University of BRISTOL

Activity-silent working memory

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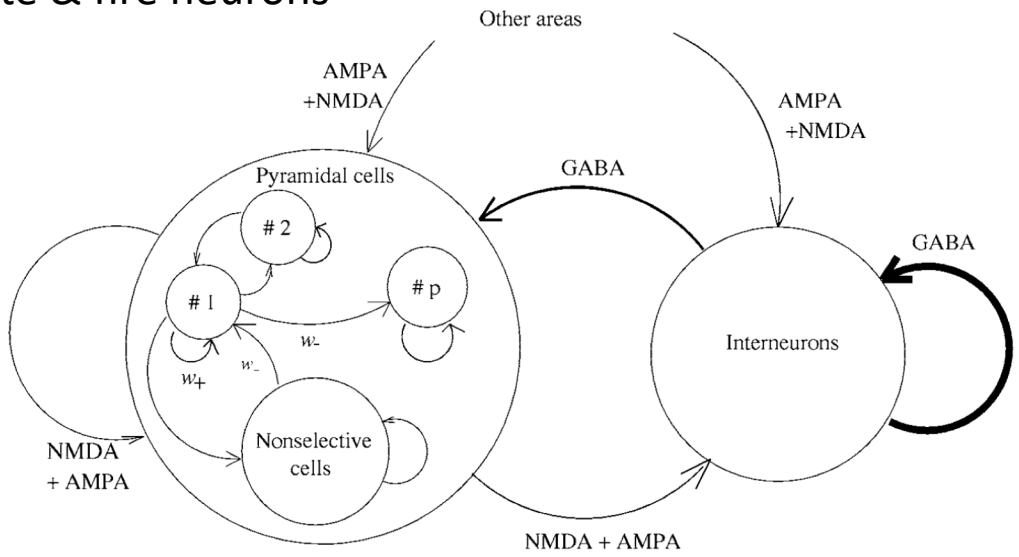
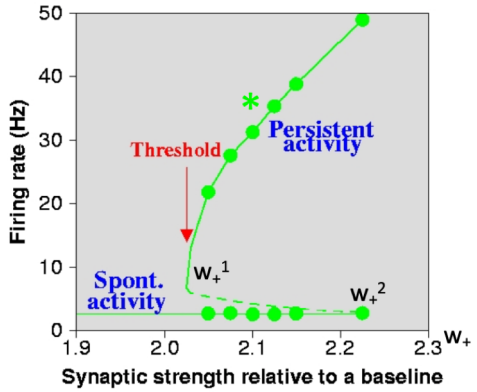
Recap – what is working memory?

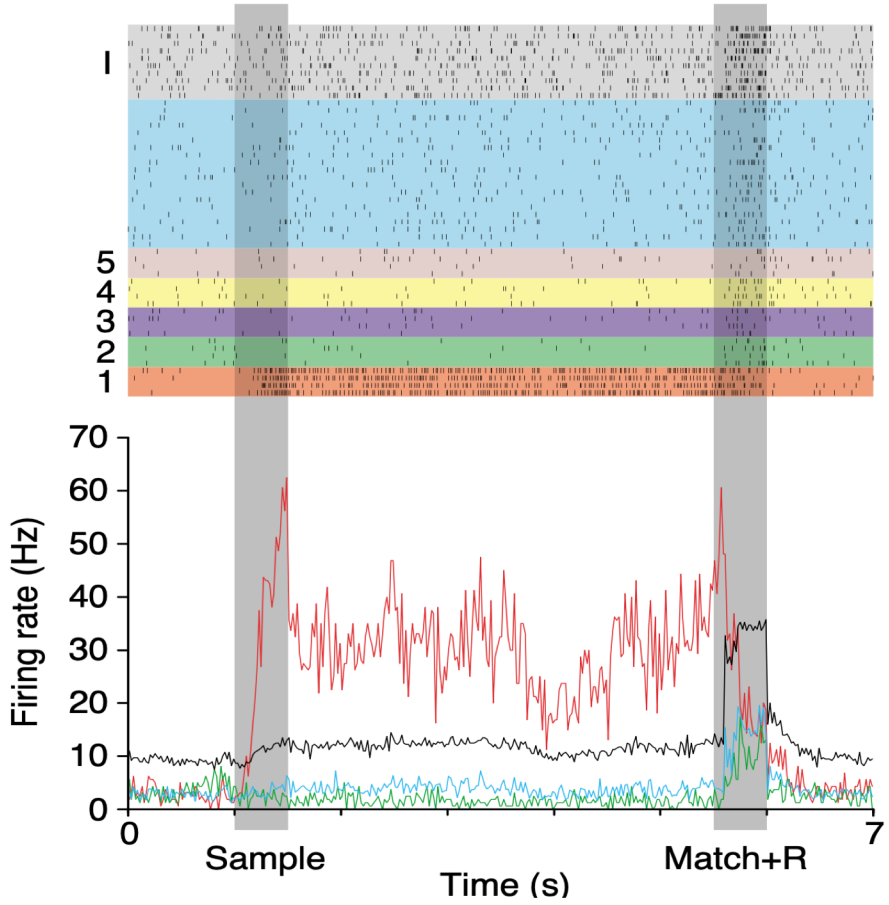
Recap – how does the brain store information in working memory?

Recap: A spiking neural network model of working memory in prefrontal cortex

Linear integrate & fire neurons







Brunel & Wang, 2001

Fight!

Persistent Spiking Activity Underlies Working Memory

Christos Constantinidis,[1] Shintaro Funahashi,[2,3] Daeyeol Lee,[4,5,6,7] John D. Murray,[5] Xue-Lian Qi,[1] Min Wang,[4] and Amy F.T. Arnsten[4]

[1]Department of Neurobiology & Anatomy, Wake Forest School of Medicine, Winston-Salem, North Carolina 27157, [2]Kokoro Research Center, Kyoto University, Yoshida Sakyo-ku, Kyoto, 606 – 8501, Japan, [3]Beijing Institute of Technology, Beijing, 100081, China, [4]Department of Neuroscience, Yale School of Medicine, New Haven, Connecticut 06510, [5]Department of Psychiatry, Yale School of Medicine, New Haven, Connecticut 06511, [6]Kavli Institute for Neuroscience, Yale School of Medicine, New Haven, Connecticut 06510, and [7]Department of Psychology, Yale University, New Haven, Connecticut 06520

Cited by 195

Working Memory: Delay Activity, Yes! Persistent Activity? Maybe Not

Mikael Lundqvist,[1] Pawel Herman,[2] and Earl K. Miller[1]

