Distributed feed-forward network activity may underlie the contextual flexibility of neurons within the frontal cortex and central thalamus

201.12

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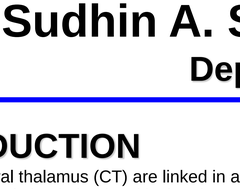
INTRODUCTION

The frontal cortex (FC) and central thalamus (CT) are linked in an intricate and distributed anatomical circuit that is critical to the performance of executive functions. At present, components of executive function have been associated with patterns of activity in both brain regions, but little is known about how these regions work to support these behaviors. In this study, we investigated two processes central to most executive functions – sustained attention and working memory, while conducting microelectrode recordings within the FC and CT of an awake behaving monkey. We find that single neurons in both areas exhibit a wide range of delay period activity profiles for both tasks. We also show that a distributed feed-forward network model can reproduce the three modes of delay period activity seen in the data: 1) neurons with delay period activity for only one task; 2) neurons with delay period activity that is similar in both tasks; 3) neurons with delay period activity that is different for the two tasks. Neighboring posters describe the model in more detail (201.13) and explore interactions between FC and CT (201.11).

GENERAL METHODS

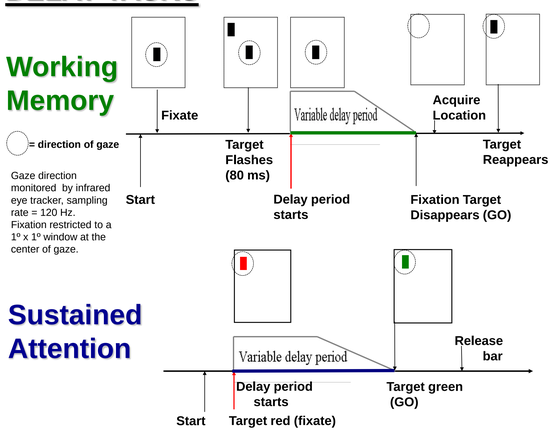
NEUROPHYSIOLOGY



Paired (simultaneous) single-unit recordings (monopolar) were made in the frontal cortex and central thalamus. Recordings were made with epoxy-insulated tungsten microelectrodes (1-4 MΩ). Neural data was streamed to disk at 20 KHz, and spike-sorting off-line was accomplished with a semi-automated custom-coded software package. Histology of the CT was performed postmortem to reconstruct electrode tracks. FC chamber placement was confirmed postmortem from examination of the brain.

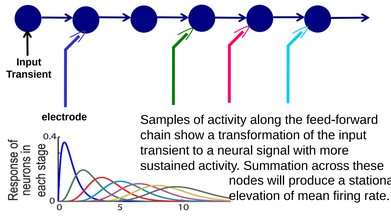
AS=arcuate sulcus; PS=principal sulcus; FEF=frontal eye fields; PMd=premotor dorsal; PMv=premotor ventral; SMA=supplementary motor area; CL=central lateral nucleus; MD=medial dorsal; LD=lateral dorsal; VL=ventral lateral; RE=reticular

DELAY TASKS



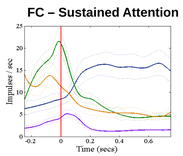
The variable delay period was a normally distributed time interval with a mean duration of 1350 ms and standard deviation of 350 ms. Performance was variable over experimental sessions that included ~1000 trials and that often switched between blocks of the sustained attention and working memory tasks. Peak performance was typically 75-80% correct on both tasks.

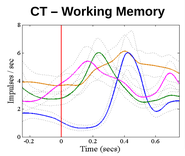
DELAY PERIOD ACTIVITY FROM FEED-FORWARD NETWORKS (FFNs)



Samples of activity along the feed-forward chain show a transformation of the input transient to a neural signal with more sustained activity. Summation across these nodes will produce a stationary elevation of mean firing rate.

Goldman MS (2009) Memory without feedback in a neural network. *Neuron 61:621-634.*

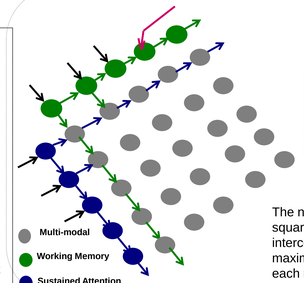




Delay period activity can be produced in FFNs (Goldman, 2009). Different time courses of delay activity seen in the FC during the sustained attention task (four neurons, left panel), or in the CT during the working memory task (four neurons, right panel) could be produced by an FFN. How do we get delay period activity for both tasks, with the same or different time courses, in one neuron?

PROPOSED MODEL: DISTRIBUTED (2-D) FFN

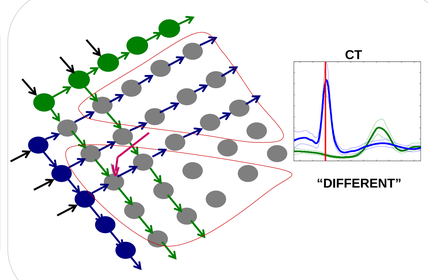
EDGE



The network need not be square, merely interconnected with a maximum of two inputs at each node (see Poster 201.13).

