Ghost in the machine: Neural mechanisms of spatial working memory

Charalampos Papadimitriou[1], Robert L. White[2], Lawrence H. Snyder[1]
[1]Anatomy and Neurobiology, Washington University in St. Louis, St. Louis, MO
[2]Department of Psychology, University of California Berkeley, Berkeley, CA

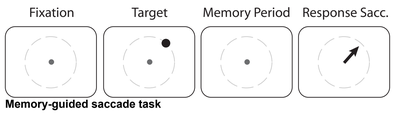
554.16
TT19

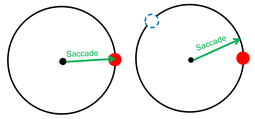
In a previous study we found that spatial memory can be biased toward the memoranda of the previous trial. In the current study we look for neural correlates of this behavior in frontal memory circuits. We find clear effects of the previous memoranda on neuronal activity, but these effects are not congruent with the behavior we observe in the animal.

We find that population memory activity in frontal eye fields (FEF) is shifted ***away*** from the previous trial's memorandum, not ***toward*** as we expected from the behavior.

One way to reconcile this conflict is to posit that the effective receptive fields of individual neurons undergo a shift in location towards the locations of the current and previous targets. There is some evidence for the former.[1] We provide a model in which fields shift in this way, producing a behavioral bias towards, and a neural bias away from, the memoranda of the previous trial.

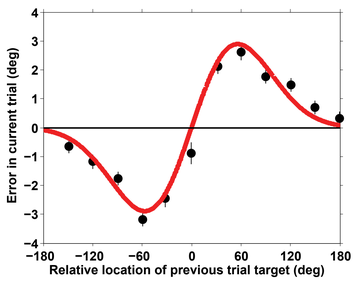
Behavioral responses are biased toward prior memoranda



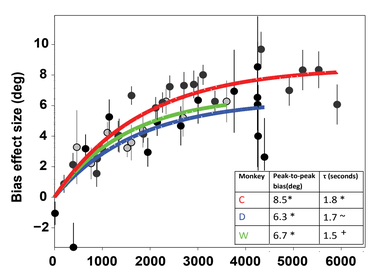


Left - A veridical saccade (green arrow) to a memory target (red circle).

Right - The observed saccade is instead biased *toward* the memory target in the previous trial (dashed blue circle).

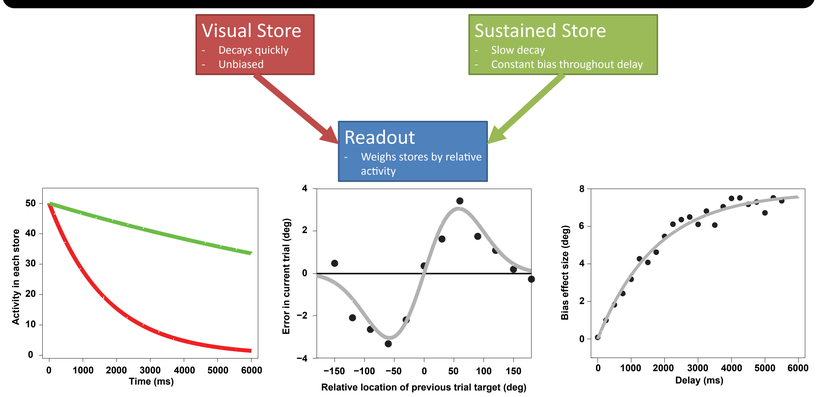


Memory bias due to a prior memory. The influence of previous targets on the memory of current targets.The x-axis is the location of the target in the previous trial relative to the location of the target in the current trial, and the y-axis is the mean residual error.