[1]Picower Institute for Learning & Memory and Department of Brain & Cognitive Sciences, Massachusetts Institute of Technology, Cambridge, Massachusetts 02139 and [2]Computational Brain Science Laboratory, Department Computational Science & Technology, KTH Royal Institute of Technology, Stockholm, Sweden 11428

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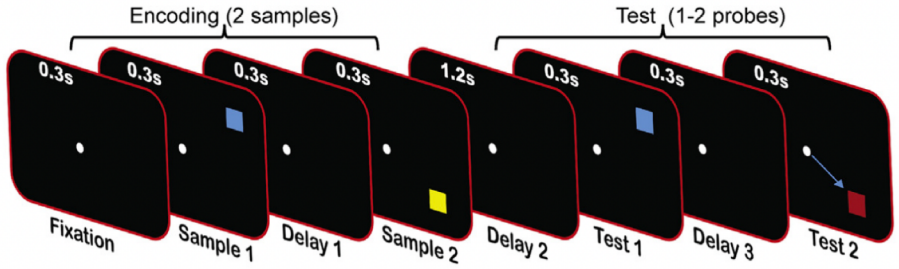
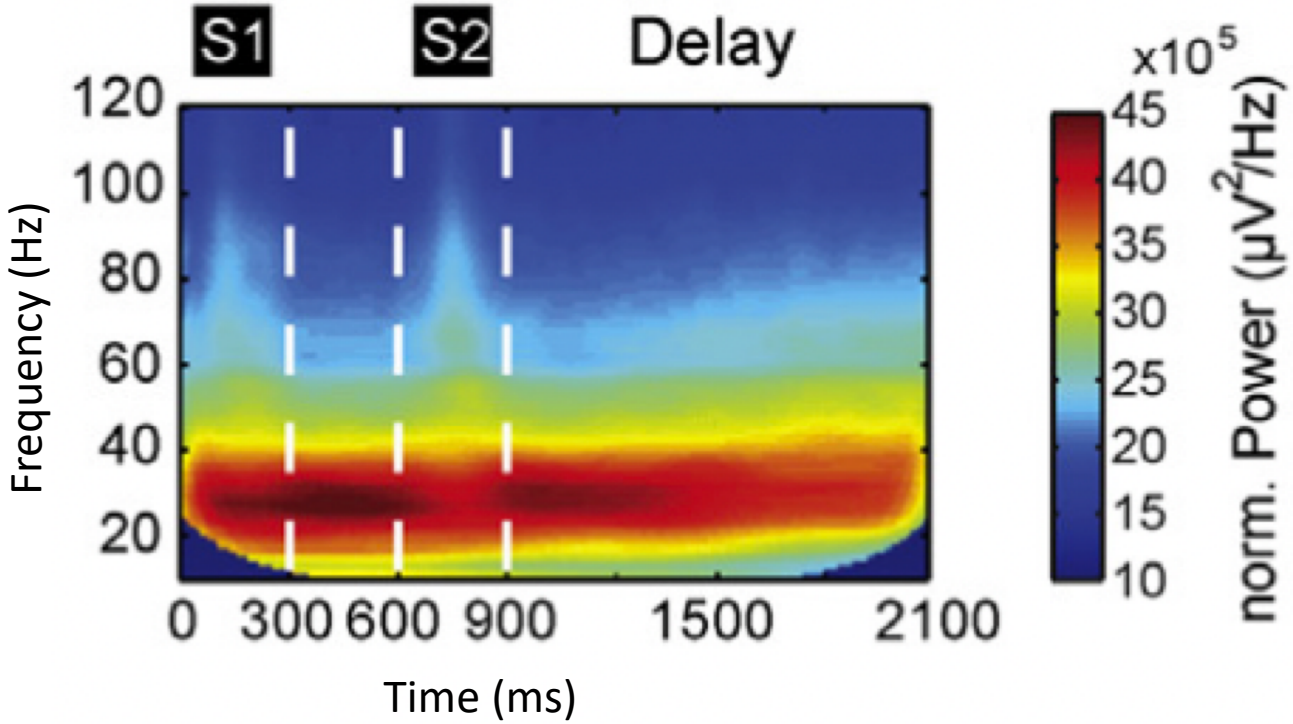
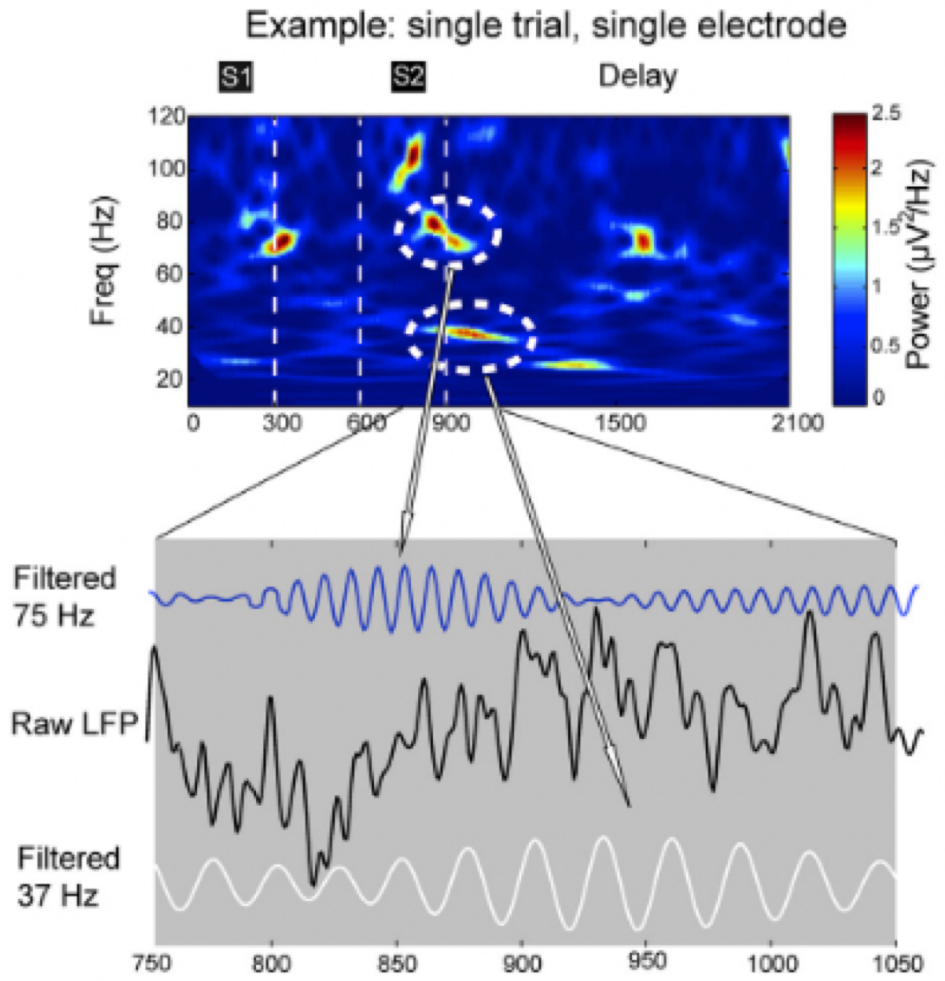
Learning objectives

- To understand the concept of ’activity-silent’ working memory
- To study a neural network model of ’activity-silent’ working memory
- To understand potential limitations of activity-silent mechanisms for working memory

Working memory activity, not always stable and persistent?







