201.13

Modeling the contextual flexibility of neurons across executive tasks within the frontal cortex and central thalamus via a distributed feed-forward network mechanism

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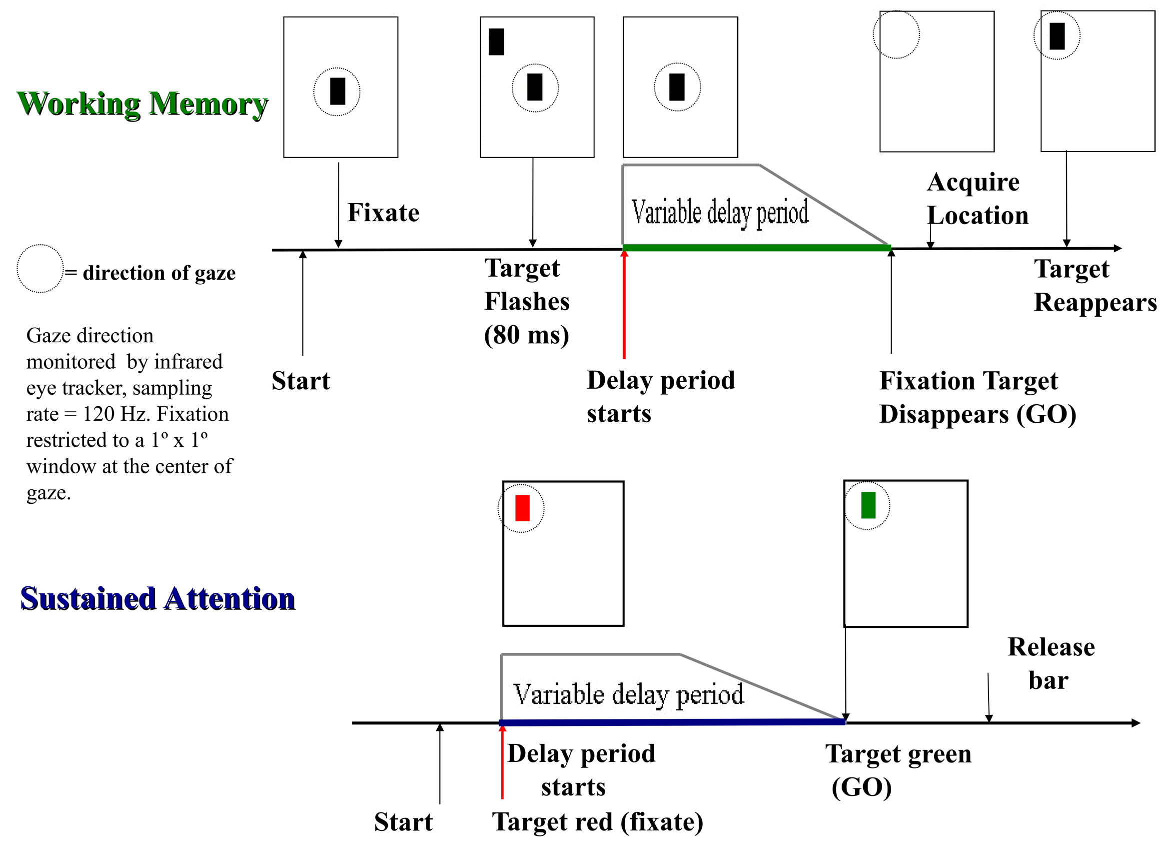
INTRODUCTION

Many executive tasks require the formation and maintenance of working memory (WM) or sustained attention (SA), or both, for extended intervals. Recent experiments show that neurons in the frontal cortex and central thalamus can participate in one or both of these tasks. Among those neurons that participate in both, some become active at similar times during the delay period for both tasks. Others become active at different times for the two tasks. We propose a feed-forward network through which pulses of activity travel. The spatio-temporal characteristics of the pulses are determined by which neurons receive the external stimulus. We utilize an established model of cortical propagation (Pinto and Ermentrout) in a 2-D feed-forward network to demonstrate a possible mechanism for the observed delay period activity in flexible neurons, those capable of participation in multiple tasks.

