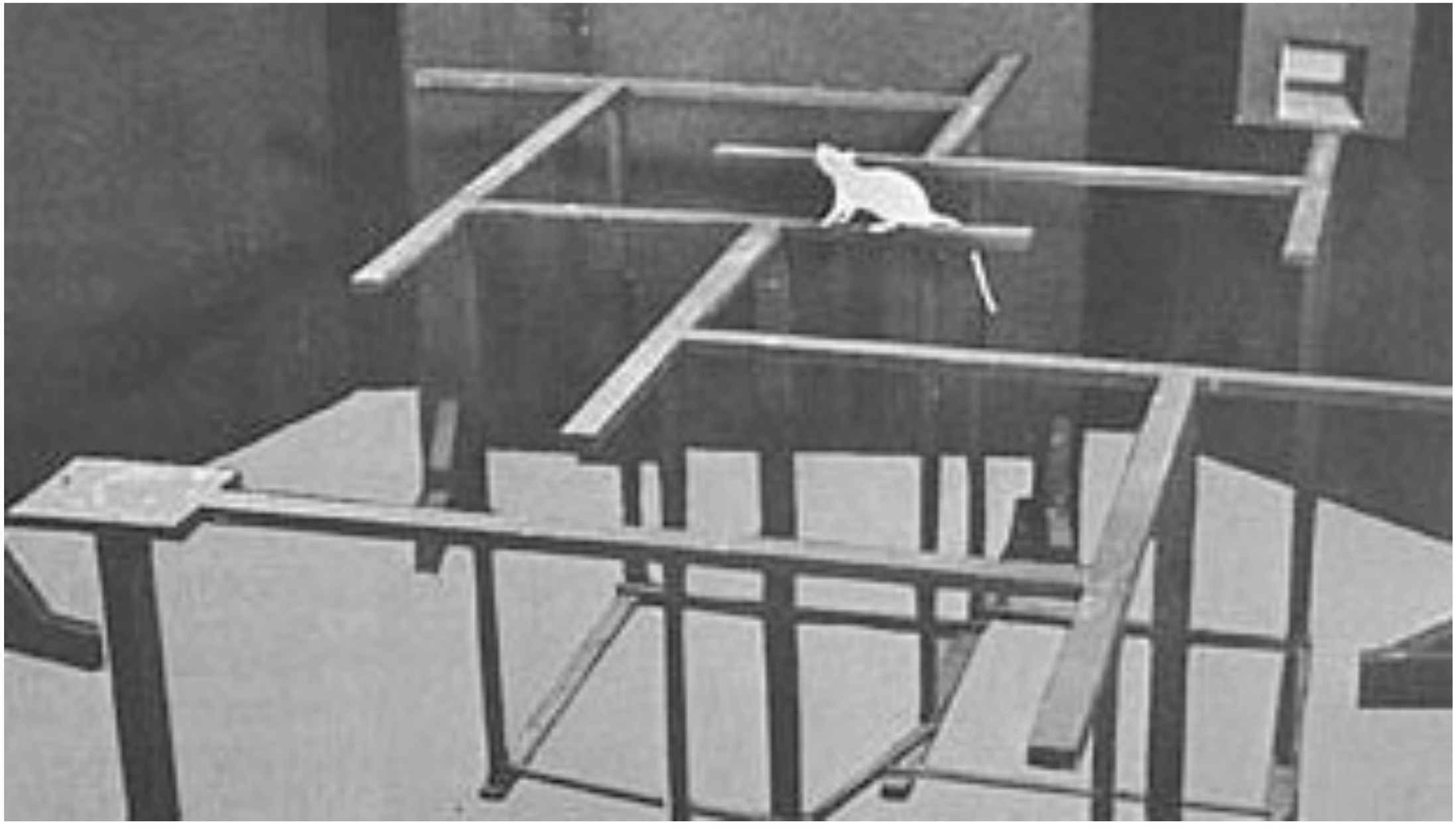
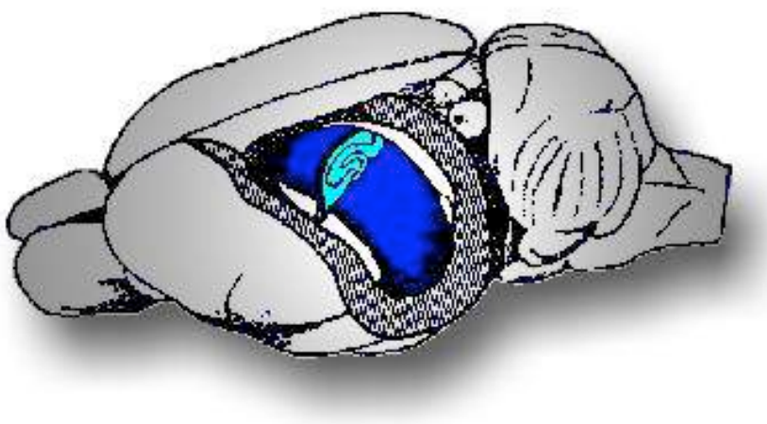
The role of the rat frontal orienting field in movement planning

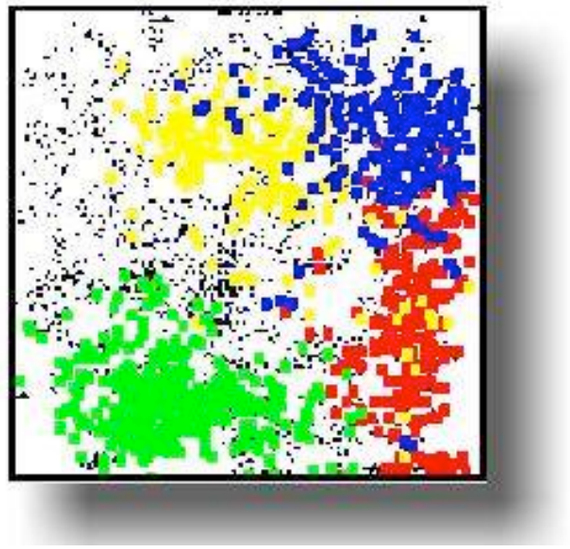
Jeffrey Erlich, Max Bialek & Carlos Brody

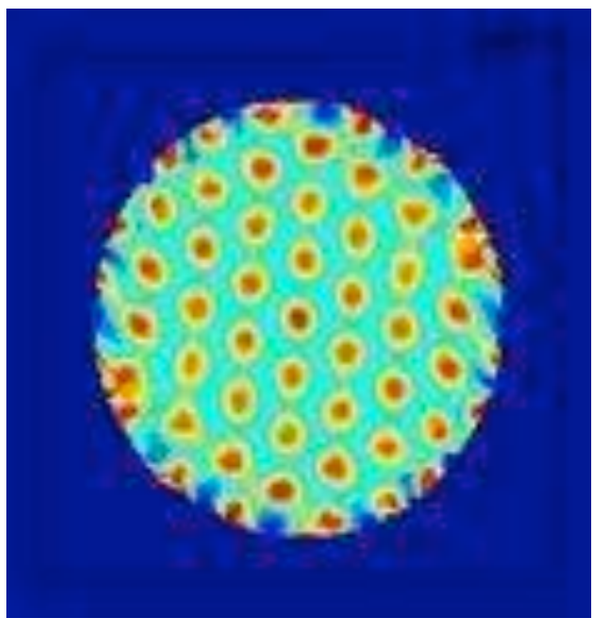
HHMI & Princeton University

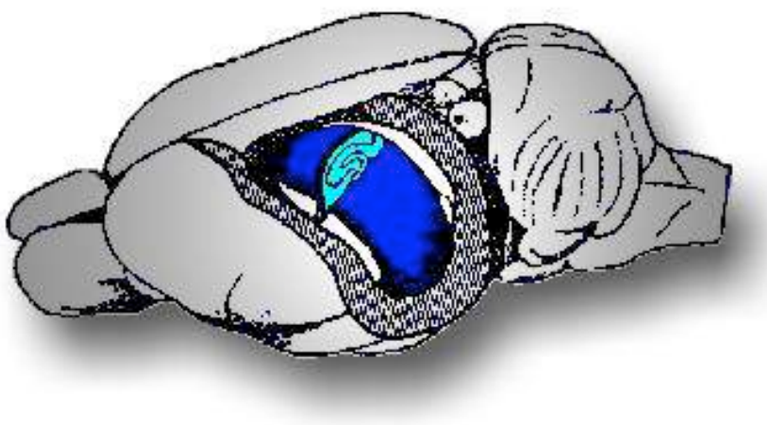
Where’s the cheese?

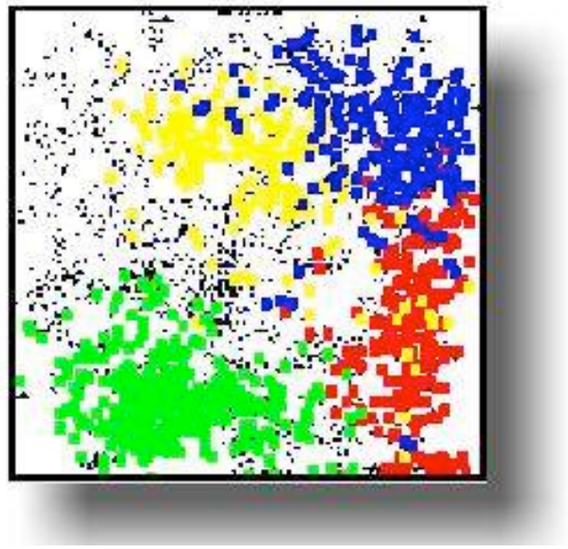






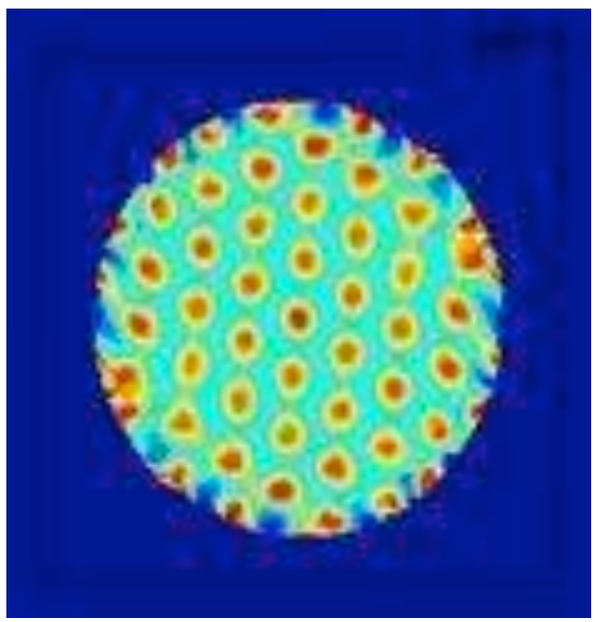






Rat hippocampus and
place cells
(from O’Keefe)

Entorhinal cortex grid cell
(from NTNU)



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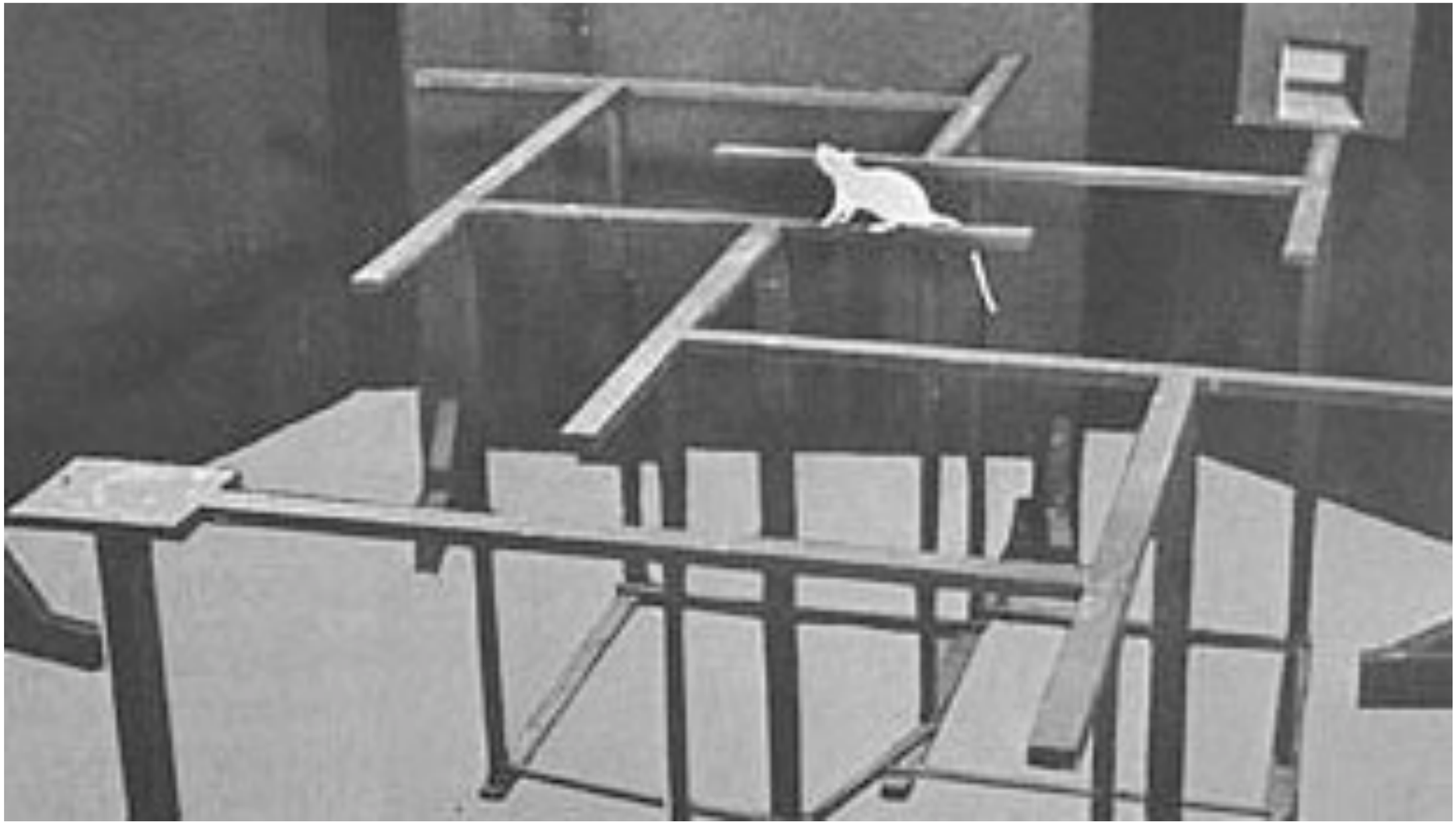