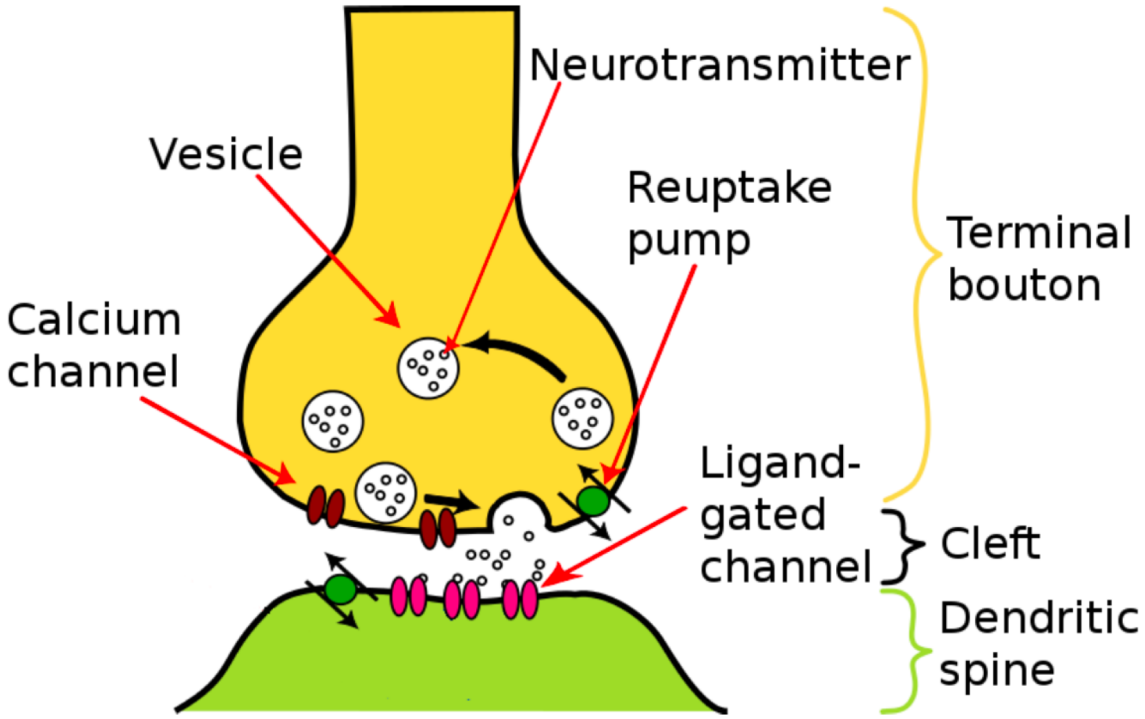
Lundqvist et al., *Neuron*, 2016

Activity-silent working memory (definition)

- *Activity-silent working memory* is
  - the ability to hold information in mind without sensory input over a period of seconds
  - with either
    - the absence of detectable stimulus-specific neural activity
    - or stimulus-specific neural activity that decays to baseline during the delay period.

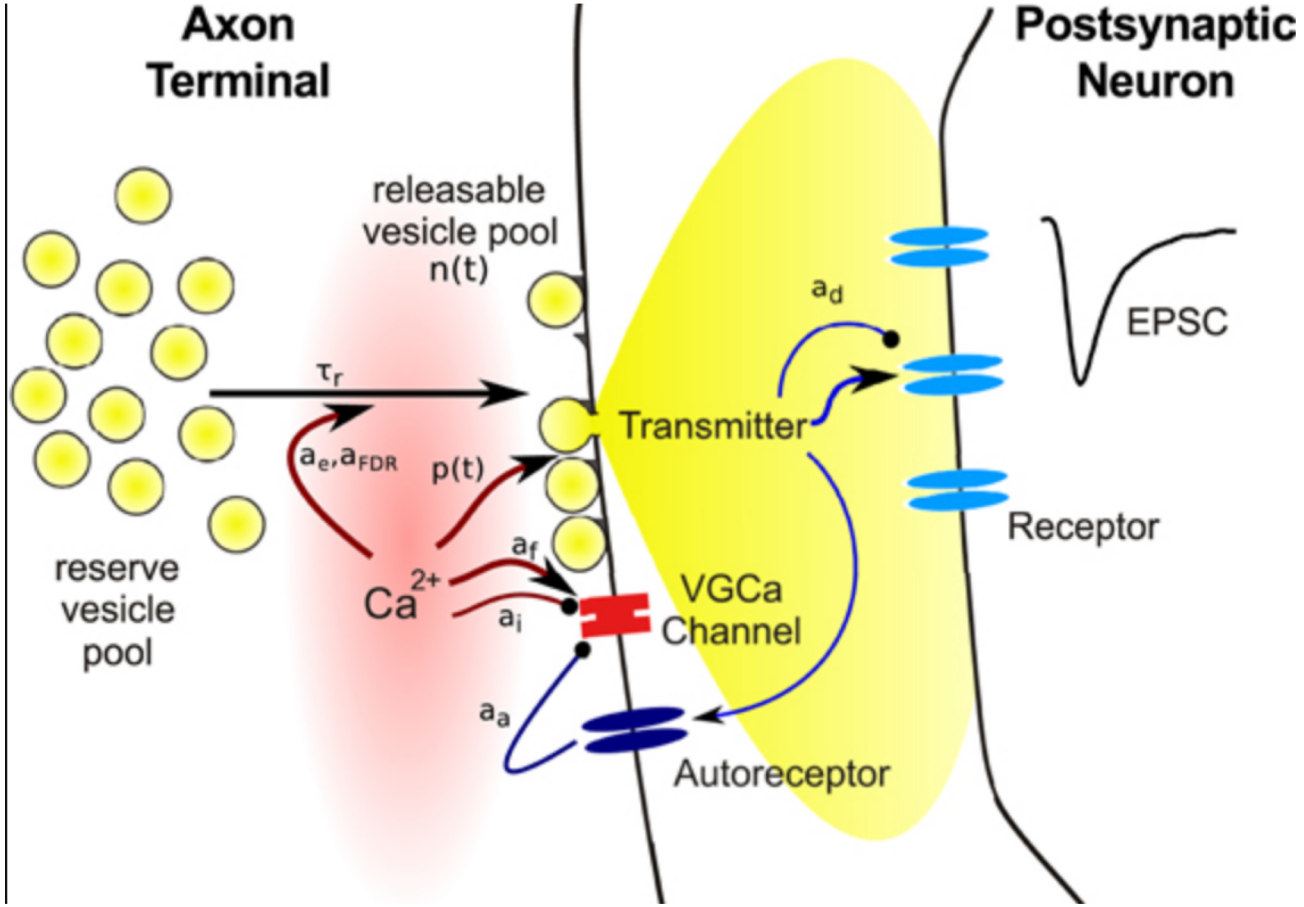
How could information be maintained in the short term without persistent activity?