NEUROPHYSIOLOGY

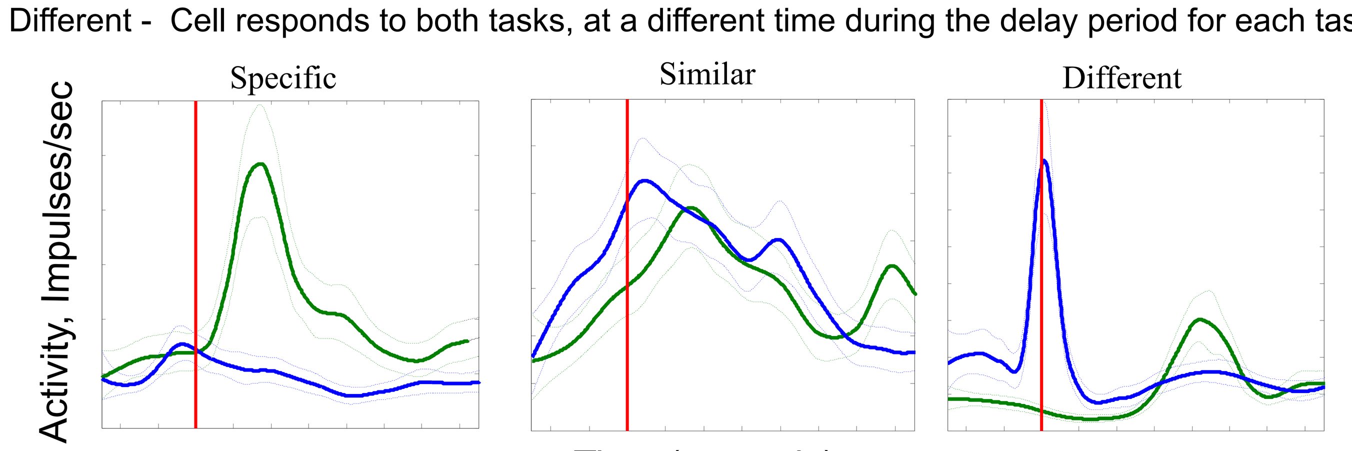
Two distinct tasks, each containing a variable delay period. During this delay period, we observe the response of neurons in the frontal cortex and the central thalamus.



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.

Neurons are separated into three categories, based on the temporal response to each of the tasks.

1. Specific - Cell responds during one task, but not the other.
2. Similar - Cell responds during each task, at a similar time of the delay period..
3. Different - Cell responds to both tasks, at a different time during the delay period for each task.



For details about the behavioral tasks, recording locations, and methods, see poster 201.12 (Shah, et. al.)

REFERENCES

1. Mark S. Goldman, Memory without feedback in a neural network, Neuron 61 (2009)
2. David J. Pinto and G. Bard Ermentrout, Spatially structured activity in synaptically coupled neuronal networks I. Traveling fronts and pulses, SIAM J Appl. Math 62 (2001)
3. Shah, S. (2010) 'Joint and independent contributions of the frontal cortex and central thalamus', Thesis, Weill Cornell Medical College.

SUPPORT

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The Model and Feed-forward Network

Pinto, Ermentrout (2001) model.