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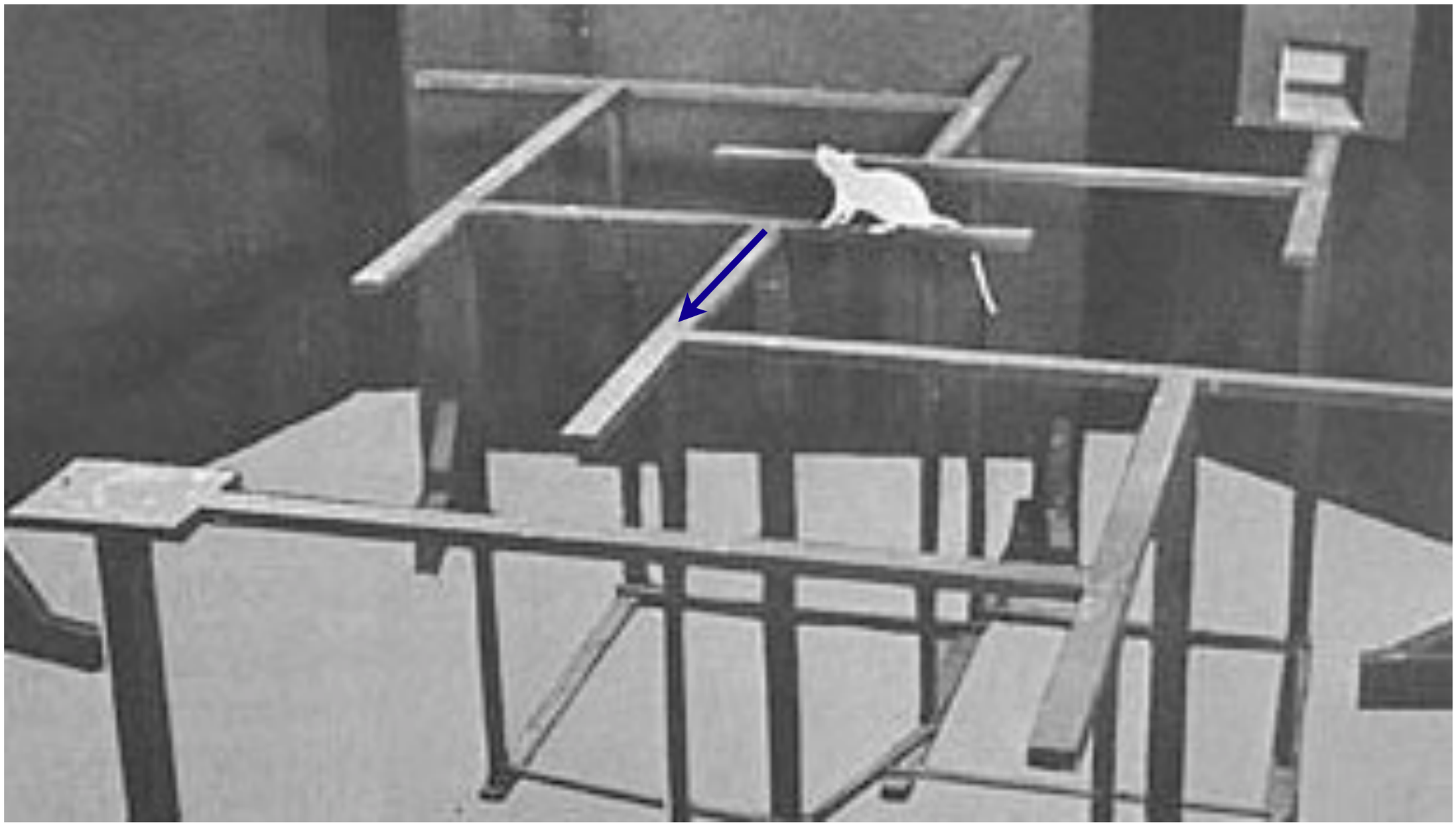

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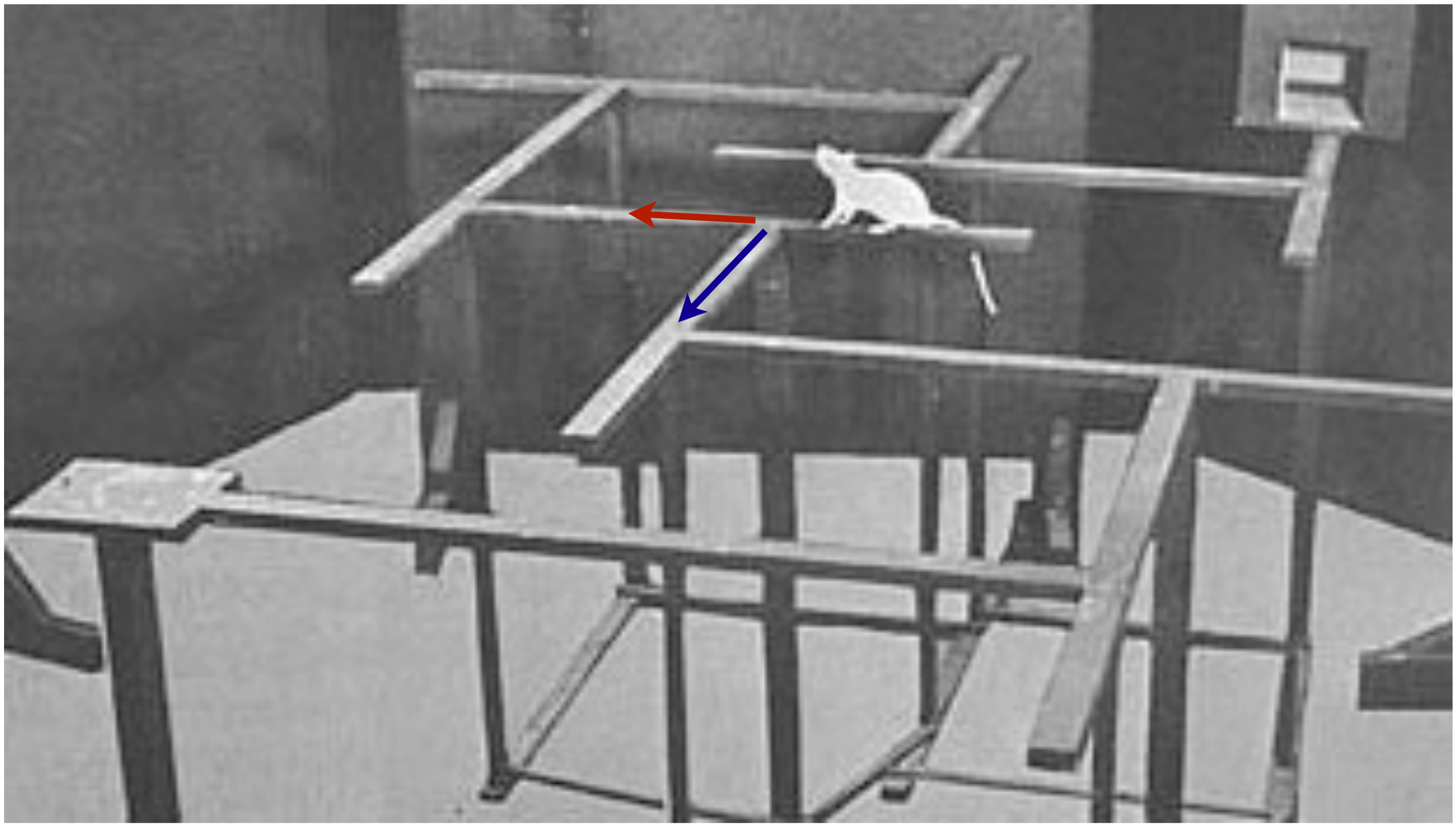
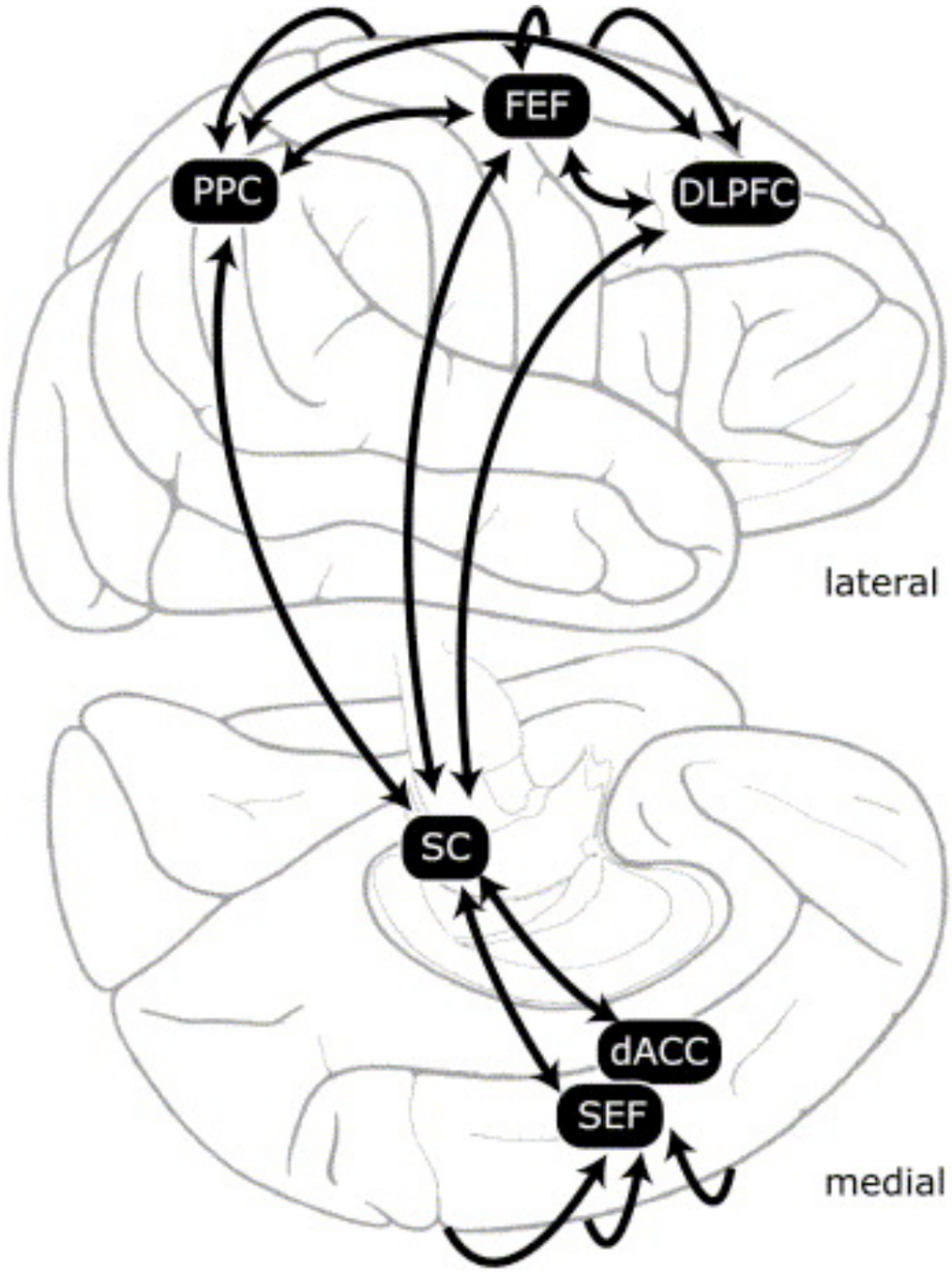


Neural circuit for deciding where to **look**



PPC Posterior Parietal Cortex

FEF Frontal Eye Field

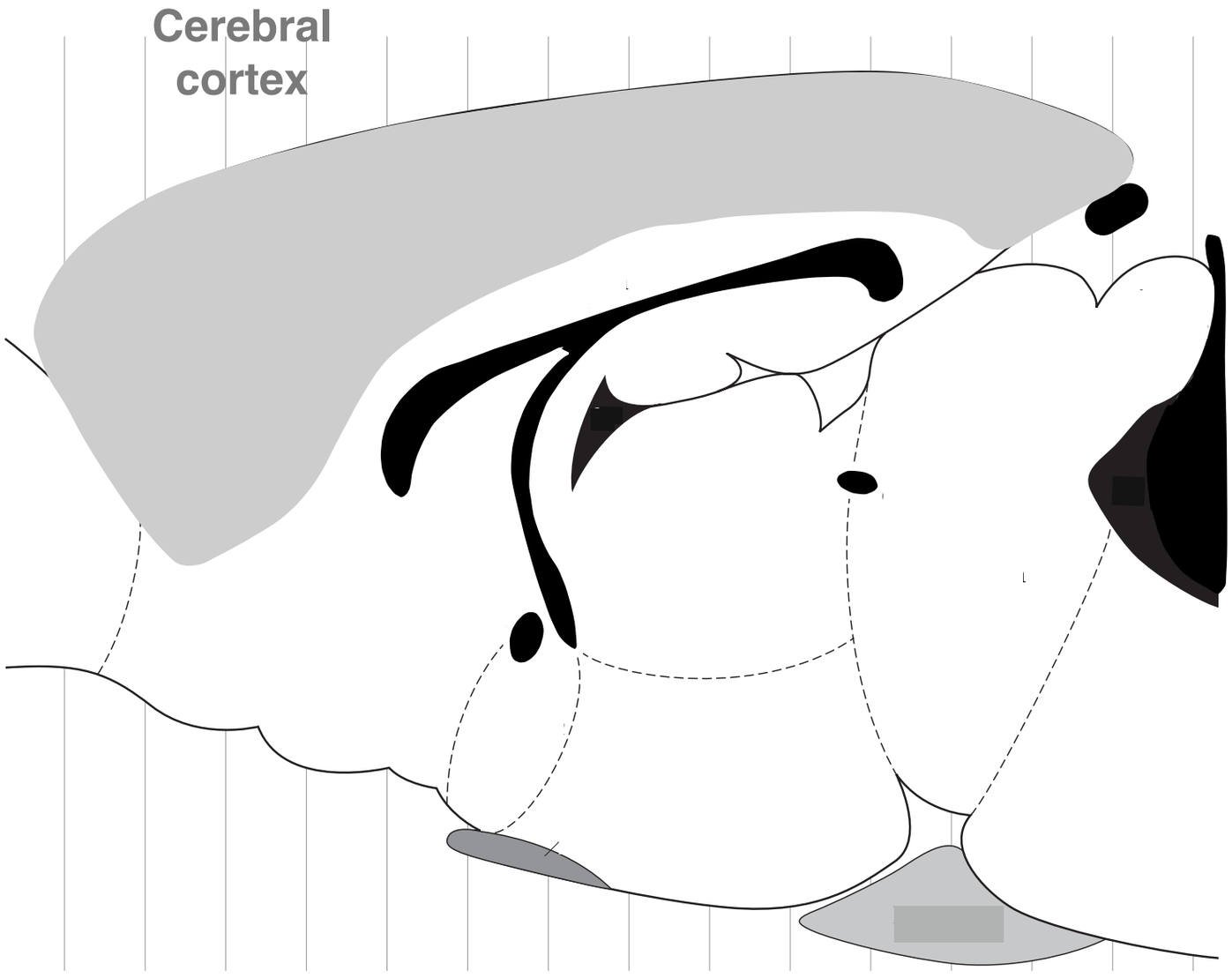
SEF Supplementary Eye Field

DLPFC Dorsolateral Prefrontal Cortex

SC Superior Colliculus

from Curtis, 2005

Is there a homologous circuit in the rat?