Recap: synapses



Conor Houghton notes

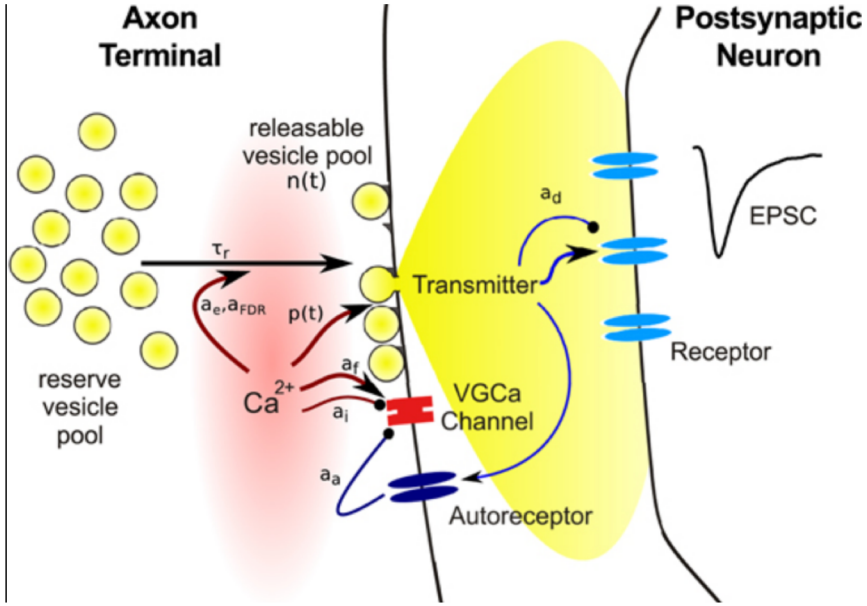
Short-term synaptic plasticity



- Facilitation
  - increased current in post-synaptic response with repeated stimulation
  - left-over calcium from earlier spikes increases the probability of vesicle fusing to membrane & releasing neurotransmitter
- Depression
  - decreased current in post-synaptic response with repeated stimulation
  - vesicles in releasable pool have not yet replenished by time of new spike

