Neuronal population dynamics during the maintenance and manipulation of information in working memory

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Allosaurus_Hop, The Overly Ambitious

Scientific context

Working memory provides stable and coherent representation of the external world (Baddeley & Hitch, 1974) despite everchanging/non-persistent neuronal activity (e.g., Stokes, 2015).

Question 1

How is this possible/implemented?

Question 2

How is working memory affected by prior learning?

Question 3

Can we recreate biological phenomena associated with working memory in a recurrent neural network?

Hypothesis 1

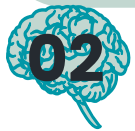
Stable representations in activity motifs generated by population dynamics (Mante et al., 2013; Vyas et al., 2019)

Hypothesis 2

Well trained populations of neurons form different activity motifs to undertrained populations when presented with the same task.

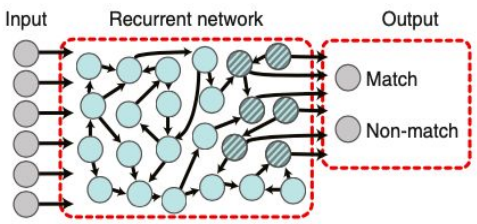
Hypothesis 3

Activity-silent periods (Stokes et al., 2013; Stokes, 2015) should be present in both RNNs and experimental data.



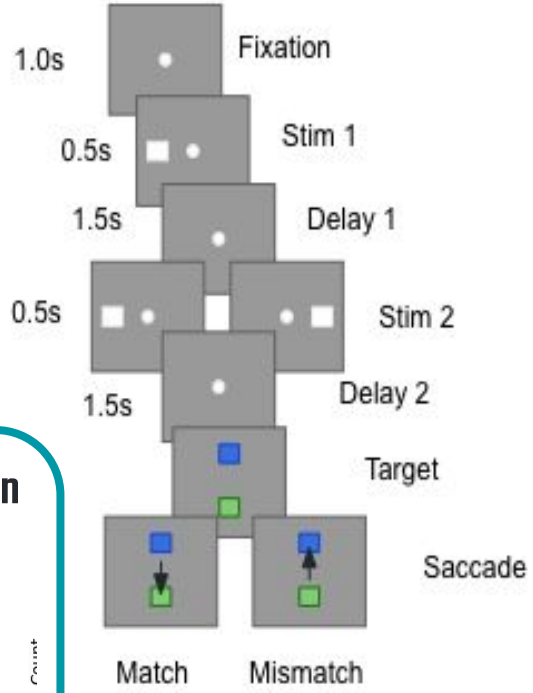
Scientific approach

Recurrent neural network model of working memory (using PsychRNN, Ehrlich et al., 2021)

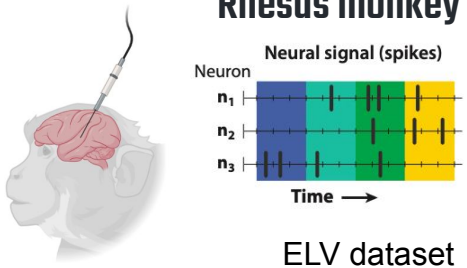


- Continuous time RNN
- PsychRNN implementation (https://github.com/murraylab/PsychRNN)
- Units: 16 input, 50 hidden, 2 output
- Binary Cross Entropy loss function
- Trial duration had a strong influence on convergence

Delayed matching task



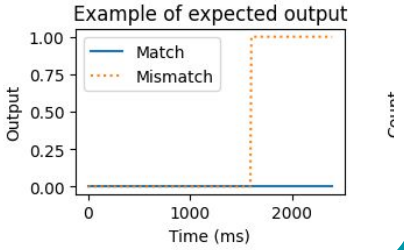
Rhesus monkey



ELV dataset

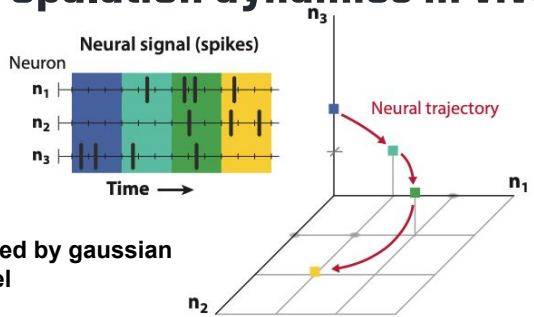
Intracranial single-neuron spike-train recordings from prefrontal cortex (Kobak et al., 2016).