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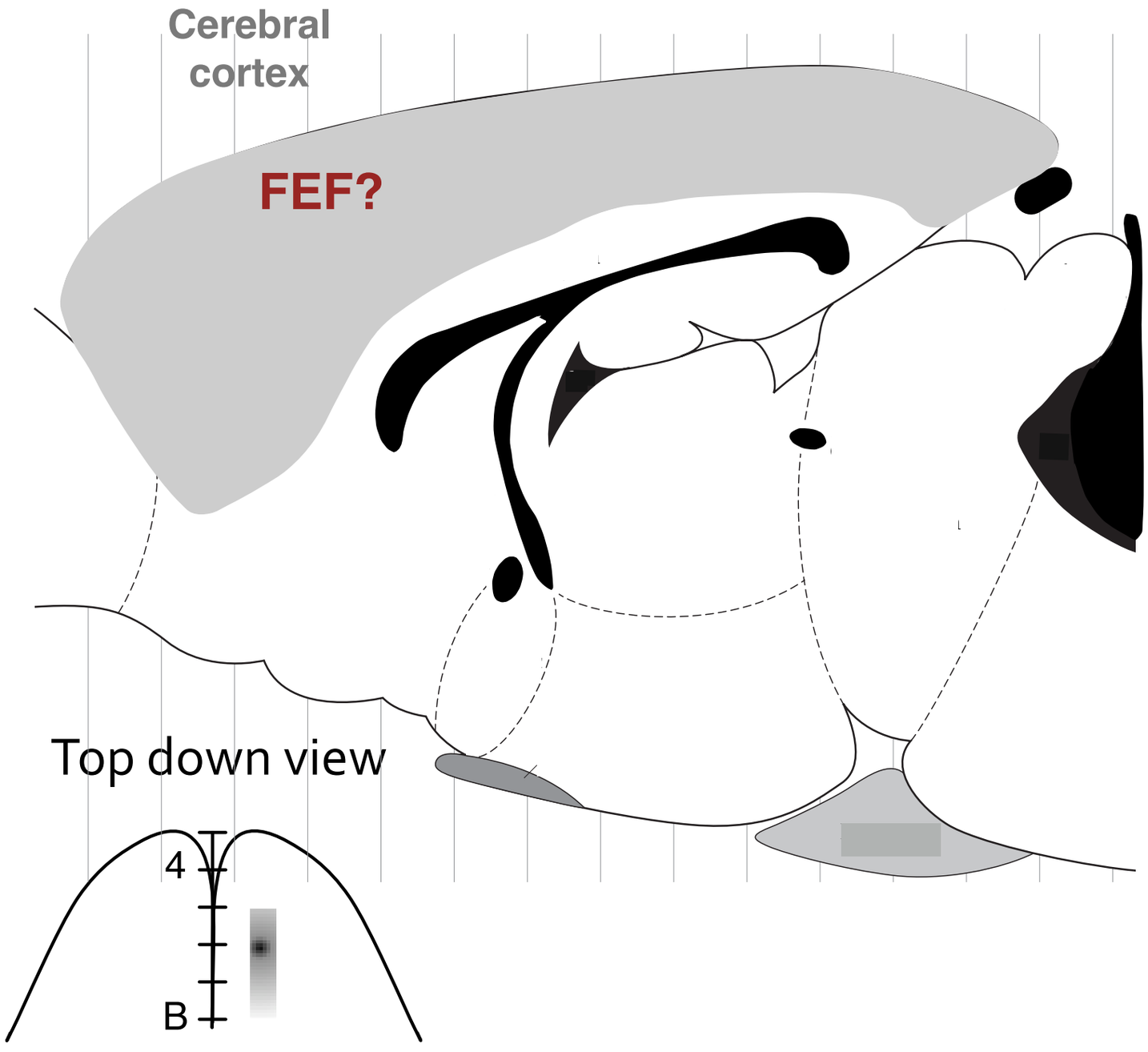

+2 AP, ±1.3 ML
from β

Leonard, 1969

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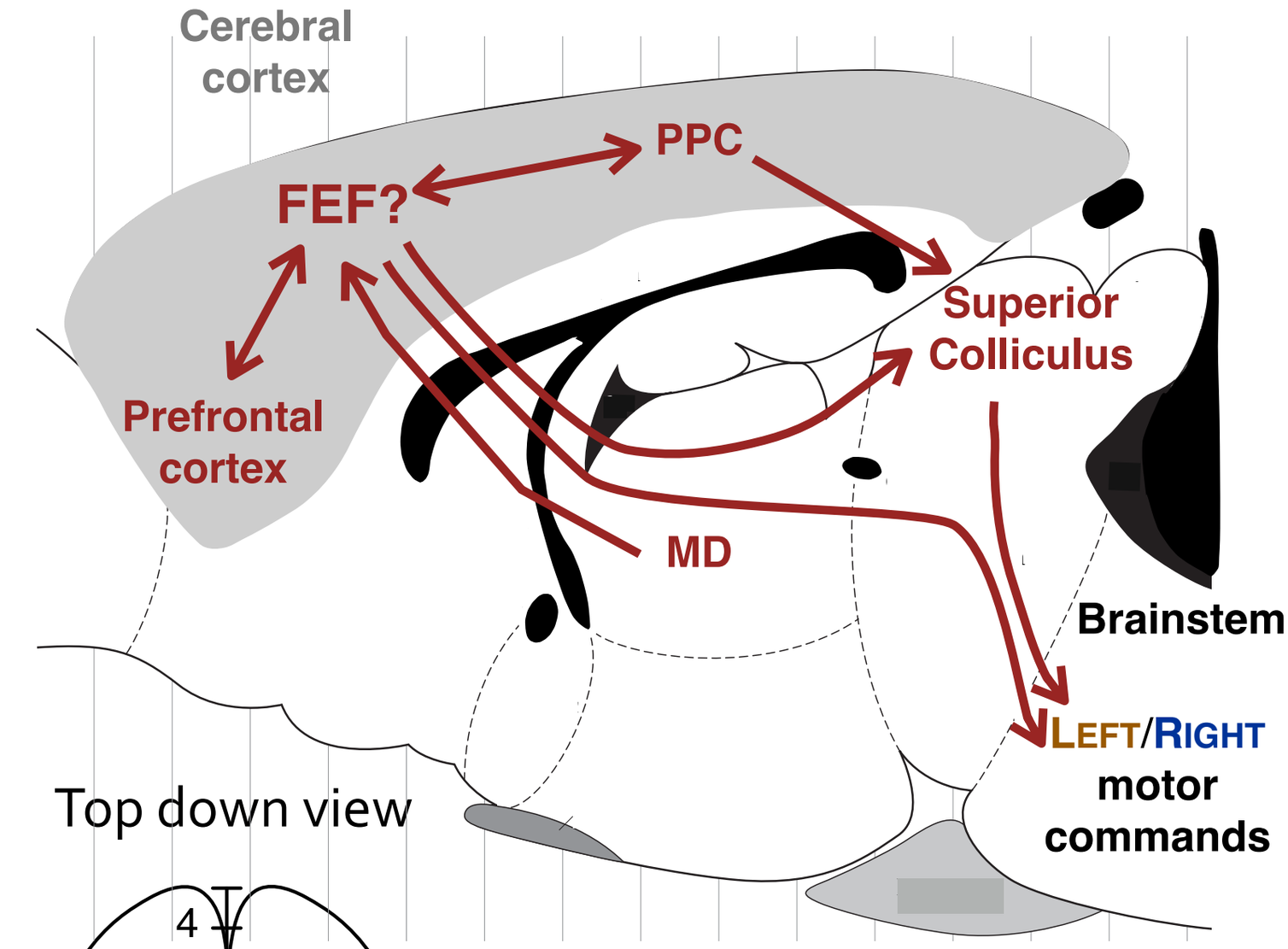

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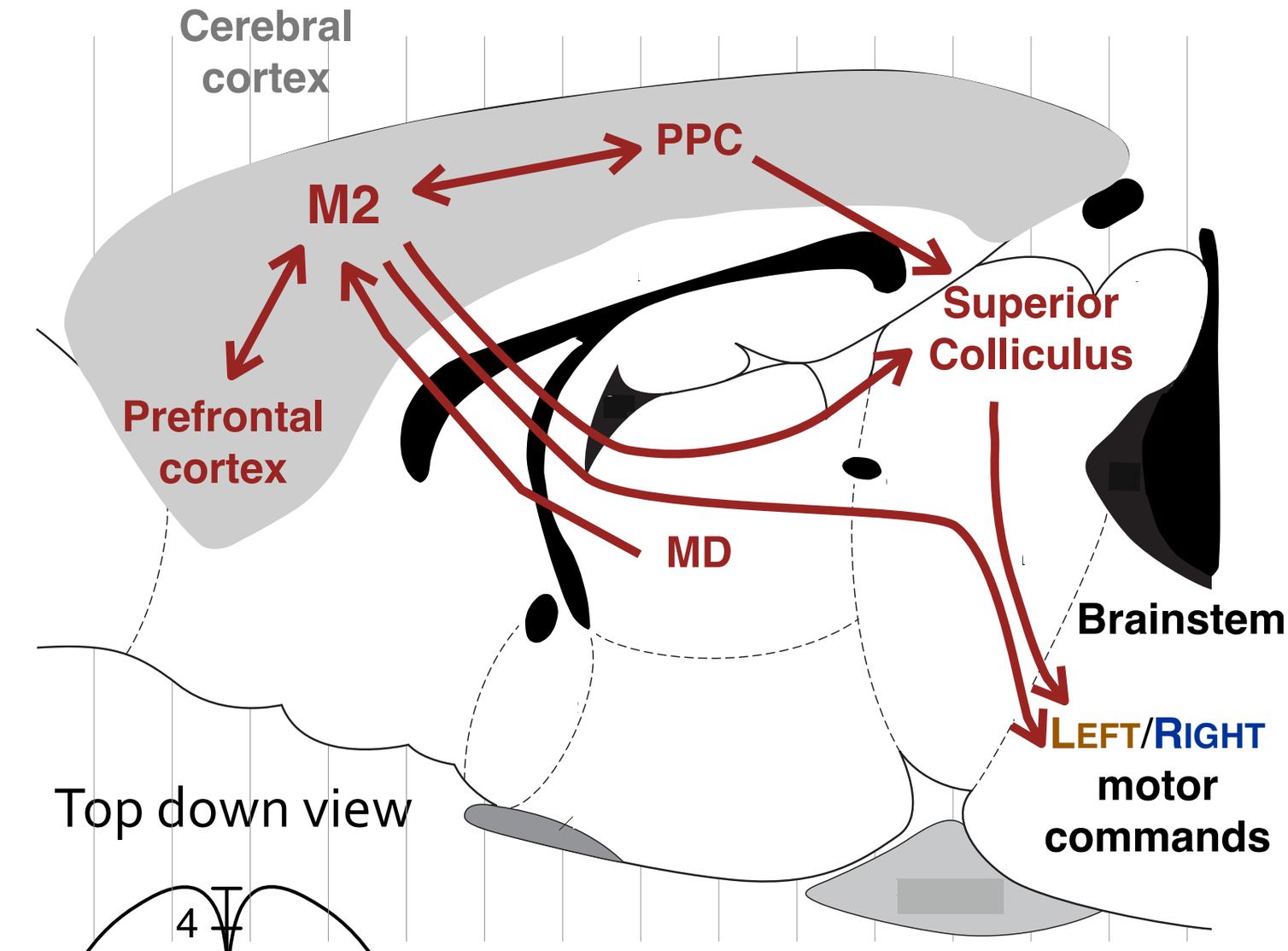