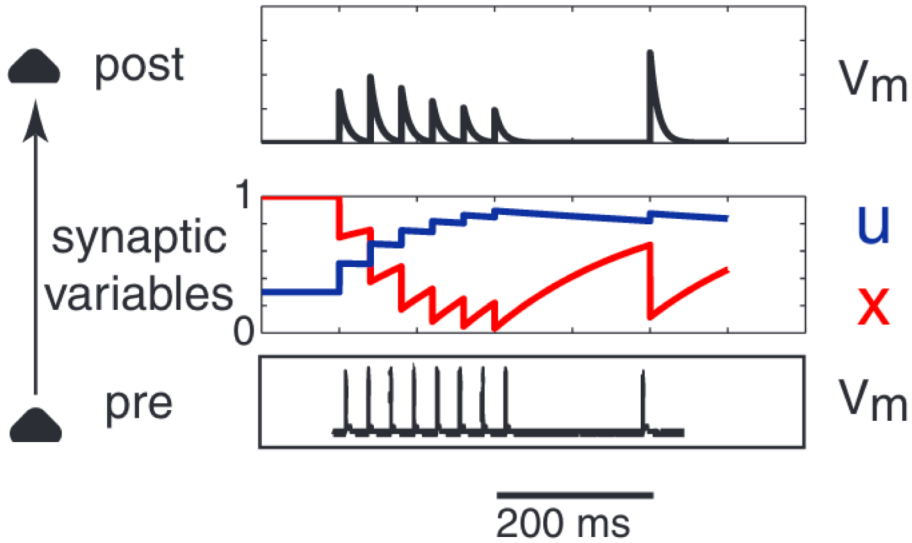
Henning, *Front. Comp. Neurosci.,* 2013

Simulating short-term plasticity



$$\frac{dx}{dt} = \frac{1 - x}{\tau_D} - u\ x\ \delta(t\text{-}t_{sp})$$

$$\frac{du}{dt} = \frac{U - u}{\tau_F} + U\ (1 - u\ )\ \delta(t\text{-}t_{sp})$$



Temporary synaptic strength from neuron j to neuron i = w_{ij}^{EE} $x_j u_j$

baseline synaptic strength x depletion of vesicles x increase in calcium

$\tau_D = 200\ ms, \tau_F = 1500\ ms$

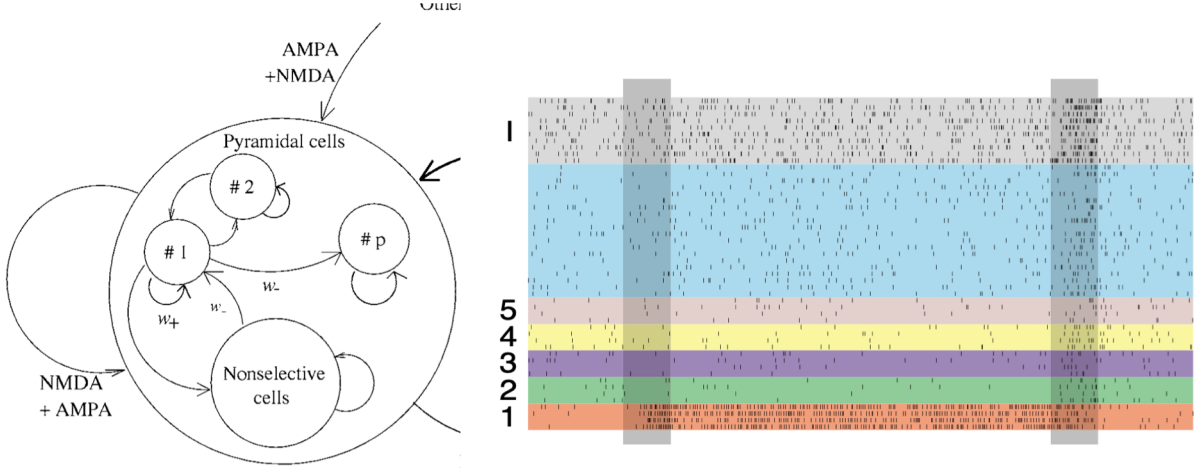
depression facilitation

Mongillo, Barak & Tsodyks, *Science*, 2008

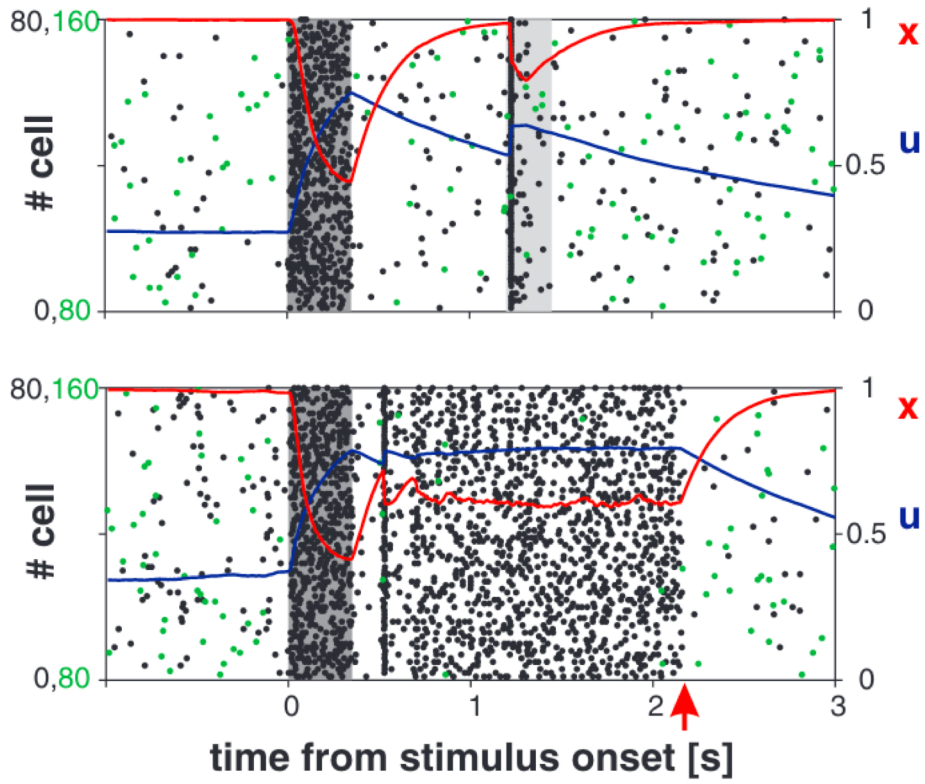
Short-term plasticity as a mechanism for activity-silent working memory