RNN output expectation



Population dynamics in biological data

Population dynamics in vivo

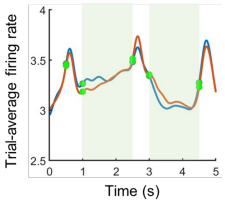


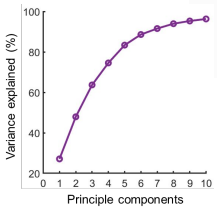
Filtered by gaussian kernel

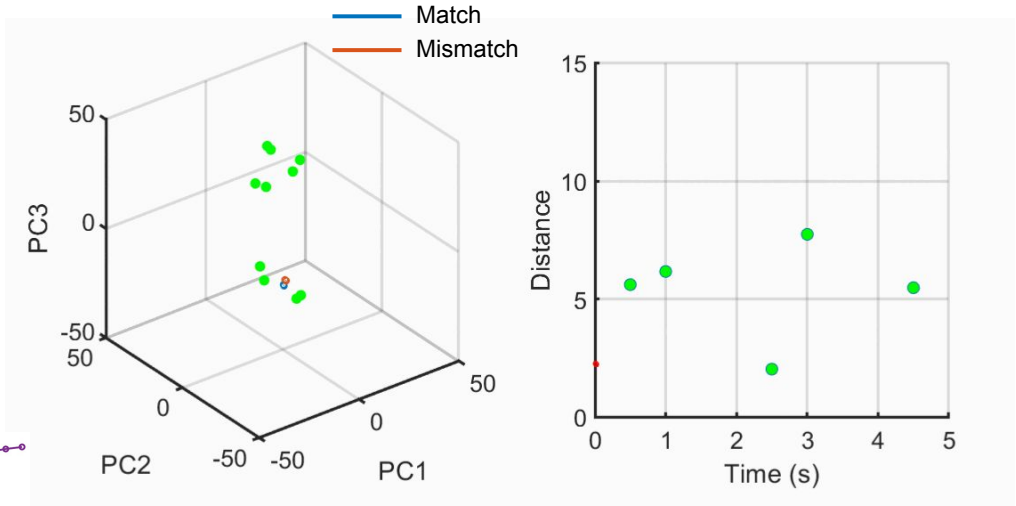
Firing rates

PCA on trial-averaged data

Principle components



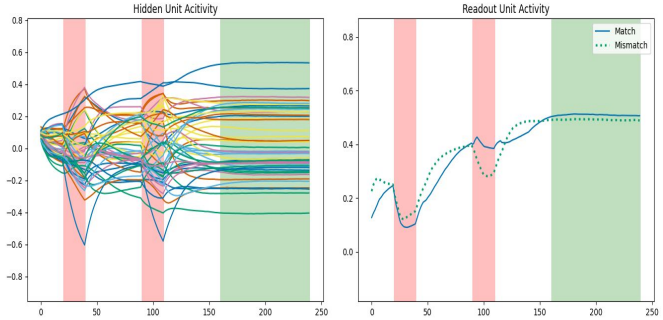


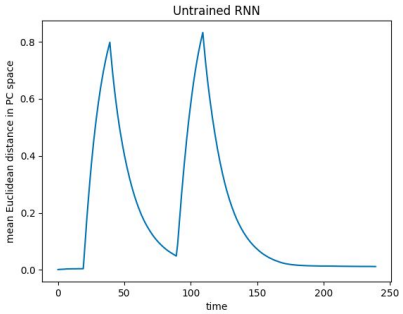


- Euclidean distance between neural trajectories under match and mismatch condition (right) peaks after the presentation of the second stimulus

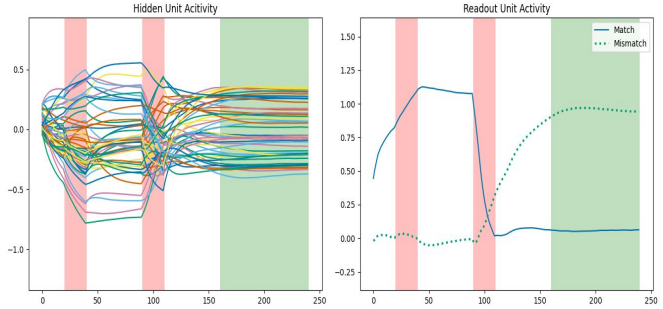
Effects of training on population dynamics in RNN model