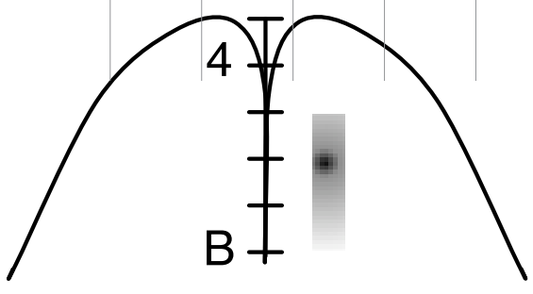

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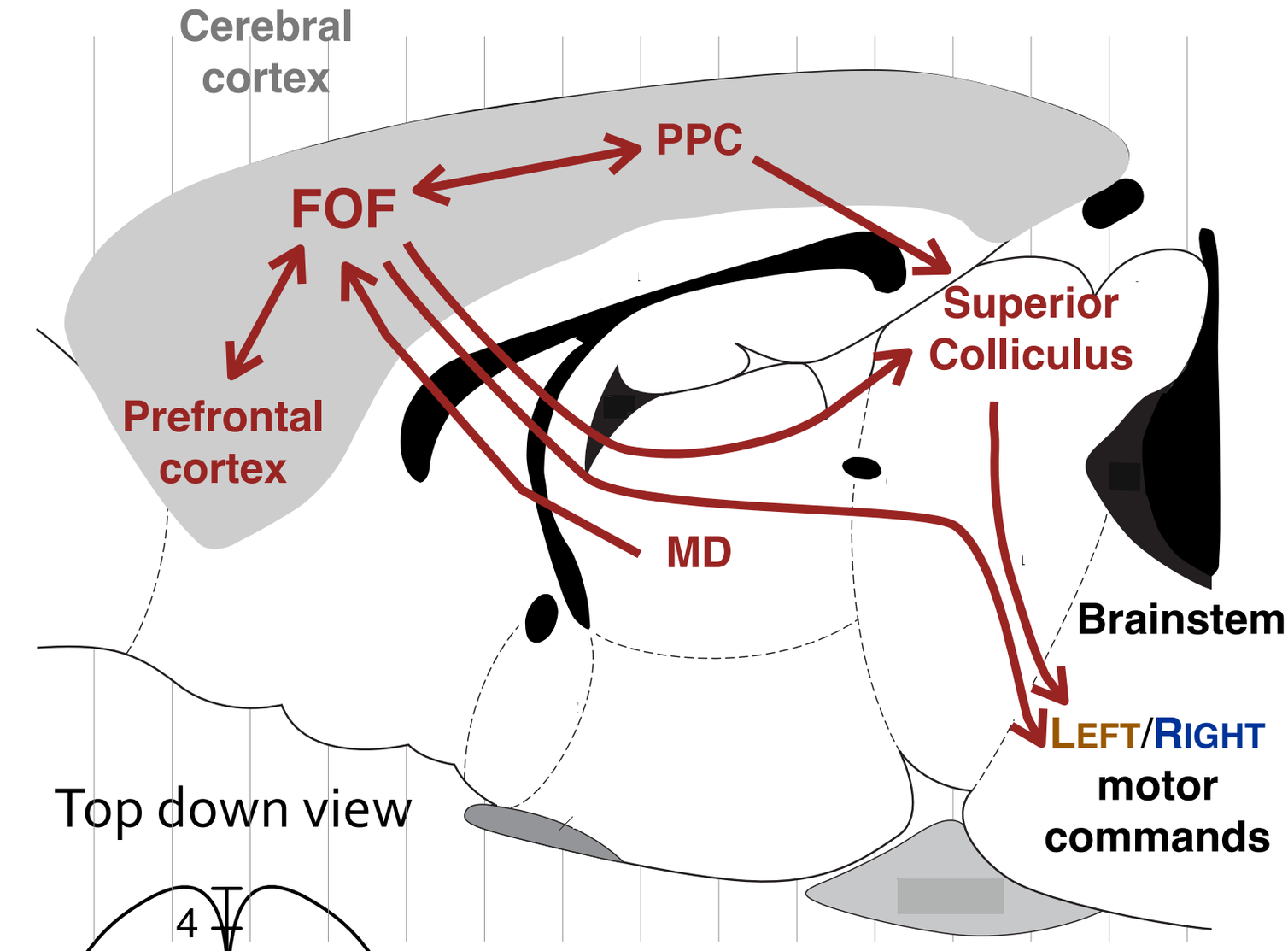

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Leonard, 1969

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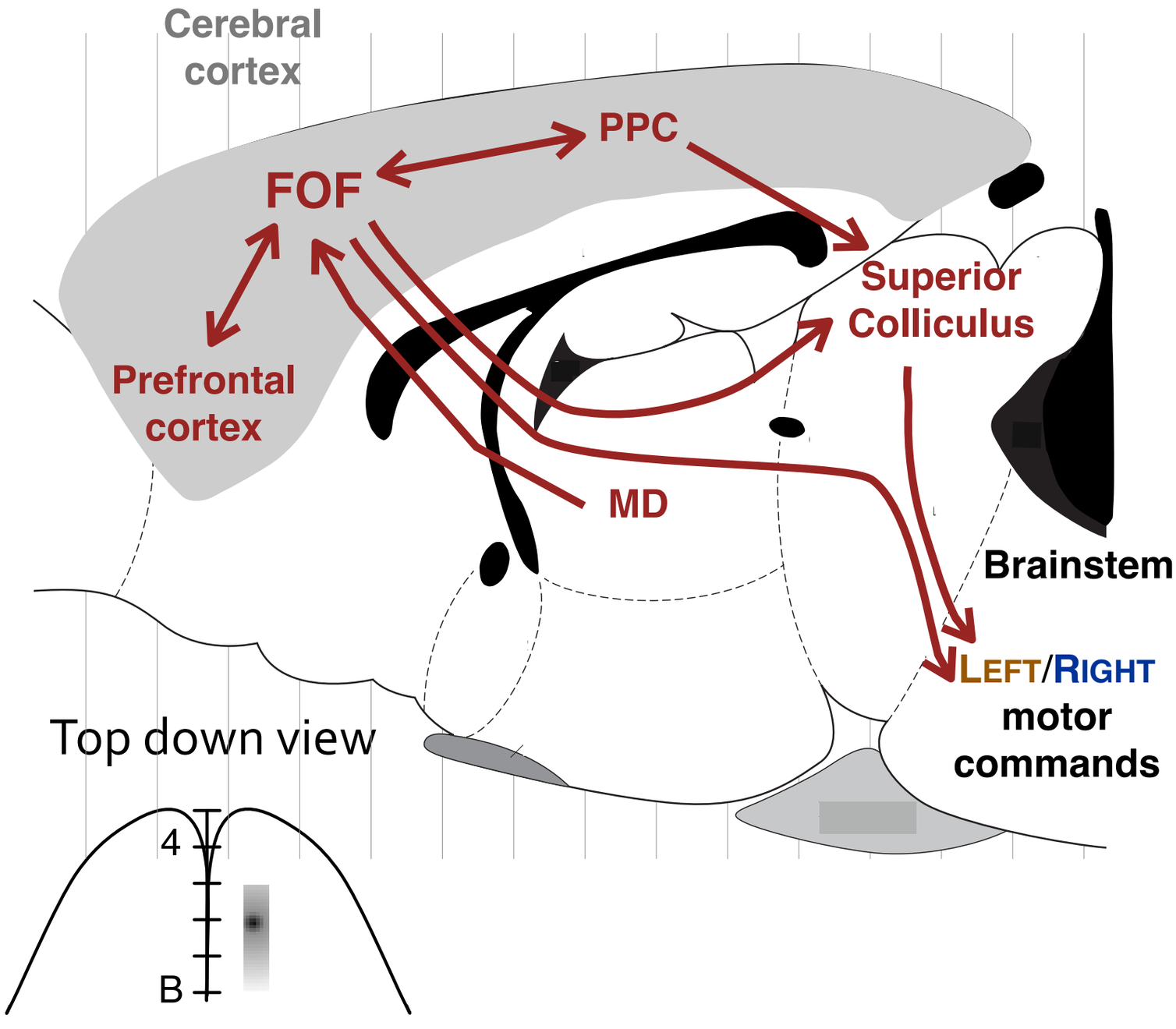


- Stimulation of FOF results in contralateral orienting movements (Sinnamon, 1984)
- Large lesions of cortex encompassing FOF results in impairments consistent with contralateral neglect (Cowey & Bozek, 1974; Crowne & Pathria, 1982)
- **No pharmacology, almost no recording!!!!!!** (1 book chapter, no papers)

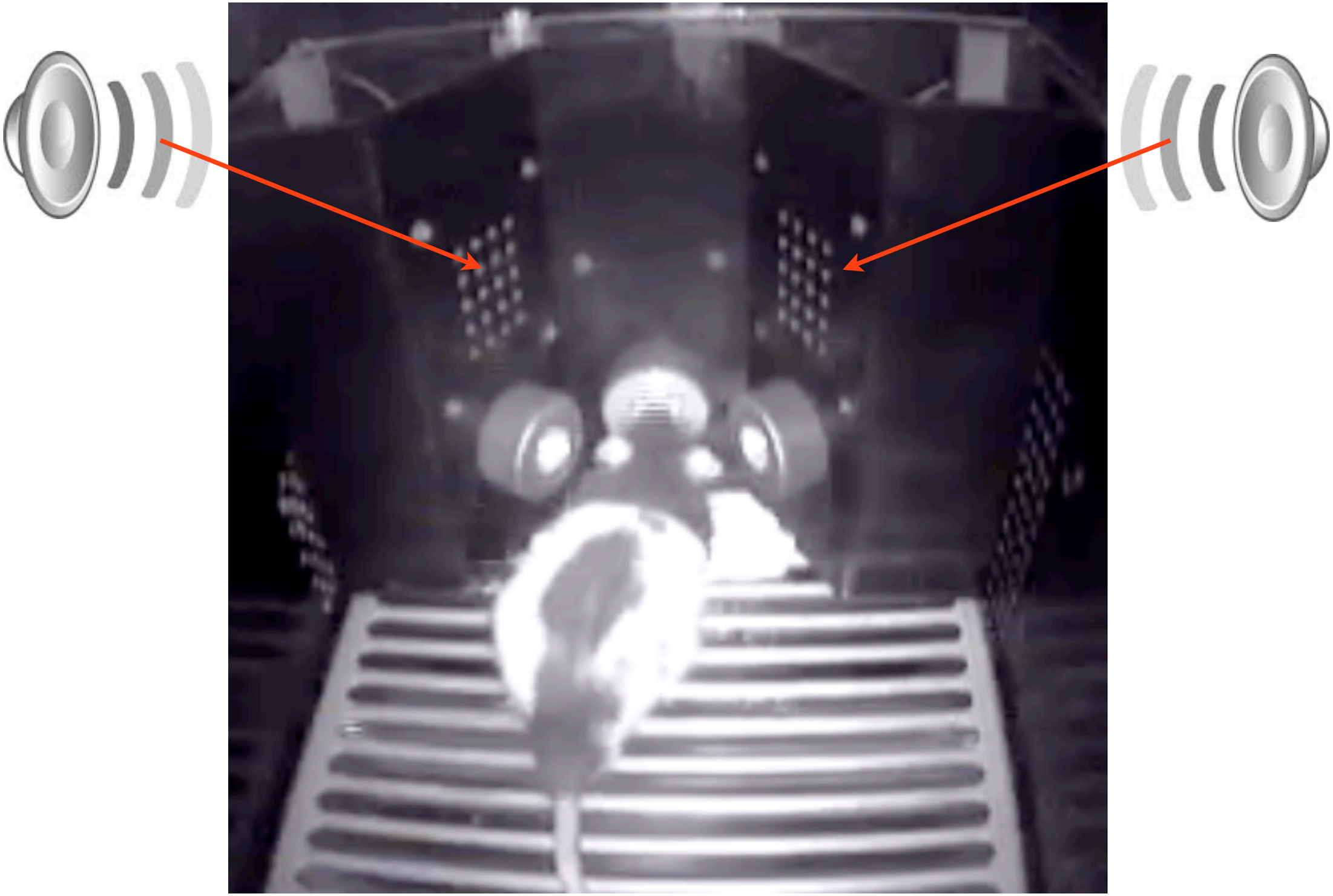
Leonard, 1969

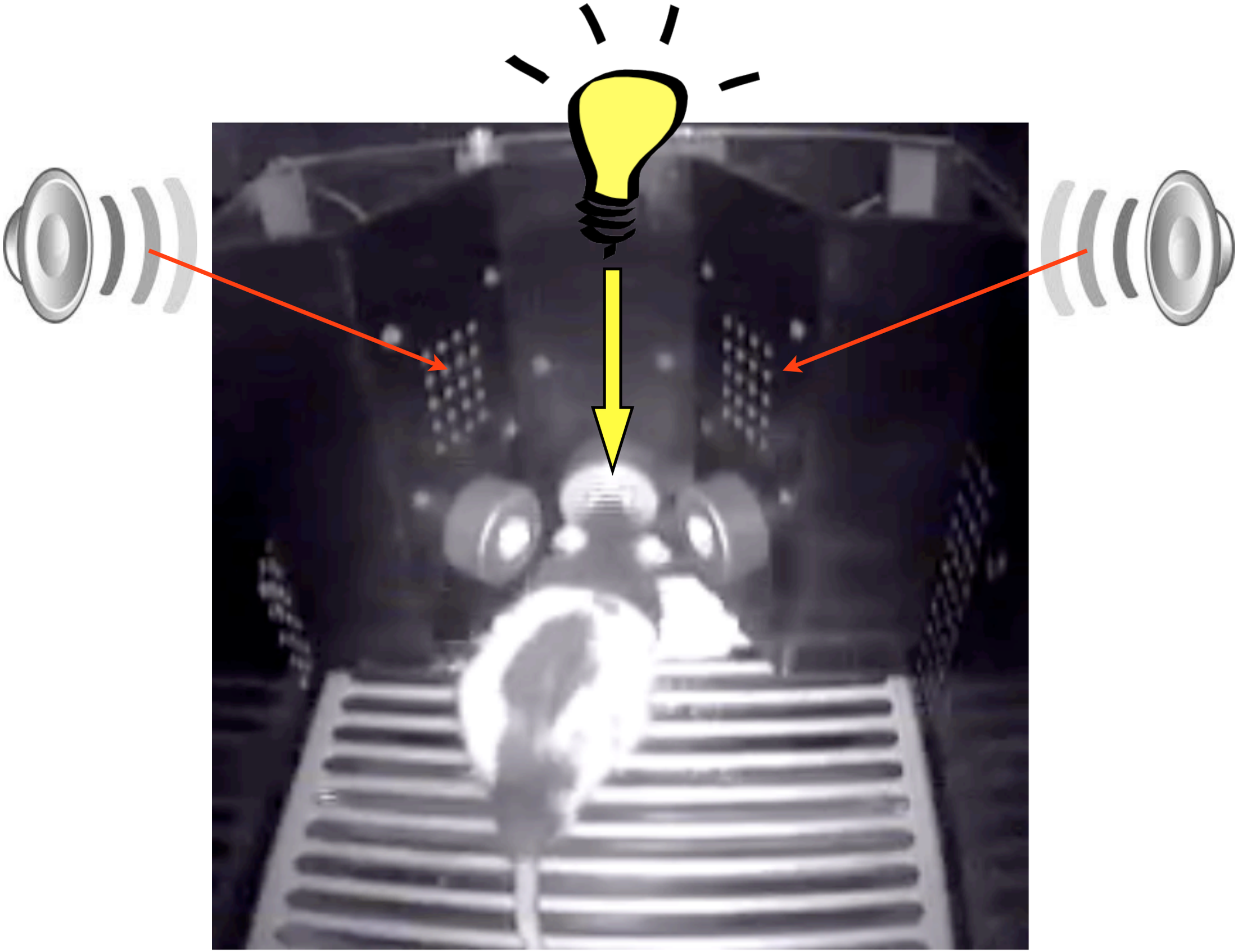
What is the role of the rat
Frontal Orienting Field
in memory-guided orienting??