$$\frac{dx}{dt} = \frac{1 - x}{\tau_D} - u\ x\ \delta(t\text{-}t_{sp})$$

$$\frac{du}{dt} = \frac{U - u}{\tau_F} + U\ (1 - u\ )\ \delta(t\text{-}t_{sp})$$

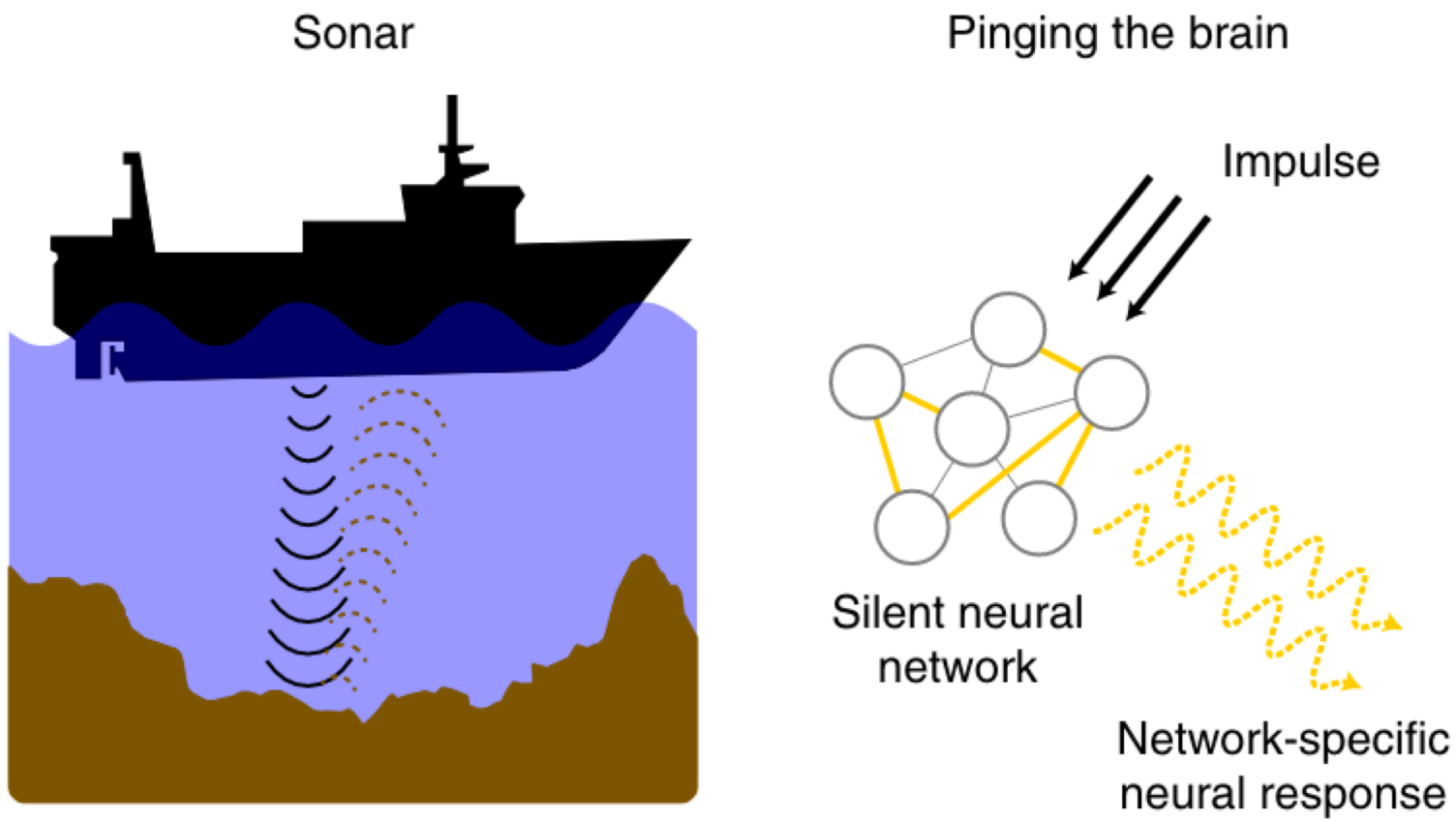


Brunel & Wang, *J. Comp. Neurosci.,* 2001



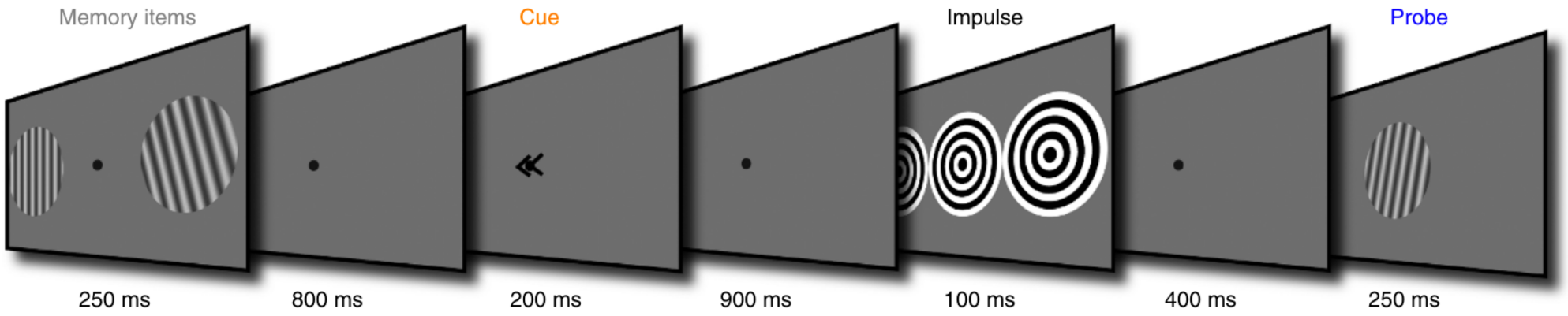
Mongillo, Barak & Tsodyks, *Science*, 2008

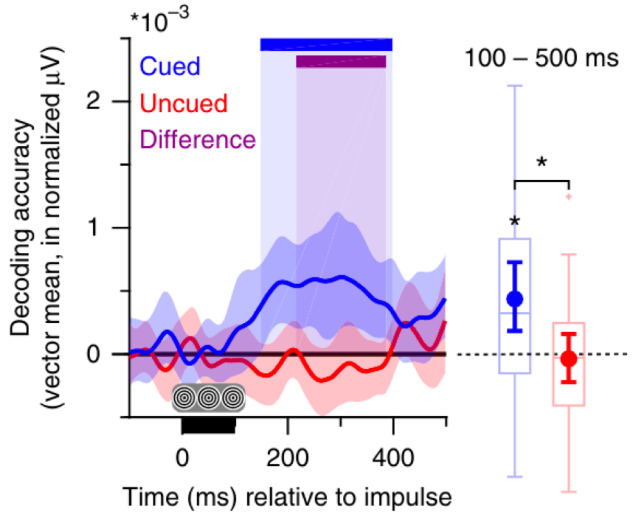
How can we detect ‘silent’ changes?

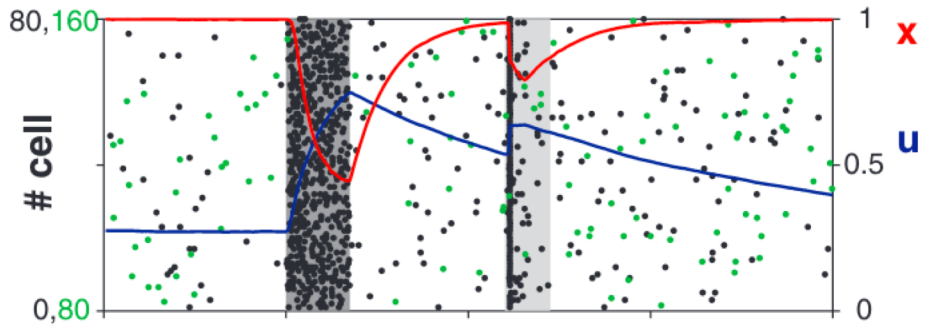


Wolff et al., *Nat. Neurosci*, 2017

Pinging the brain to reveal signatures of ‘activity silent’ working memory in the brain