$$\frac{d\vec{u}}{dt} = -\vec{u} + cW\vec{P}(\vec{u}-\theta) - \vec{v}$$

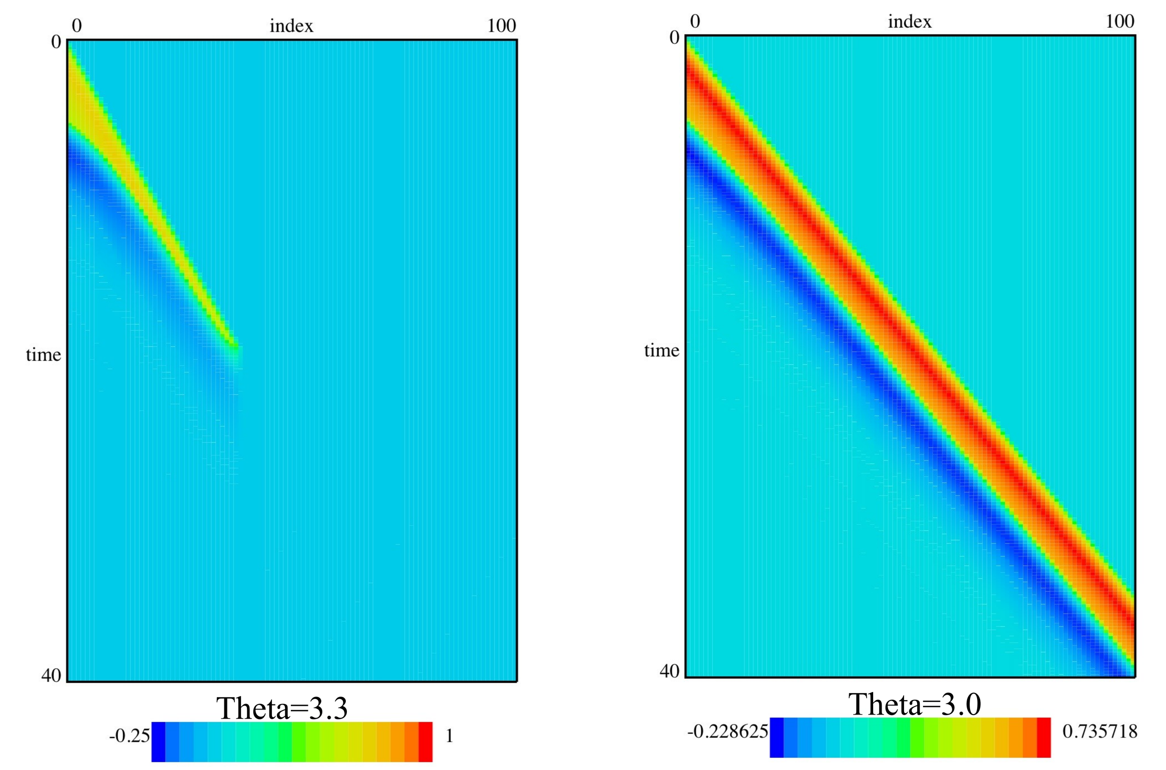
$$\frac{d\vec{v}}{dt} = \epsilon(\vec{u} - \beta\vec{v})$$

$$P_i(\vec{u}-\theta) = \begin{cases} 1 \; if \; u_i > \theta \\ 0 \; otherwise \end{cases}$$

Variables and parameters

W is a connection matrix
u_i is an activity variable (index i)
P_i is a threshold function
v_i is a slow feedback variable

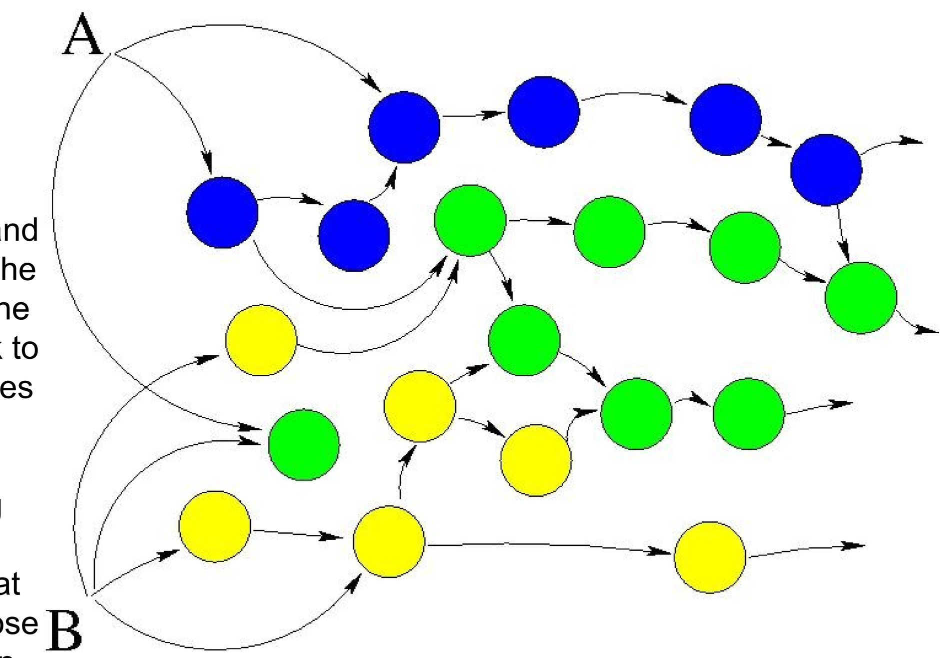
We only consider a feed-forward network. Goldman (2009) shows that a network does not need to be feed-forward to behave like one. He also showed that a network is capable, at the population level, of persistent activity without the presence of feedback. For these reasons, we only consider the case where W is triangular.