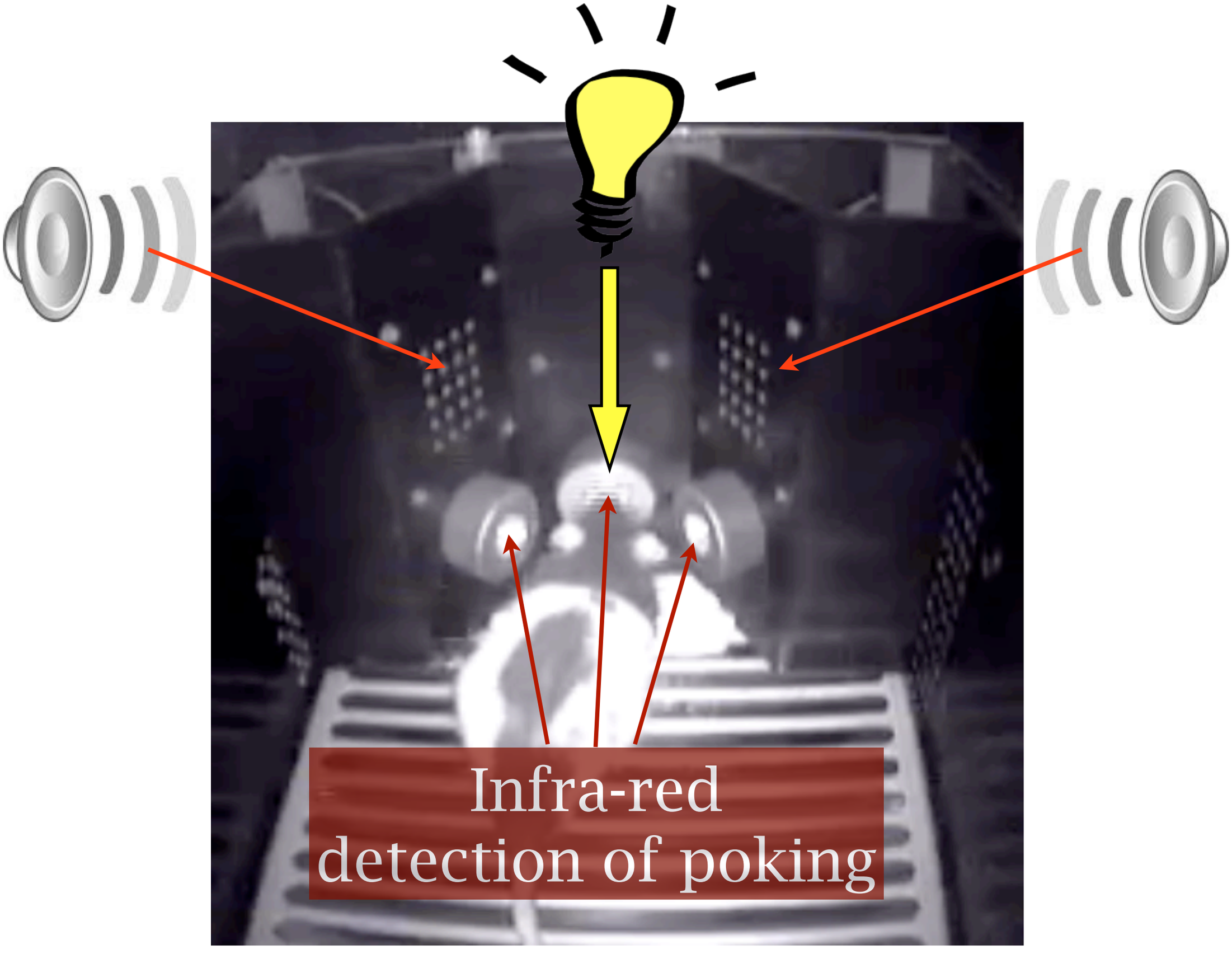
- Behavior: Memory-Guided Orienting
- Muscimol inactivation of FOF
- Tetrode recording of single units in FOF
- Conclusion: FOF is an essential part of the neural circuit for movement planning

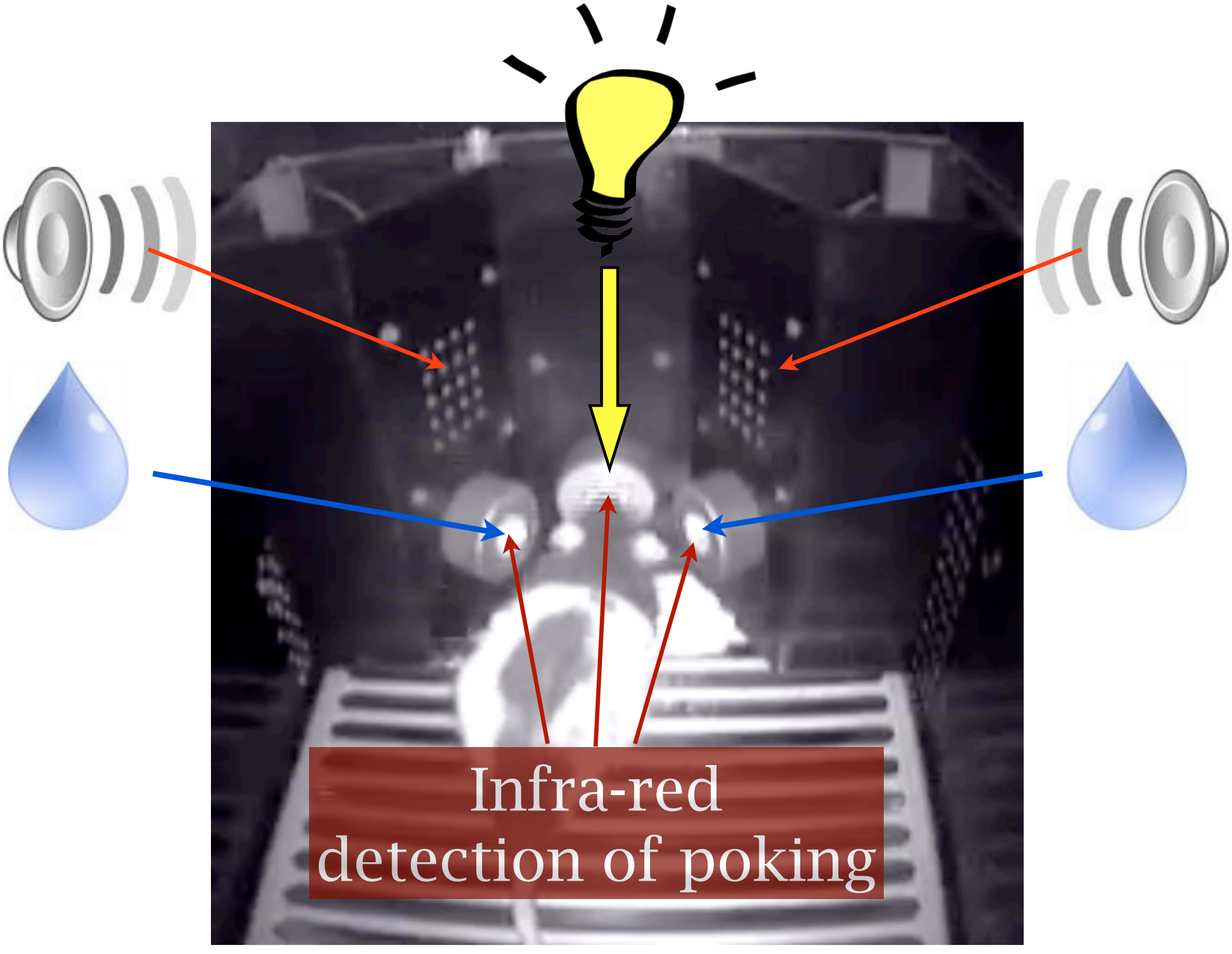
in prep

The Training Room






Infra-red
detection of poking


Infra-red
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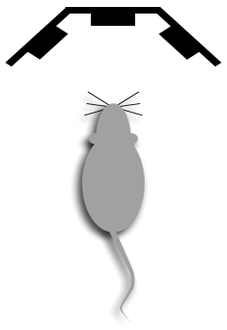
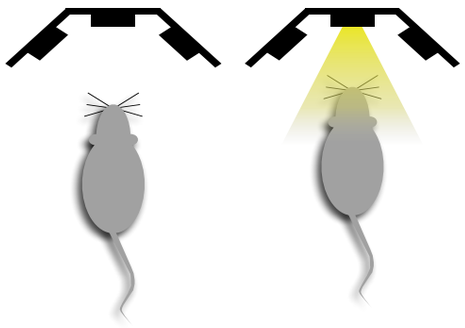
Memory-Guided Orienting

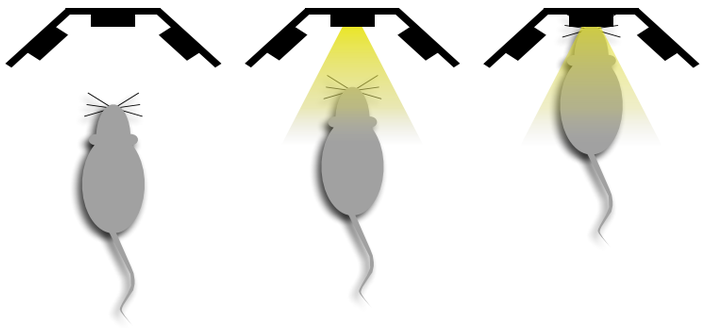


Memory-Guided Orienting



Center LED on

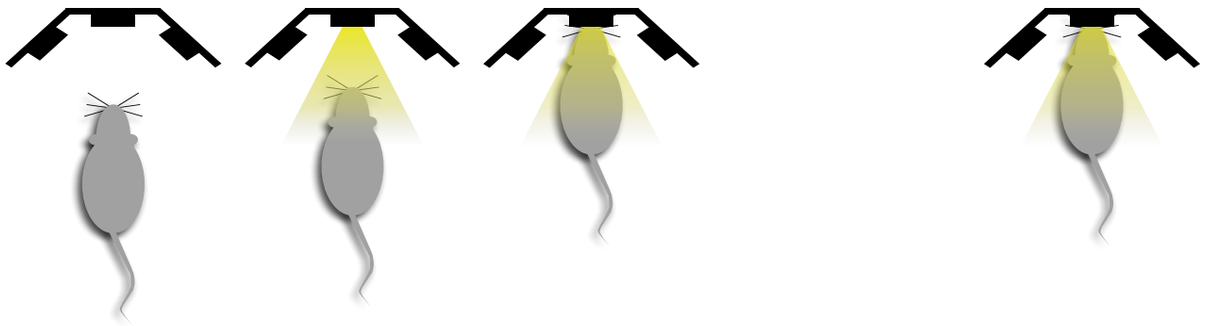
Memory-Guided Orienting

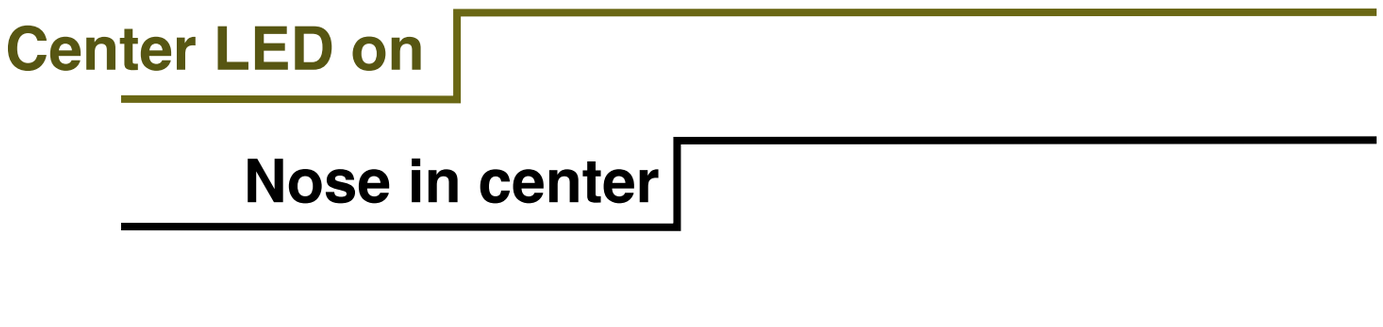


Center LED on

Nose in center

Memory-Guided Orienting





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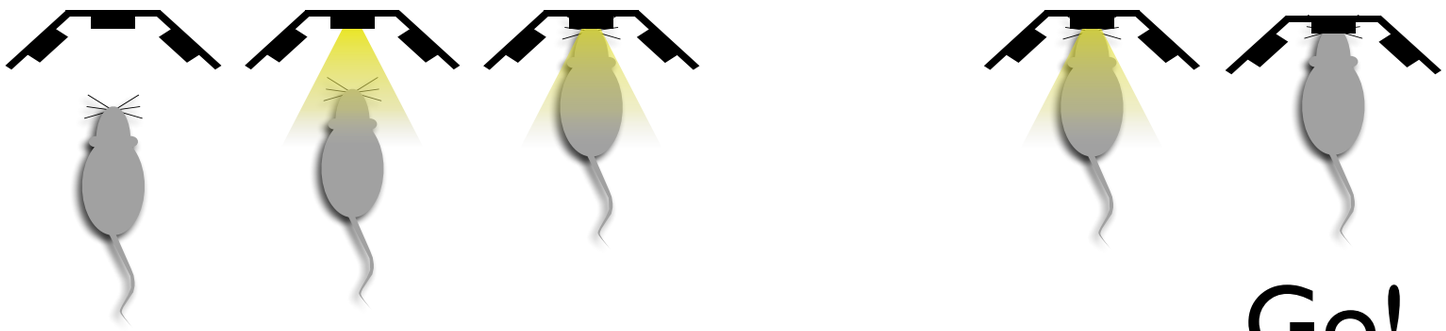

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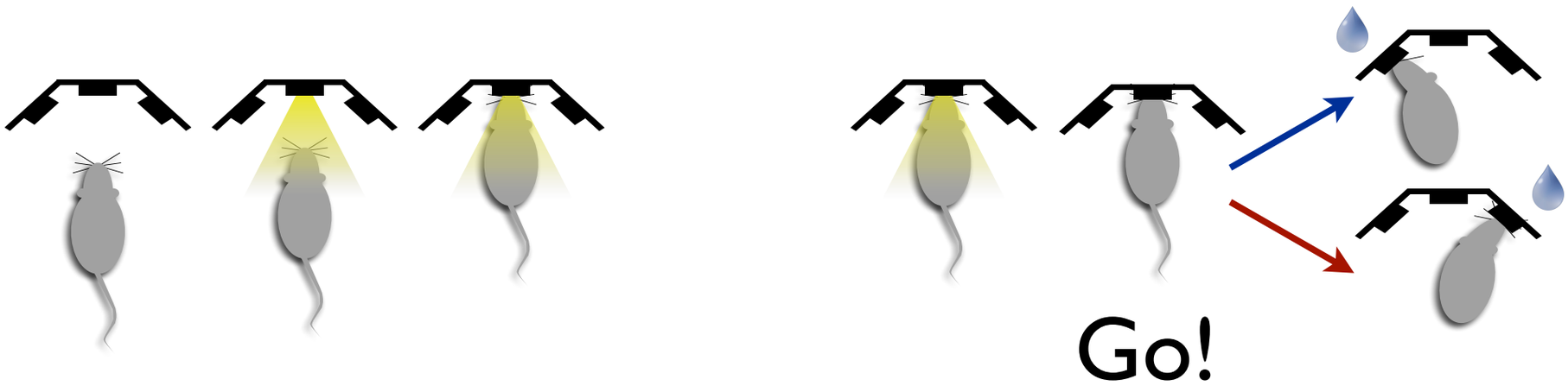