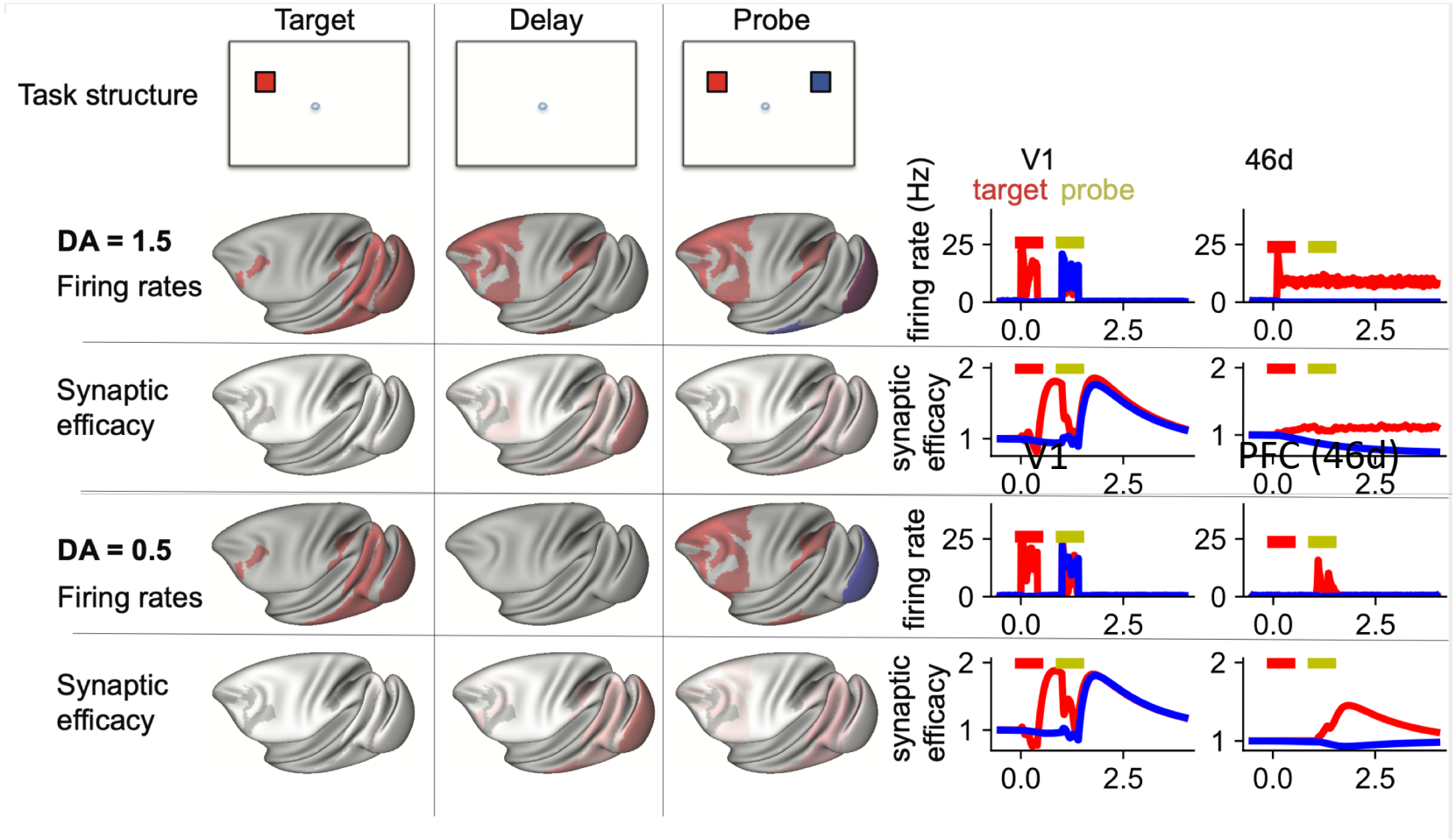




Mongillo, Barak & Tsodyks, *Science*, 2008

Wolff et al., *Nat. Neurosci*, 2017
see also:
Rose et al., *Science*, 2016

Switching from the activity-silent state to persistent firing by releasing dopamine