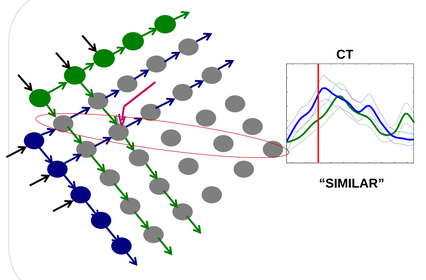
Sampling single-unit activity from the edge of a 2-D FFN would find neurons that produce delay period activity during the execution of only one of the tasks. The time-to-peak of the delay period activity is still subject to the network dynamics imposed by the 1-D FFN along the edge. Inputs to the edges are modeled as pulses of rate activity from sensory and/ or sensorimotor elements.

INTERIOR OFF-DIAGONAL



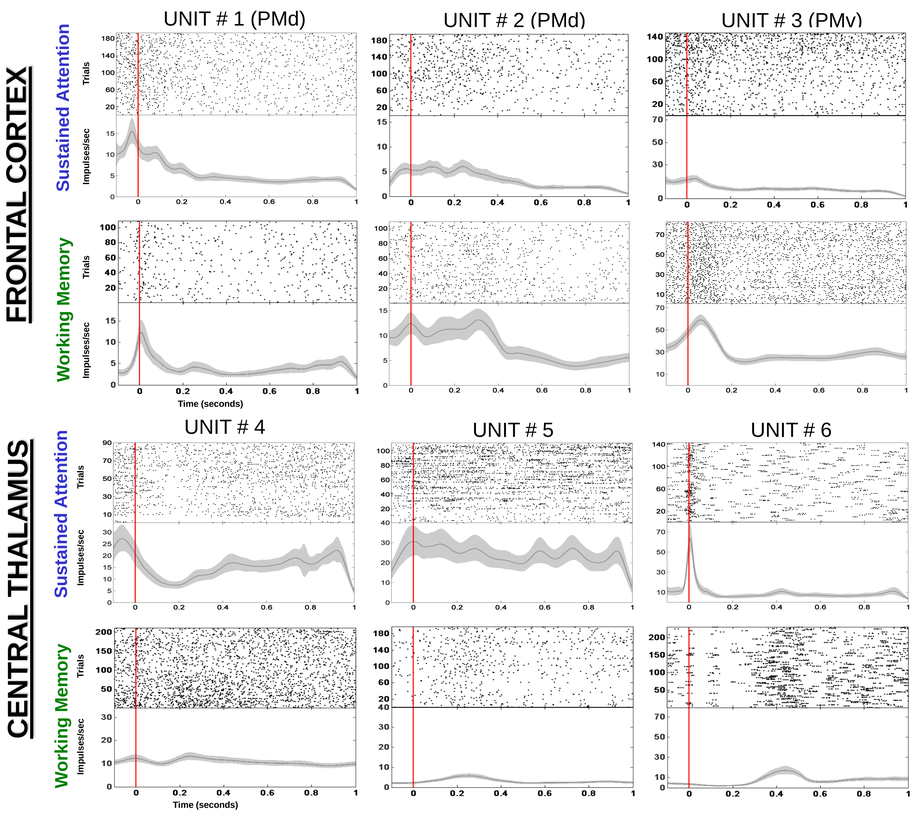
Sampling single-unit activity from within the 2-D FFN closer to one edge (blue) than the other (green), would find neurons that produce delay period activity during the execution of both tasks. Here, however, the time to peak of the delay period activity is different for the two tasks because the neuron is closer to one edge than to the other. Most neurons (red boundaries) would operate in this mode.

INTERIOR ON-DIAGONAL



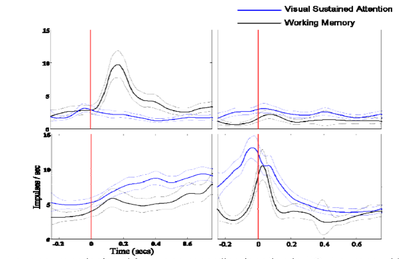
Sampling single-unit activity along the diagonal of the 2-D FFN would find neurons that produce similar delay period activity during the execution of the two tasks.

RESULTS: SINGLE UNIT ACTIVITY (rasters and rates)



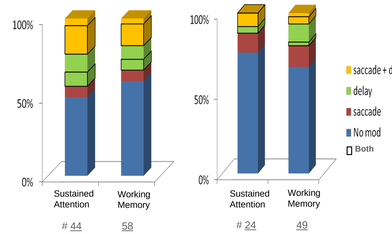
Red line: start of delay period; Thin black line: mean of rate estimate; Gray band: jackknife estimate of 95% confidence interval for rate estimate.

RESPONSE HETEROGENEITY



Four neurons isolated from one recording location in FC. Neurons within ~150 microns of each other can exhibit several different network behaviors. Spatial extent of an FFN can be restricted to local cortical circuits.

SUMMARY



SUMMARY & CONCLUSIONS

- Our results reveal neurons that are active during the delay period in just one task, neurons that are active during the delay periods of both tasks, and a large majority that are relatively inactive in both.
- Moreover, for the neurons that are active during both, their temporal activity profiles could either be similar or different for the two tasks.
- Proposed model: Neurons are connected via feed-forward chains and these chains can be interconnected into higher-dimensional networks. The participation during one or more delay tasks is dependent on the task- or function-specific inputs to the edges of the network and the position of the neuron with respect to the network's edge.
- This model suggests a mechanism by which the time-varying similarities and differences seen for a single neuron across tasks can be achieved through the neuron's functional location within the distributed network.

Grant Support: NIH-NS067249; James S. McDonnell Foundation
Industry Sponsored Research Agreement: IntElect Medical, Inc. Cleveland, OH.