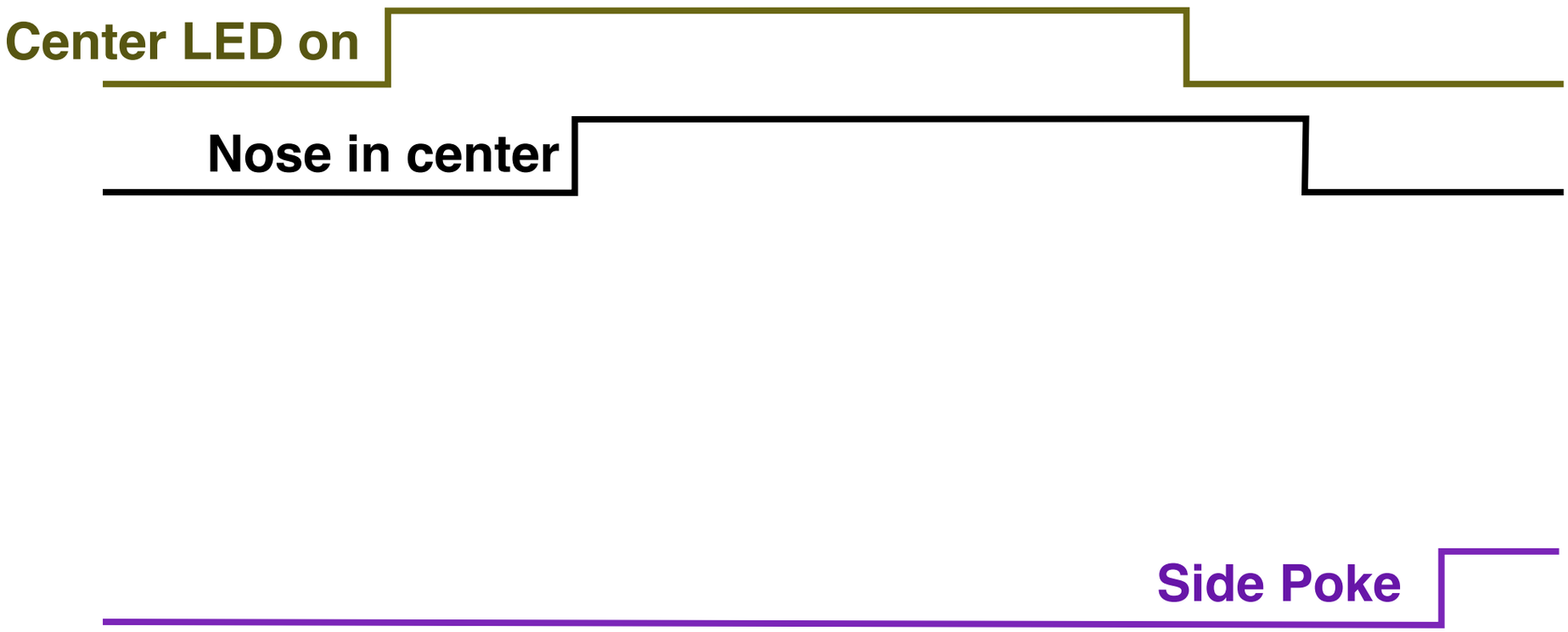

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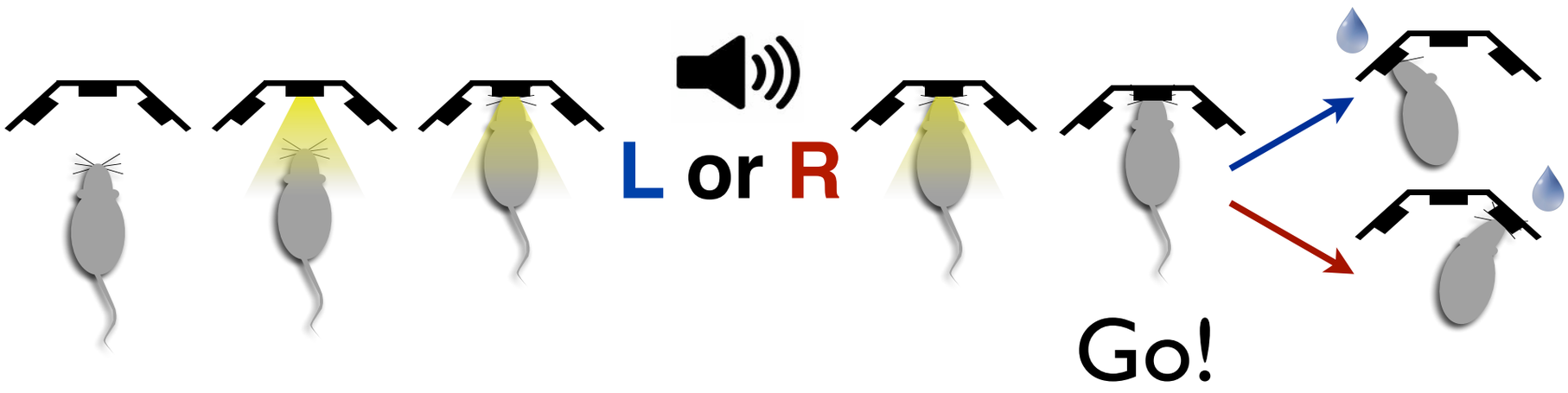

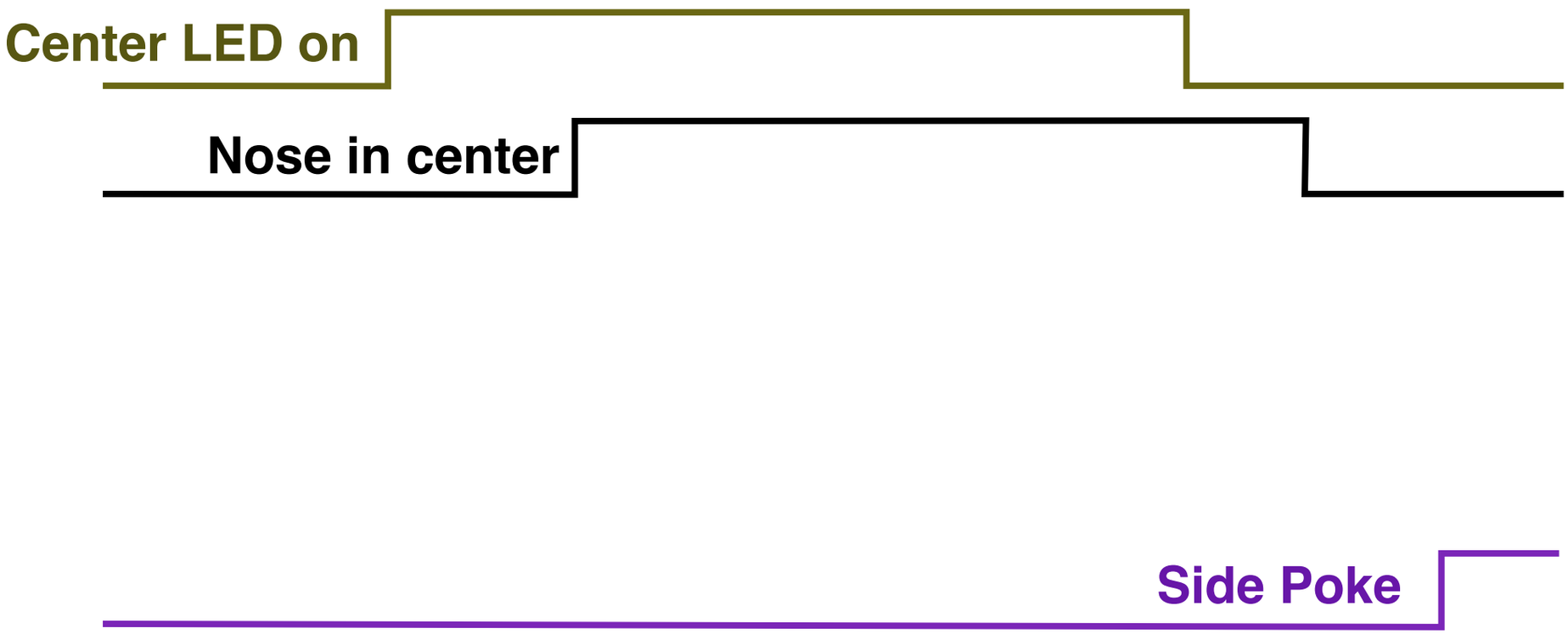

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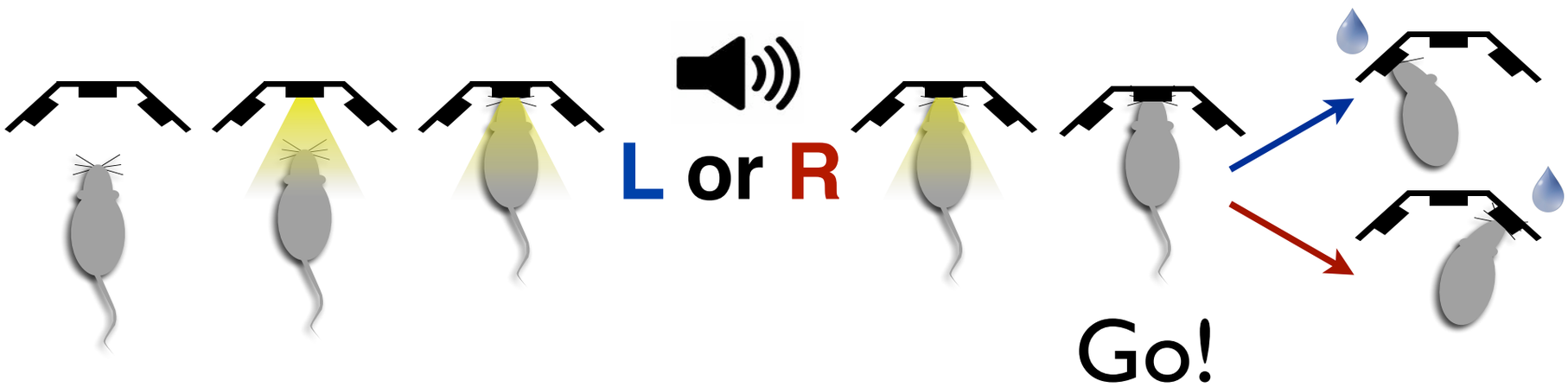
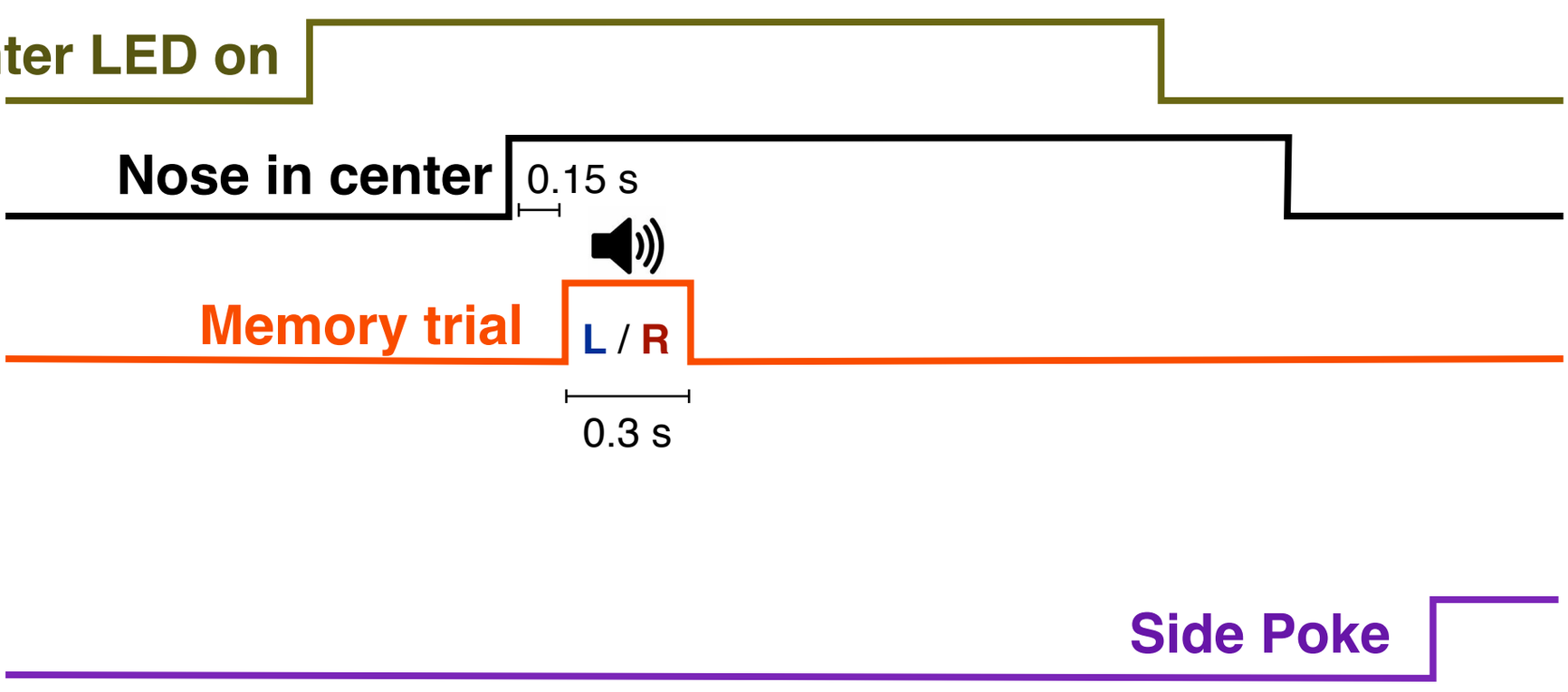
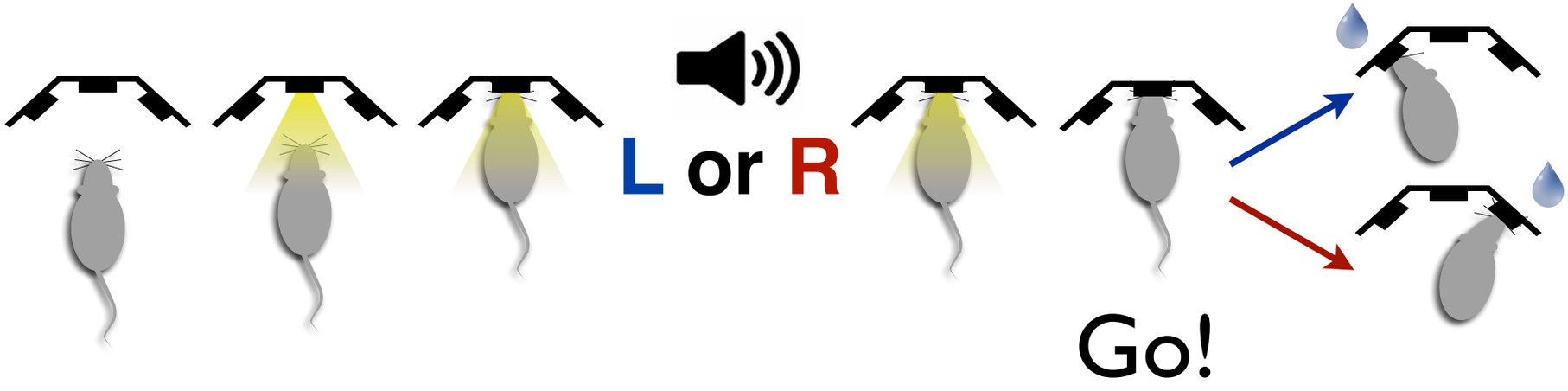
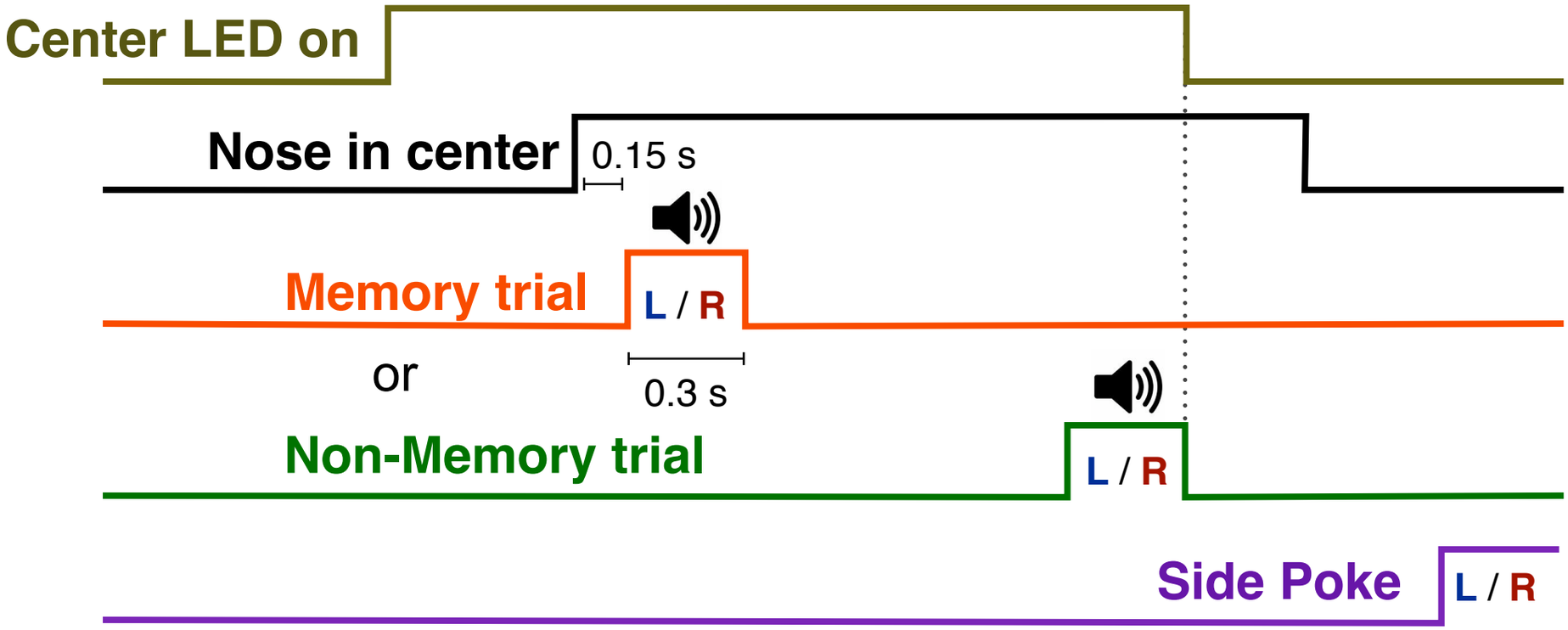




