Synaptically imprinted memories reignite bump-attractor dynamics prior to stimulus in a visuo-spatial working memory task

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Summary

Persistent activity of prefrontal neurons is thought to maintain locations in memory during the delay of spatial working memory tasks. The bump-attractor model offers an elegant explanation for the physiology and the behavioral precision via diffusing bumps. Such model can naturally explain serial biases in this task, whereby previous memoranda interfere attractively with newly stored locations. However, this is only consistent with a bump-attractor perspective if instead of being reset after the subject's report, the circuit keeps old memory representations as activity bumps that interfere with future trials. To address the neural basis of this interference, we analyzed behavioral and prefrontal neural data from monkeys performing an oculomotor delayed response task. We found that monkeys showed a bias towards previous reported locations, which was attractive for previous reports similar to the currently memorized location, and repulsive for more distant previous reports. This could be explained by interacting bump-attractors. However, single neuron dynamics was not consistent with this hypothesis, since neuronal firing rates typically returned to spontaneous levels in inter-trial intervals (ITI). Nevertheless, 500 ms before the cue presentation, single neuron activity became consistent with a re-emergent activity bump at the population level: we found significant tuning to previous cue, negative noise correlations between pairs of neurons on the opposite flank of the bump and significant decoding accuracies for previous stimuli. Since the previous stimulus code was temporarily absent and later reemerged, this is suggestive of a second mechanism holding latent information possibly at the synaptic level. This was supported by stimulus selectivity in the peak cross-correlation of pairs of neurons with similar memory fields during the ITI. This showed that during fixation the prefrontal network is still imprinted with previous memories, revealing two distinct but interacting memory substrates in the prefrontal circuit based on persistent activity and short-term synaptic plasticity.

Significance

Our results suggest the existence of two memory systems: i) current trial information is kept in working memory in the form of a stable activity bump[1]; neurons supporting this bump are co-active for the whole delay period and this leads to ii) a behaviorally irrelevant memory trace of the previous stimulus becoming latent through synaptic facilitation of those neurons. Since this information is hidden from a decoder based on spike counts, only when neurons increase their overall firing rate this information can be extracted from their co-activation. These memory systems have been suggested as opposing alternatives for the neural substrate of working memory[2]. Here, we put forward the hypothesis that they are co-active and underlie different behavioral effects in spatial working memory.

References

[1] K. Wimmer, D. Q. Nykamp, C. Constantinidis, and A. Compte, "Bump attractor dynamics in prefrontal cortex explains behavioral precision in spatial working memory," *Nature neuroscience*, vol. 17, no. 3, pp. 431–439, 2014.

[2] G. Mongillo, O. Barak, and M. Tsodyks, "Synaptic theory of working memory," *Science*, vol. 319, no. 5869, pp. 1543–1546, 2008.