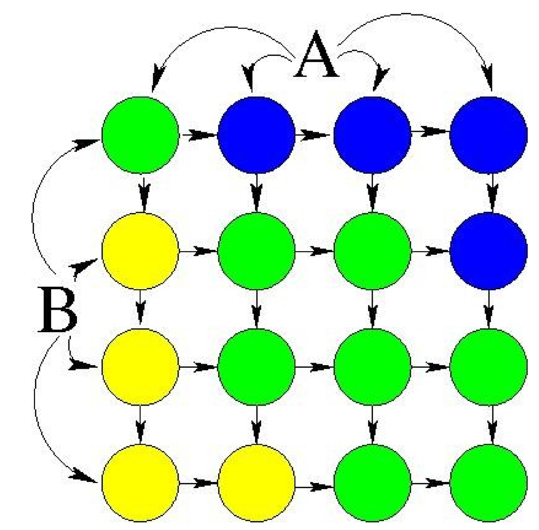
Two types of one-dimensional pulses. The horizontal axis indicates the position along a line. The vertical axis indicates time. The color indicates the value of u_i. Pulses only differ in the value of the threshold parameter, Theta. In each case, the first cell in the line is stimulated, starting a pulse of activity. In the left panel, the threshold is too high and eventually the output is a pulse that is too small in amplitude to excite further cells. In the right panel, the threshold is lower, and so the network is capable of persistence, limited only by the number of cells present in the network. On the left, the cells that are downstream and yet too far from a given input stimulus, do not receive a pulse. When the threshold is lower, as in the right panel, no downstream cells are excluded. Thus, a cell's response in the network to an input, whether it responds and when, depends on where the cell is located in the network and where in the feed-forward chain the initial input is delivered.

Feed-Forward Network

A feed-forward network that participates in two distinct tasks (A and B). The lines with arrows represent the feed forward connections between the cells. Connections that are too weak to elicit a response in downstream nodes are not shown. This picture makes clear how feed-forward architecture can induce specialization depending on the particular cells the stimulus excites. The blue circles are cells that respond only to A, the yellow are those that respond only to B, and the green respond during each task.