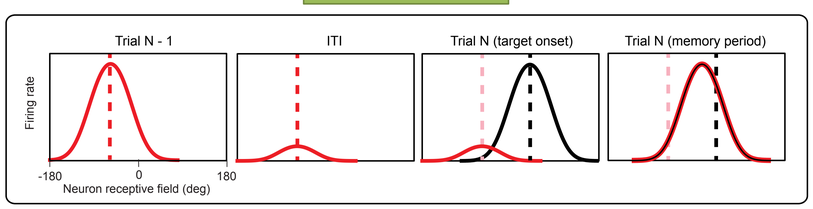


Bias as a function of memory delay. Effect of increasing delay period on peak-to-peak bias for monkey C (dark grey, $p < 0.0001$), monkey D (black, $p < 0.002$), and monkey W (light grey, $p < 0.02$). The inset shows fit coefficients for each monkey (* $p < 0.002$, + $p = 0.06$, ~ $p = 0.28$).

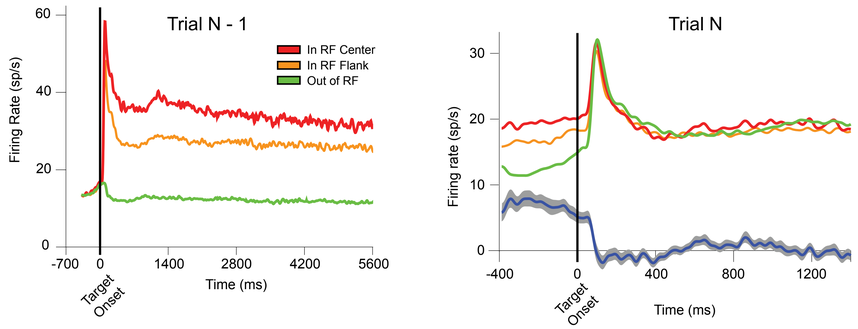
Two-store model of short-term memory



Sustained Store Model



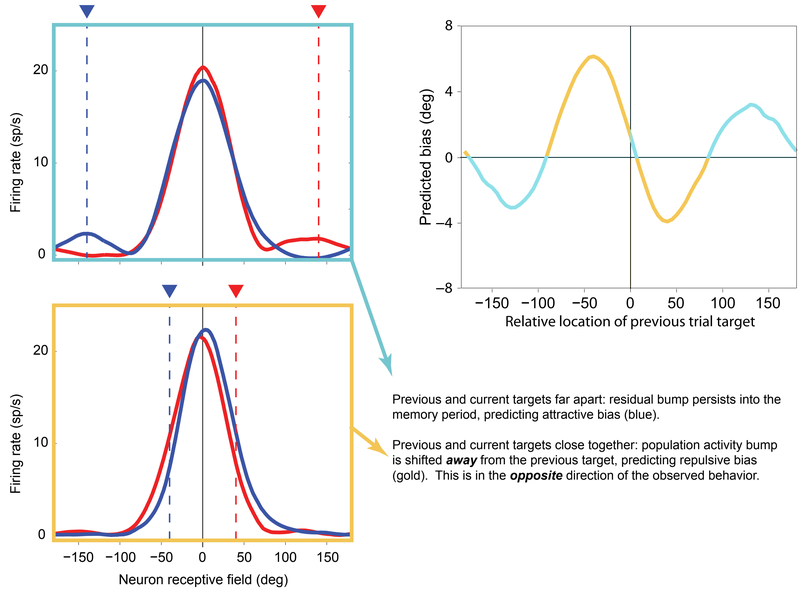
Neural responses to the memory target



Left - Neural activity shows tuning to the memory target of trial N - 1.

Right - Tuning to the target in trial N - 1 persists into the fixation period of trial N, but disappears as soon as the target is presented.

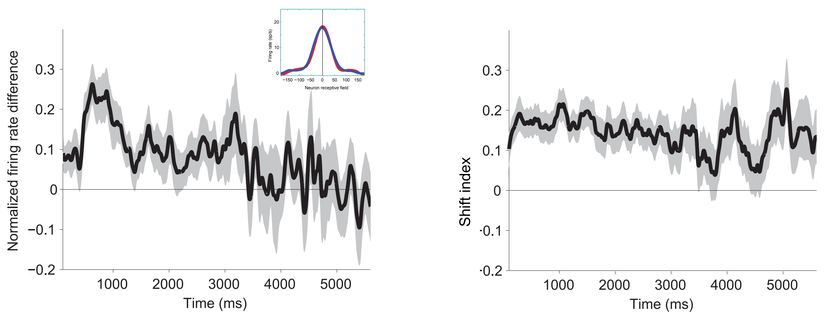
Predicted bias by decoded memory-period activity



Previous and current targets far apart: residual bump persists into the memory period, predicting attractive bias (blue).