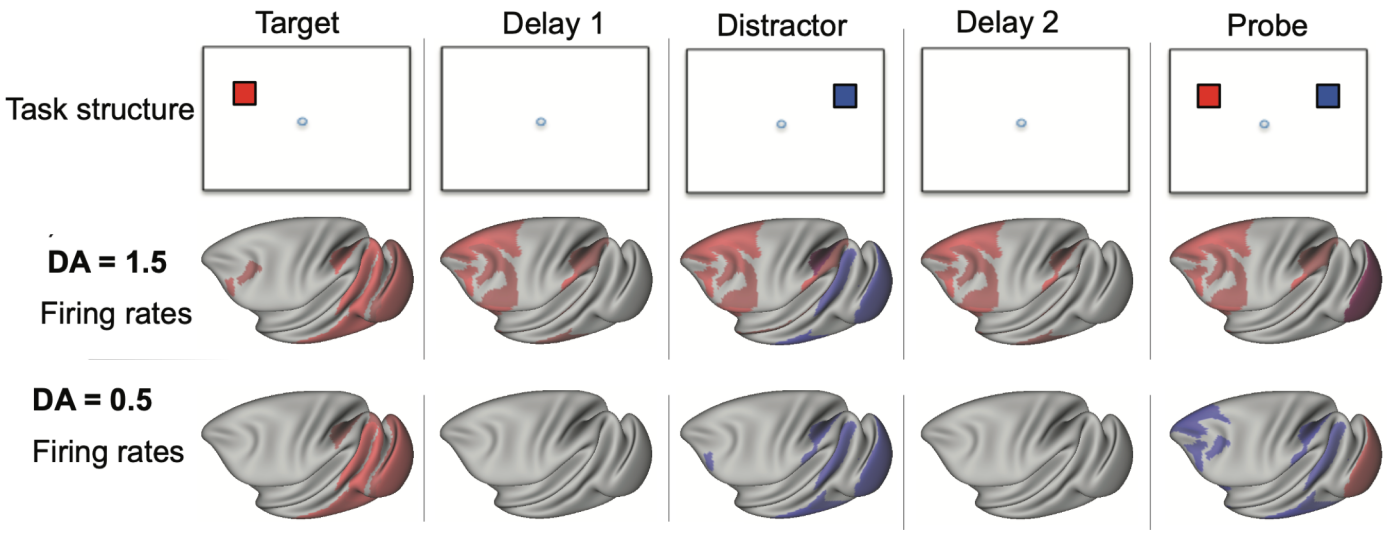


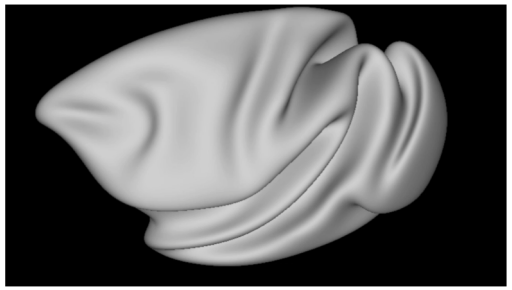
Higher dopamine

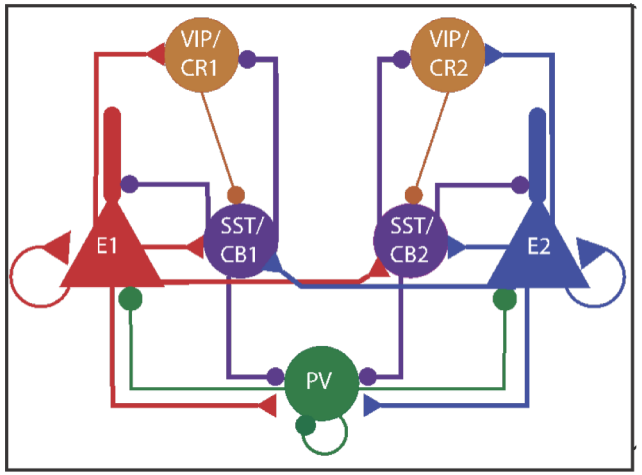
Lower dopamine

Froudist-Walsh et al., *Neuron*, 2021

‘Activity-silent’ working memory is vulnerable to distraction

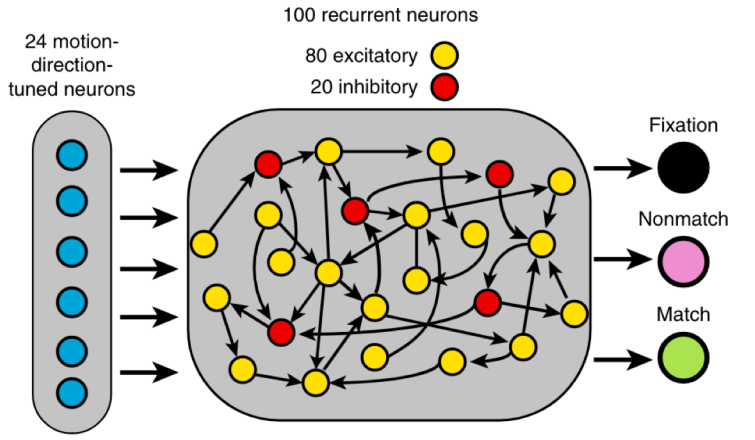


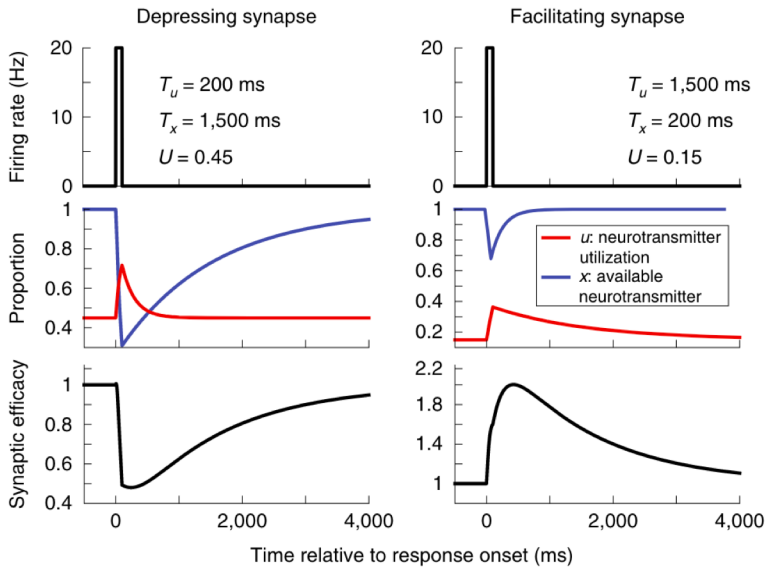


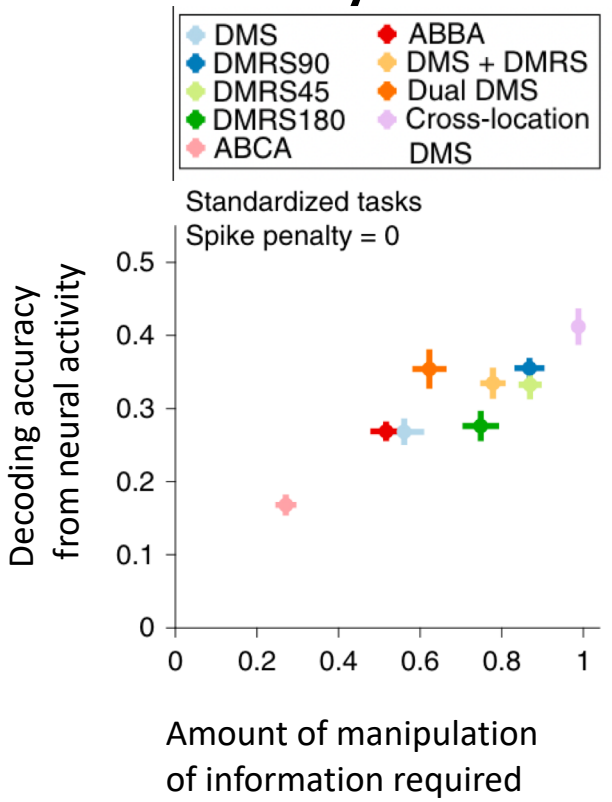


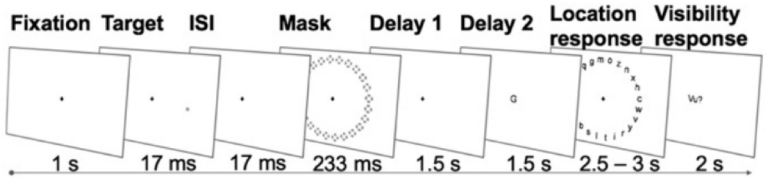
Froudist-Walsh et al., *Neuron*, 2021

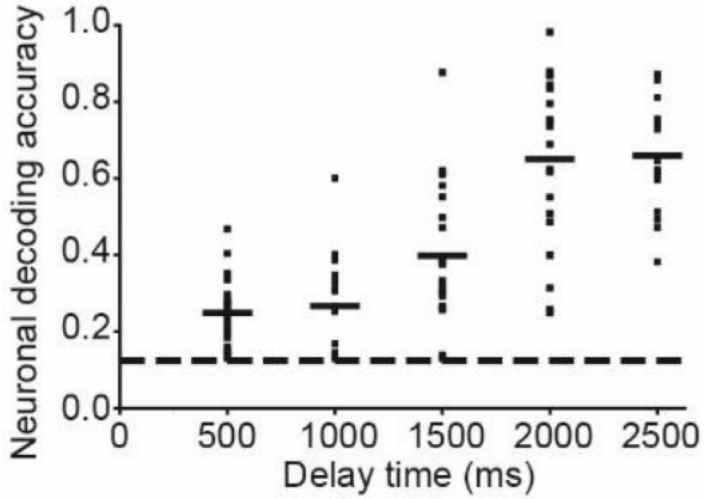
Training networks to solve tasks using activity-silent or persistent activity mechanisms











Greater reliance on neural activity when working memory tasks

- have a longer delay
- require manipulation of information stored in working memory

Masse et al., *Nat. Neurosci.*, 2019; Trubutschek et al., *PNAS*, 2019

Reviewing learning objectives

- To understand the concept of ’activity-silent’ working memory
  - Some studies do not detect persistent activity throughout the delay, so there may be ‘activity-silent’ mechanisms to store information in the short-term
- To study a neural network model of ’activity-silent’ working memory
  - Mongillo, Barak & Tsodyks’ model based on short-term synaptic plasticity
- To understand potential limitations of activity-silent mechanisms for working memory
  - Vulnerable to distractors
  - limited time
  - not suitable for manipulating information

Thank you!

- Contact me on Teams!