Memory-Guided Orienting





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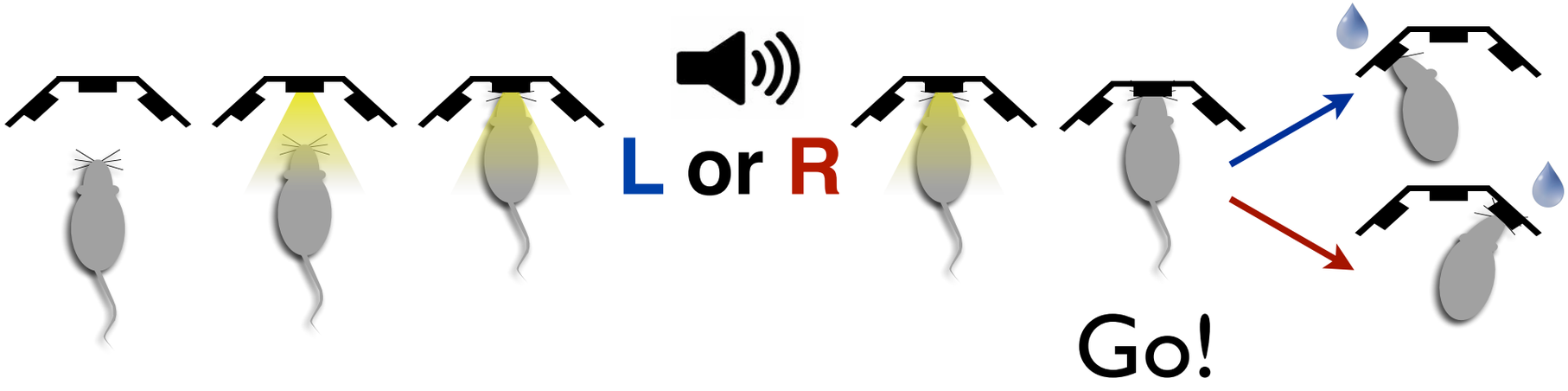
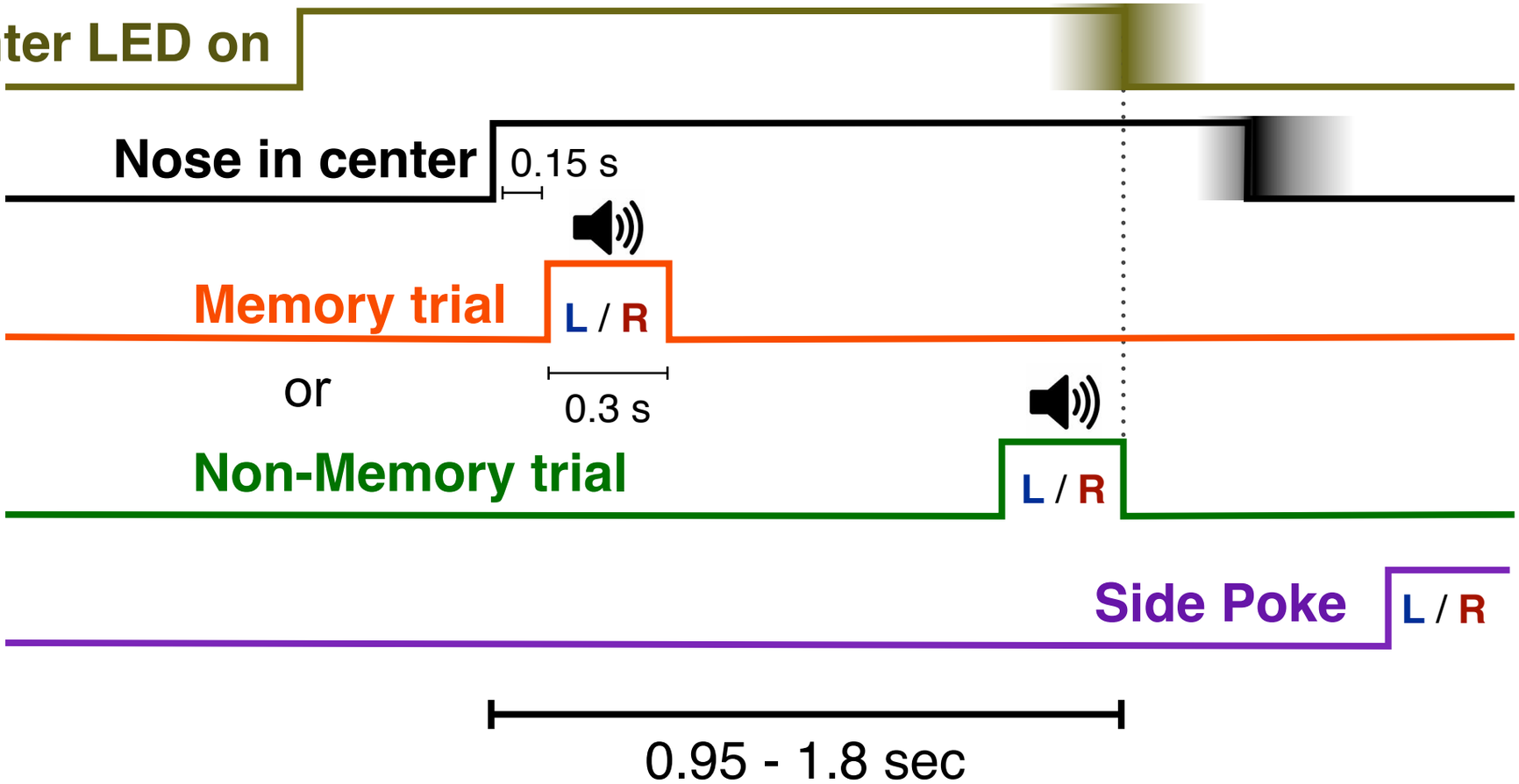
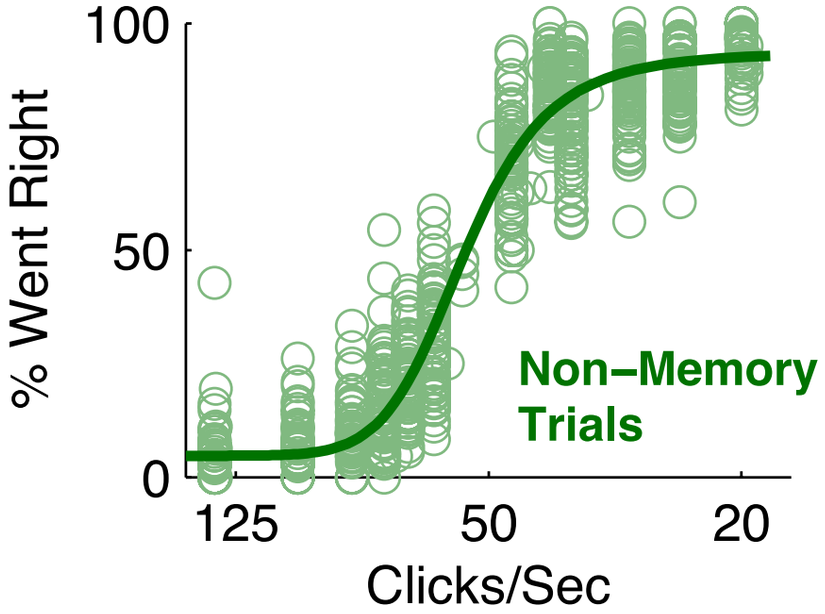