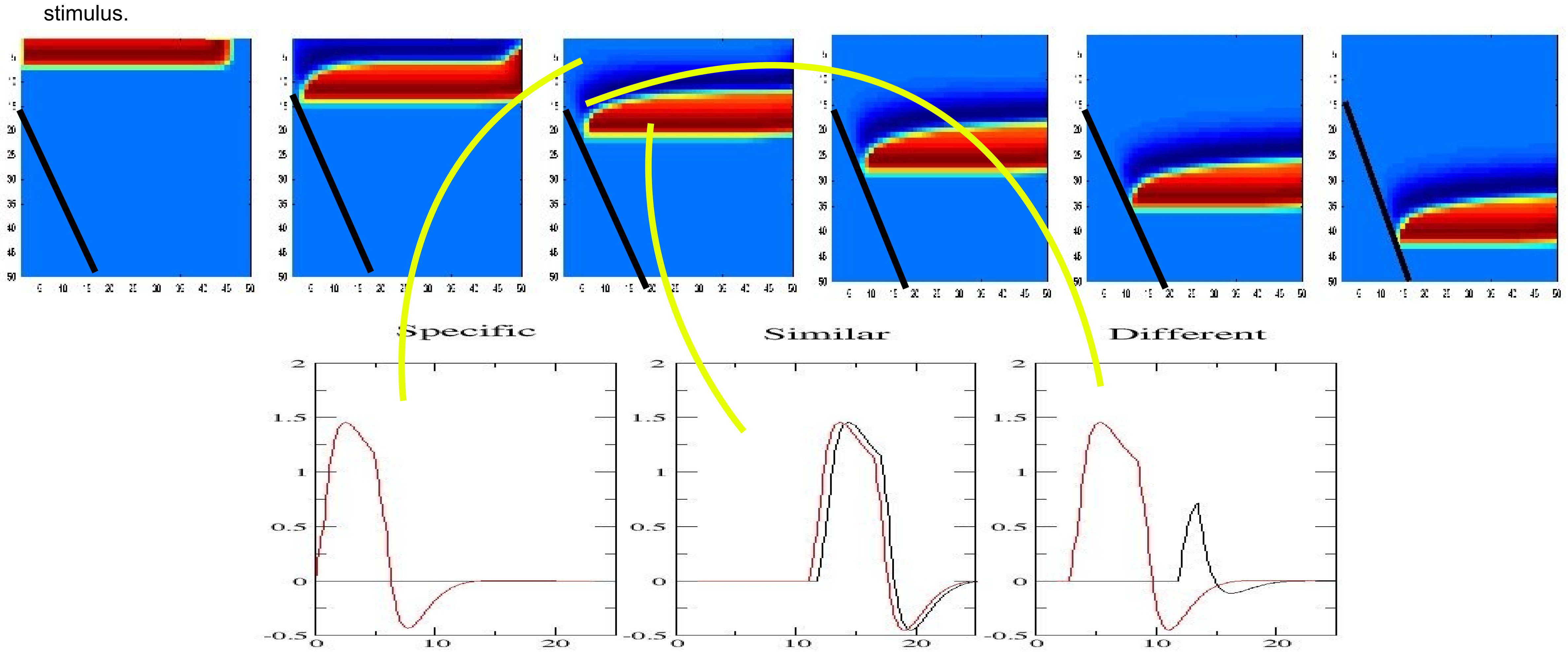


Reshaping the network into a "functional array". Here we rearrange the cells so that the external stimuli are applied on the edges of a square. The color scheme is the same as above. The stimulus A is not carried with enough strength to propagate down the left edge of the square. On the other hand, B arrives along this edge. These cells are "specific" to task "B". Nodes along the diagonal will receive input from each at similar times during the delay period. Green cells off-center will activate to each stimulus, but at different times.



Simulation of the network

We simulate the network on a 50x50 grid of cells. In the figure shown on the left, the stimulus is applied along the top edge. A stimulus along the left edge will result in the transpose of that shown. The individual panels of this figure are 6 time snapshots, time increases from left to right. The horizontal and vertical axis of each panel are location coordinates in the rearranged configuration described above. Stimulus A is applied to the top edge, and stimulus B is applied to the left edge (not shown). Along the left edge, the input is too weak to support propagation and so these cells will only participate in task B (stimulus applied along the left edge). Away from the left edge, the cells receive sufficient input to become active (they receive more inputs, which sum). A line showing the cutoff location between cells specific to stimulus B and those that respond to each stimulus is shown in each panel. To the right of this line, activity arising due to task A pulses through the medium. To the left, cells will not respond to task A, but they will respond to a stimulus along the left edge (task B). In the lower figure, the time traces are shown for three of the cells (yellow dots) chosen to show how the activity patterns generated by the network can produce cells that respond "specifically", "similarly" and "differently" to the various task specific inputs. In each of these, the red curve results from a side edge stimulus and the black curve is the evolution resulting from a top edge stimulus.



SUMMARY & CONCLUSIONS

- **We suggest a mechanism that would give rise to the activity patterns seen by recording neurons in the frontal cortex and the central thalamus during two distinct tasks.**
- **A traveling pulse originates at a task-specific location in the brain, causing rising and falling activity levels during the delay period for each task.**
- **The functional location of a given cell in the network determines when, if at all, its activity level will rise. Cells closer (functionally) to the stimulated location will be most active early in the delay period, and those farther away will be most active later.**
- **Varying temporal responses can provide insight into the relative "location" of the stimulating event, providing insight into the connectivity within and between the frontal cortex and central thalamus.**