts of object memory in VSTM (Luck & Vogel, 1997).

The results indicate that VSTM is used to update the binding of surface features to locations in an object-based manner. However, this updating can be accomplished only for a subset of objects in VSTM.

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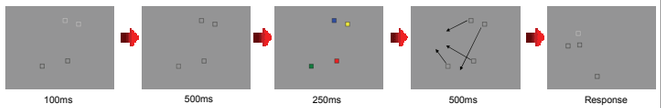
Experiment 1



• Four blocks appeared in random locations, and either 1, 2, 3, or 4 of them were highlighted in white as "to-be-tracked".

• Colors (always red, green, blue, and yellow) appeared in all blocks for a brief period, the colors offset, and the boxes moved new locations that did not overlap with the original object locations.

• Concurrent articulatory suppression (not pictured) minimized verbal encoding of color.

• The participant's task was to remember the binding of color to object and track the objects as they moved. Four objects (with no distractors) placed minimal demands on spatial tracking.

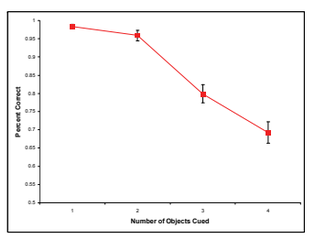
• When the motion stopped, one of the previously cued objects was probed, and the participant reported which color had appeared in that object, using a 4-alternative (RGBY), forced-choice response.

• Because the same four colors were used on every trial, demands on memory for color per se were minimized; participants needed only to remember the binding of colors to locations and update that binding with motion.

Results

Percentage Correct:

Performance fell significantly below ceiling when more than two objects were tracked, suggesting a capacity of approximately 2 objects.



Capacity Estimates:

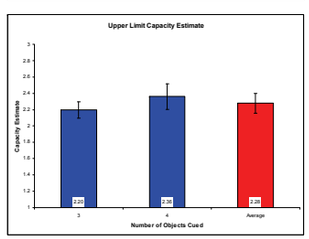
We assume that participants respond correctly if they have updated the probed object and guess when they have not.

If participants guess randomly from among all four possible colors, capacity (K) can be calculated as:

$$K = (P - (.333 * (1 - P))) * N$$

Where P = proportion correct and N = number of cued objects.

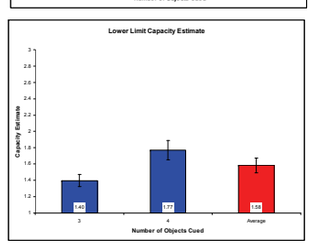
This allows us to establish a liberal upper-estimate of capacity.



If participants can limit their guesses to one of the tracked colors and optimally use memory for the color of non-probed objects to constrain guessing, capacity (K) can be calculated as:

$$K = P * N - 1$$

This allows us to establish a conservative lower-estimate of capacity.



True capacity lies between 1.77 and 2.36 objects

Experiment 2

In Experiment 2, we compared updating capacity with memory capacity for colors without motion.

Participants performed two blocks of trials:

Updating Block: The method was the same as in Experiment 1 with two exceptions:

Participants tracked all 4 objects on each trial.

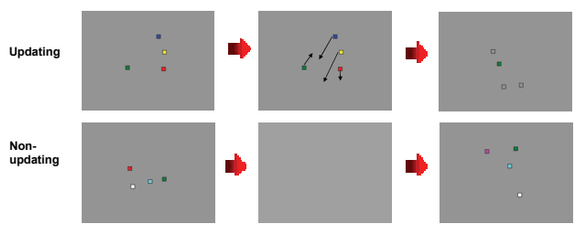
The test was change detection. One color was presented either in the appropriate location given the motion or in a different location.

Non-Updating Block: A standard color change detection task that did not require updating:

Four colors were randomly drawn from a set of eight.

Motion was replaced by a blank ISI.

Instead of reporting whether colors appeared in appropriate objects, participants reported whether all colors were the same or one had changed (to a new color from the set of eight).



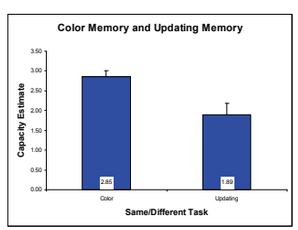
Results

Cowan's K

$$K = (HIT - FA) * N$$

was used to estimate capacity in each condition. For color memory in the non-updating condition, Cowan's K provides a conservative estimate of capacity. For updating memory, Cowan's formula provides a liberal estimate of capacity, because it assumes that when the probed color was not updated, participants guess without taking into consideration the other tracked colors.

Capacity for updating was again approximately two objects and was reliably smaller than capacity for color without updating.



References

Cowan, N., Elliott, E. M., Saults, J. S., Morey, C. C., Mattox, S., Ismajatulina, A., et al. (2005). On the capacity of attention: Its estimation and its role in working memory and cognitive aptitudes. *Cognitive Psychology, 51*, 42-100.

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Experiment 3

There has been some debate over whether object files and VSTM are equivalent. In Experiment 3, we examined whether the updating of color memory with motion depends on VSTM. If so, then updating should exhibit object-based properties characteristic of VSTM (Luck & Vogel, 1997).

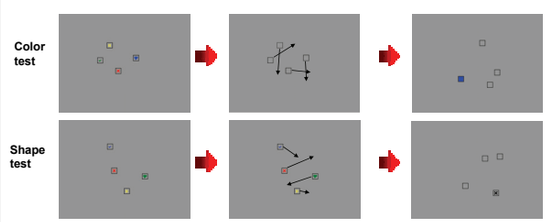
Each object had two features associated with it: color and shape.

Color Only Condition: Participants were required to track only the color associated with each object.

Shape Only Condition: Participants were required to track only the shape associated with each object.

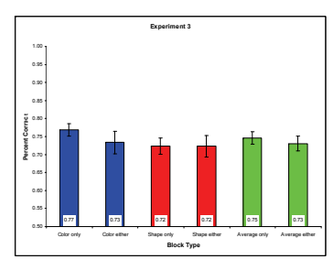
Either Condition: Participants were required to track both the color and shape associated with each object, as either might be tested.

In the test image, a color or shape was presented, and participants responded to indicate whether it was or was not in the correct location. Condition was blocked.



Results

Participants performed no worse when they updated two features of each object than when they only updated one feature of each object.



Conclusions

Participants can update memory for the binding of perceptual features to object locations, but only for approximately two objects, which is significantly smaller than VSTM capacity and significantly smaller than the capacity for spatial tracking.

Nevertheless, updating depends directly on the VSTM system, as spatial updating capacity was driven by the number of objects to update rather than by the number of features to update.