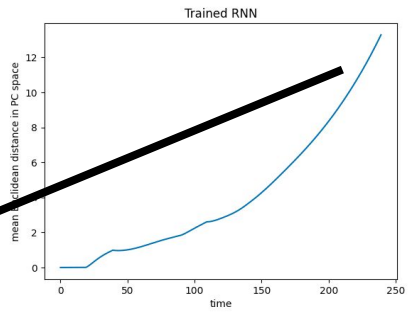
Before training

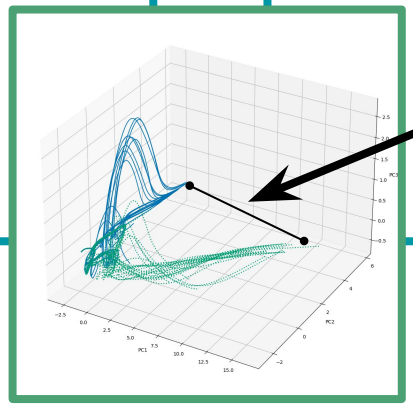




After training

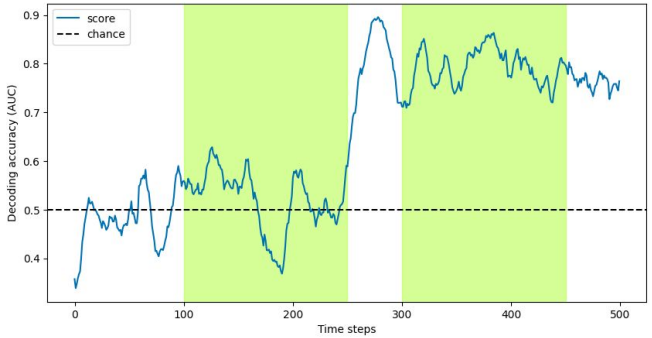


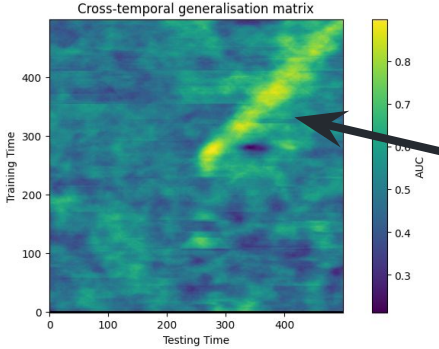




Activity-silent periods?

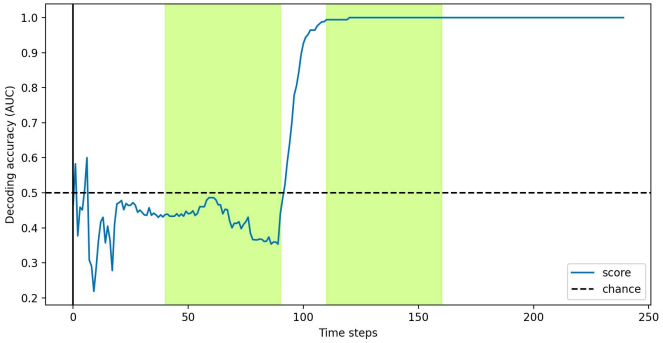
Monkey

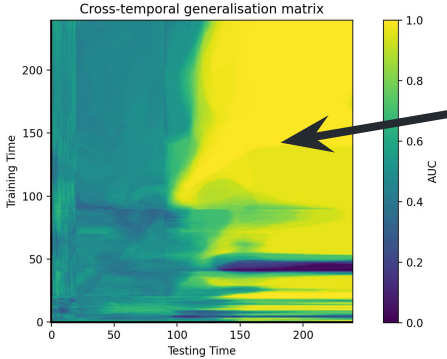




Suggests sustained but dynamic coding

RNN





Suggests ramping neuronal activity

Summary: Sustained but dynamic coding in the monkey's PFC vs. sustained ramping neuronal coding in the RNN.

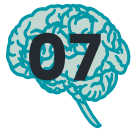
Summary & Perspectives

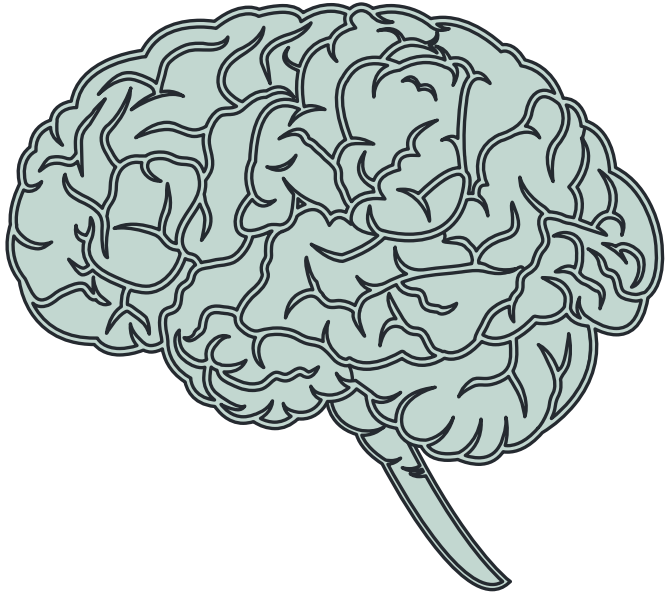
We developed and trained a RNN model of working memory and compared its performance and neuronal population dynamics to that of a rhesus monkey performing a delayed match-to-sample task.

How is representational stability possible despite ever changing brain activity? Dynamic coding at the population level in the monkey's PFC.

RNN's ramping and ceiling neuronal activity may be due to the lack of motor planning and preparation (could be assessed by looking at the decodability of the cue position during the first delay period).

How could we make the RNN's behaviour more similar to the monkey's behaviour? Could implement more biologically-inspired constraints (e.g., with STSP, inhibitory cells, as in Masse et al., 2019) and/or implement an explicit motor response to be given.





THANK YOU FOR YOUR ATTENTION!

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