Previous and current targets close together: population activity bump is shifted ***away*** from the previous target, predicting repulsive bias (gold). This is in the ***opposite*** direction of the observed behavior.

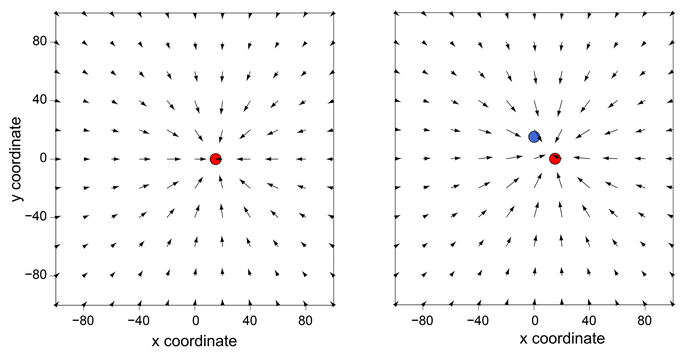
Time course of previous target effects

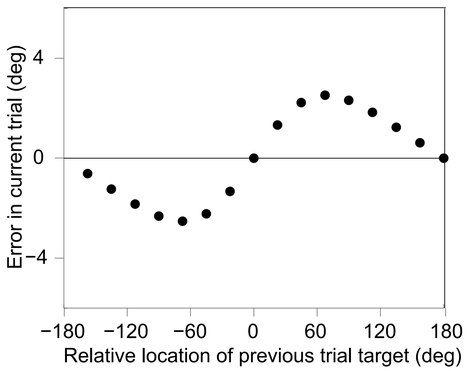


Residual ghost fades after 3s and does not shift the population bump.

Shift persists throughout the memory period.

A proposed mechanism

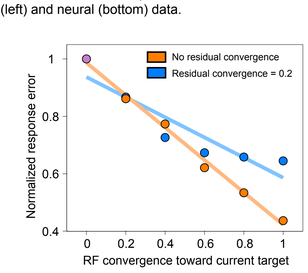


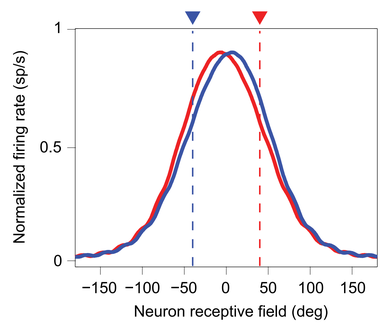


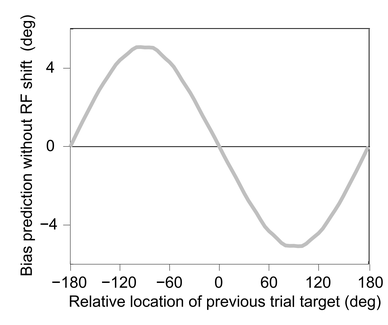
Receptive fields may shift in the direction of the memory target - (above).

These changes may occur to enhance task performance - (below).

This model is able to replicate both the behavioral (left) and neural (bottom) data.







Conclusions

We find carryover effects from the previous trial to the subsequent trial in FEF.

The behavior we observe is inconsistent with conventional models of FEF circuits. Our two-store model, combined with a receptive field shift, comes closer to explaining the data.

We can reconcile the behavioral and neuronal data by assuming that FEF receptive fields shift toward the memory target.

1. Zirnsak, M., Steinmetz, N. A., Noudoost, B., Xu, K. Z. & Moore, T. Nature