Mem and Non-mem trials are randomly interleaved

Click Frequency Discrimination

138 Sessions from a single rat



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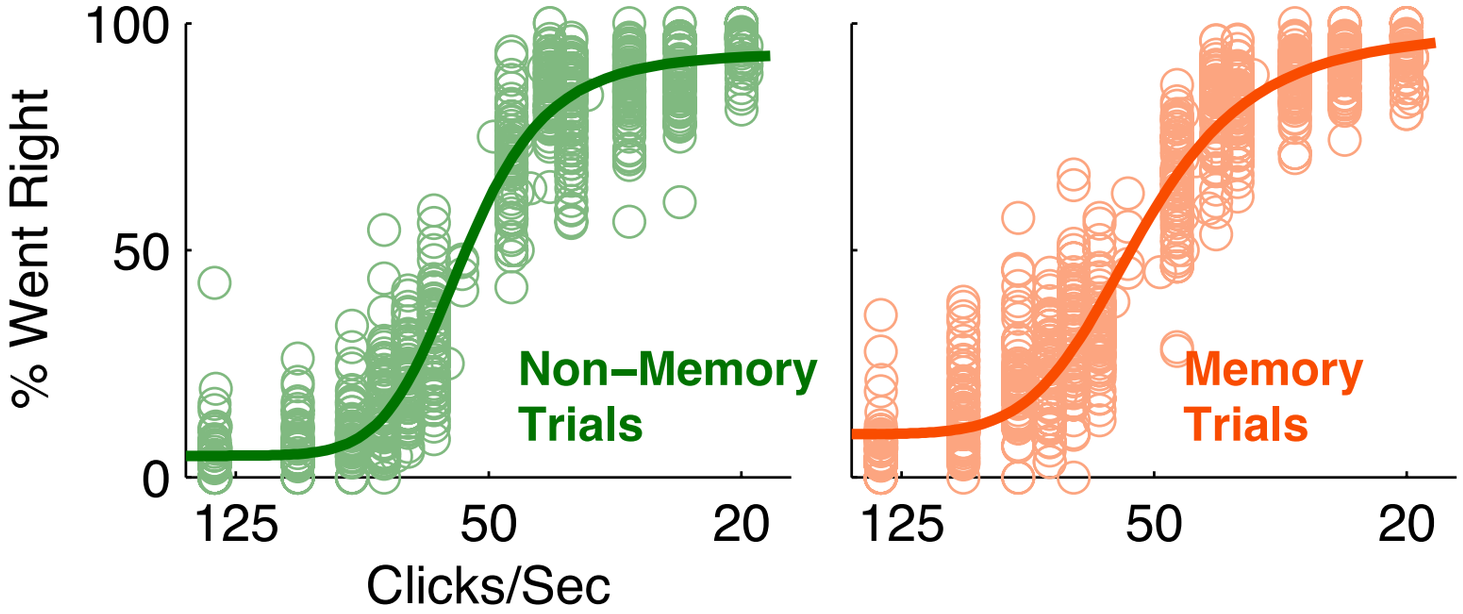
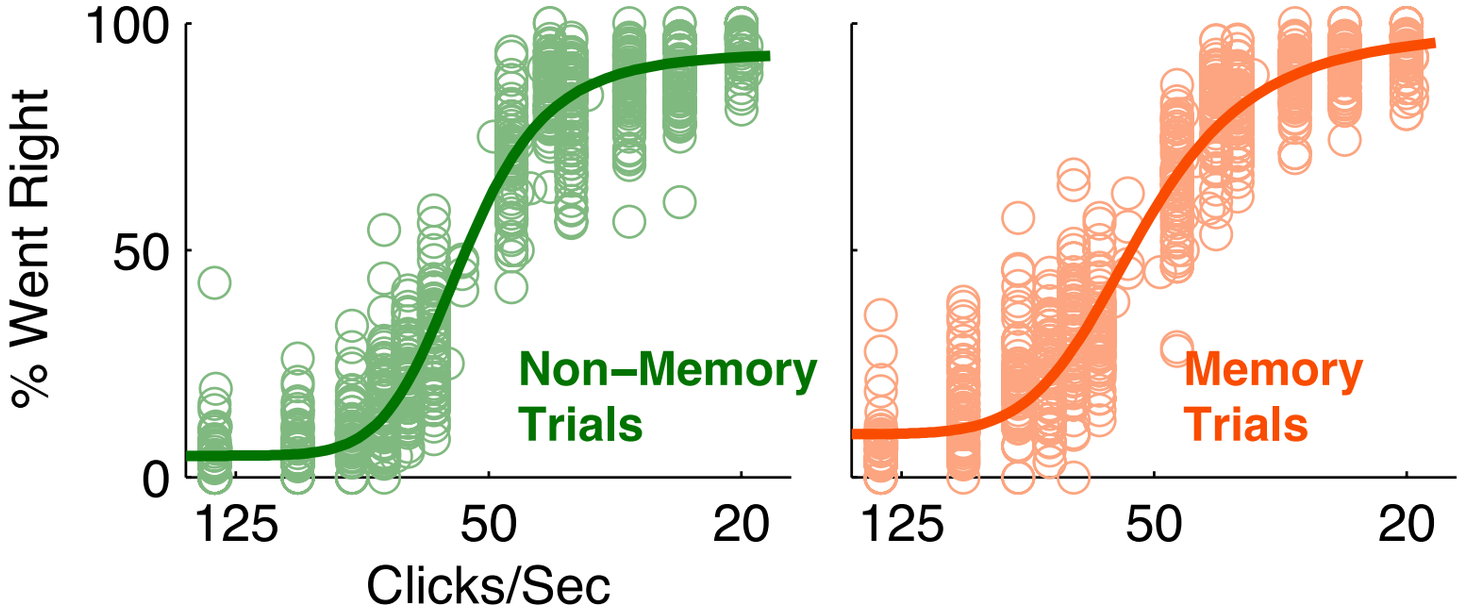


Each circle is data from one session

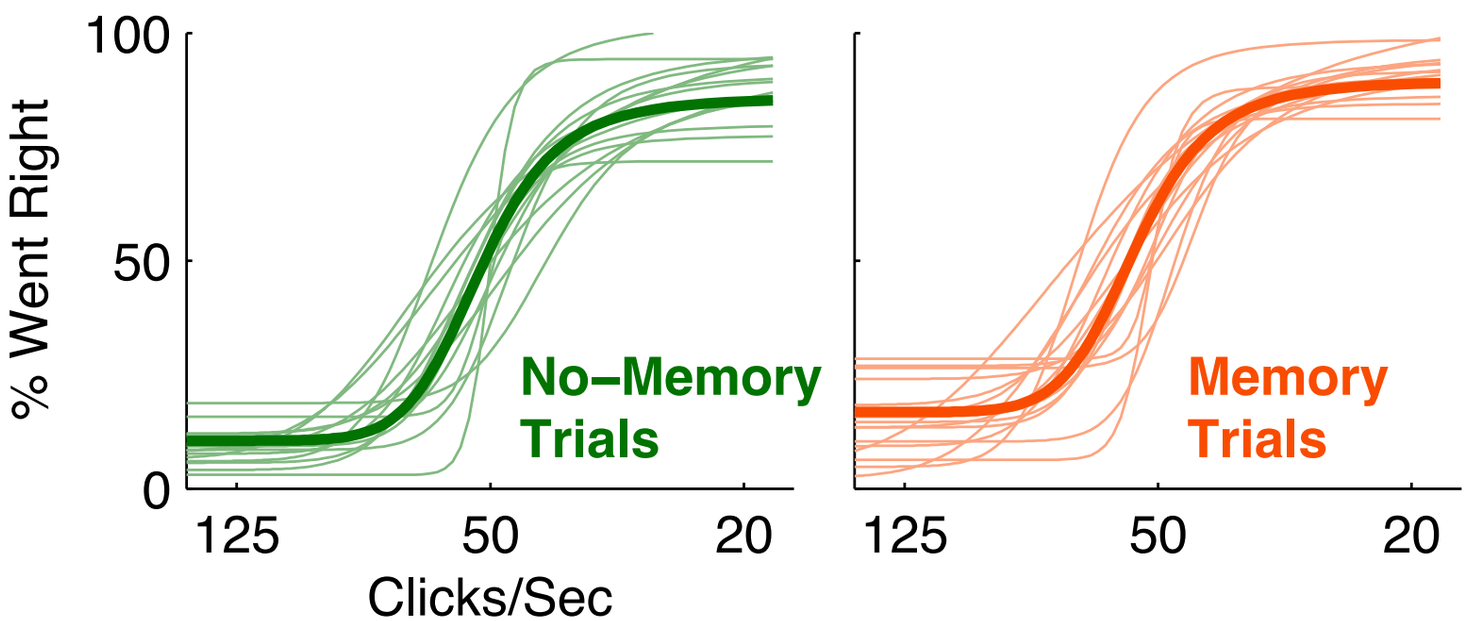
Click Frequency Discrimination

138 Sessions from a single rat



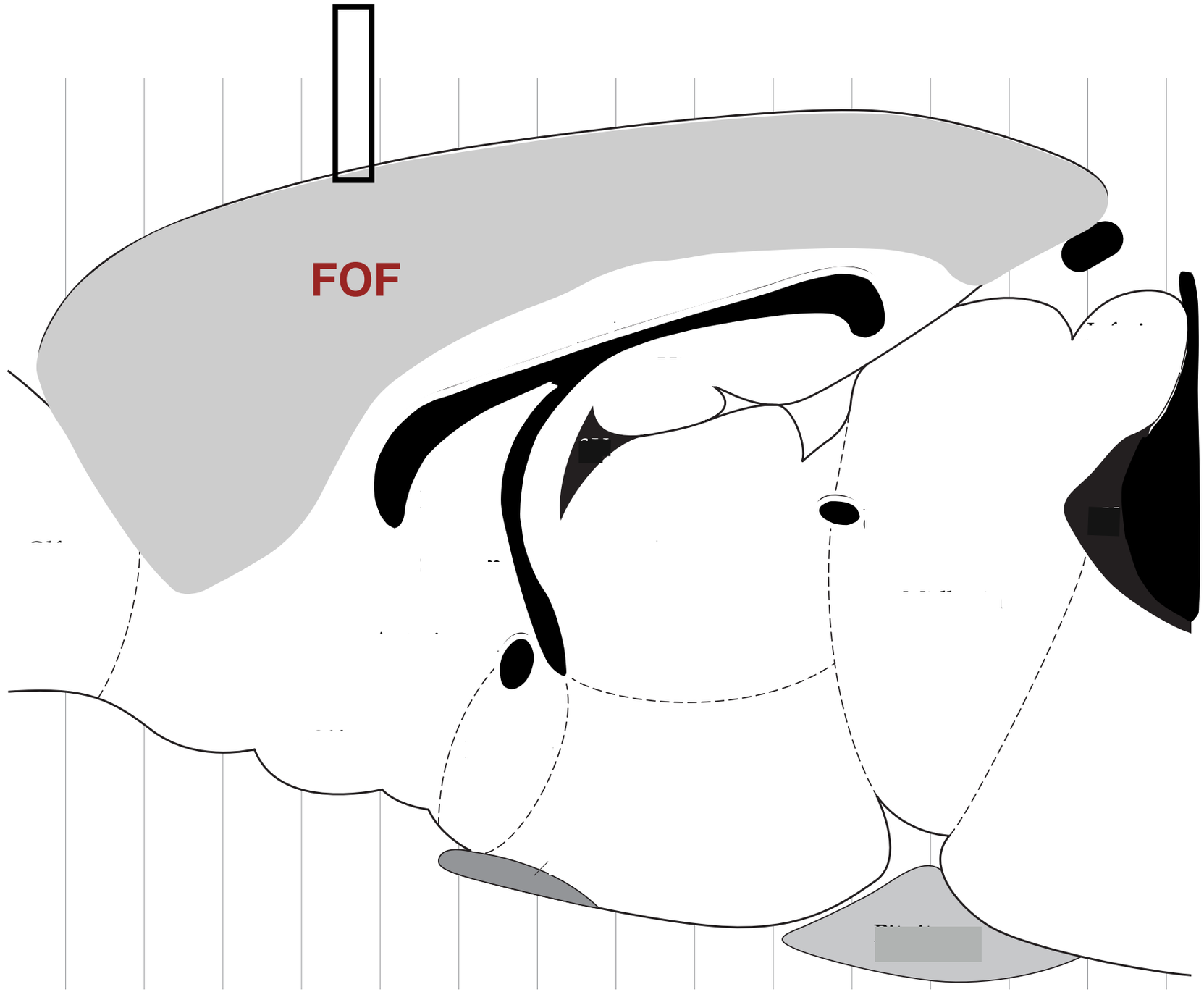
Each circle is data from one session

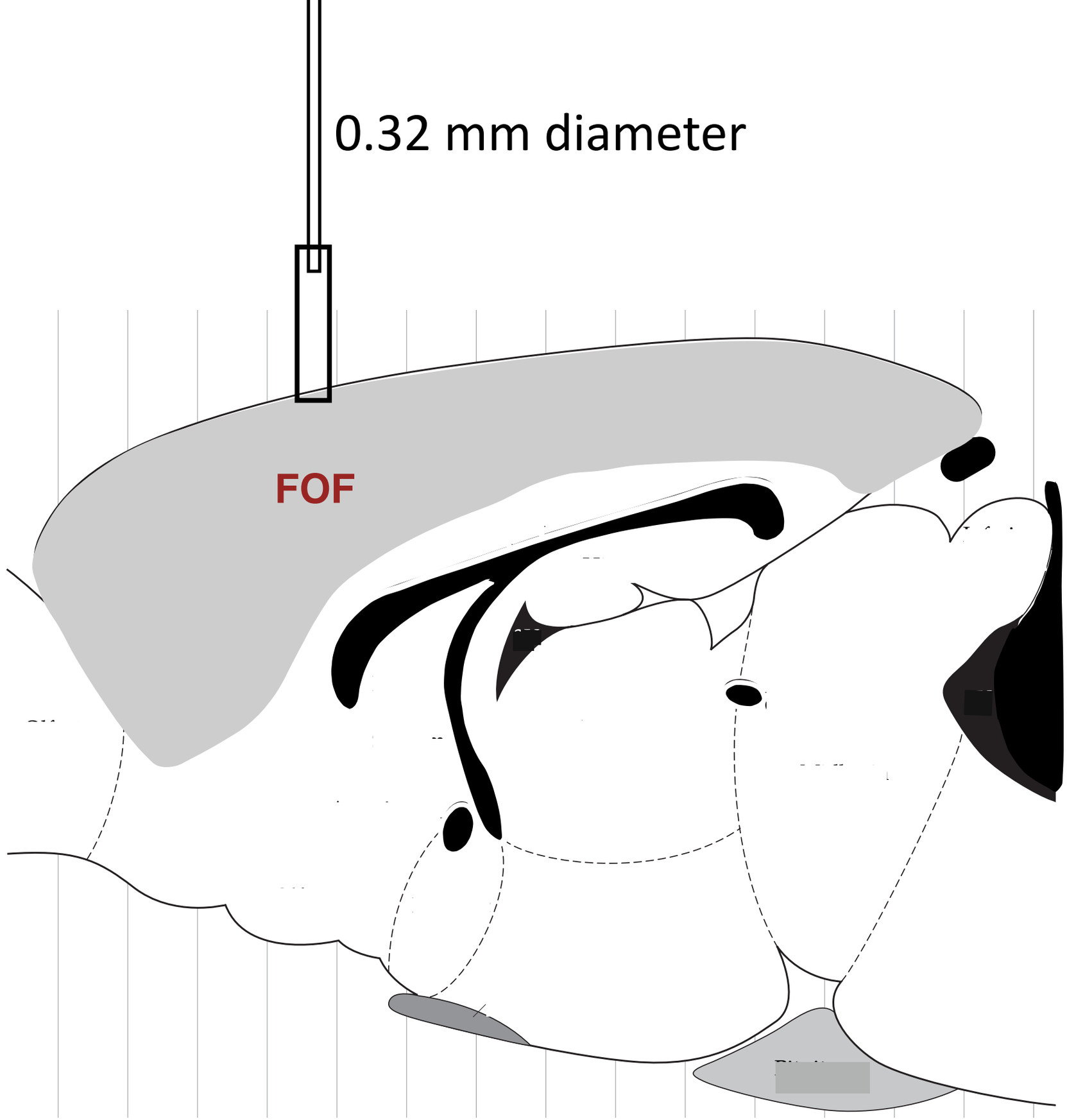
Population Summary - 20 rats

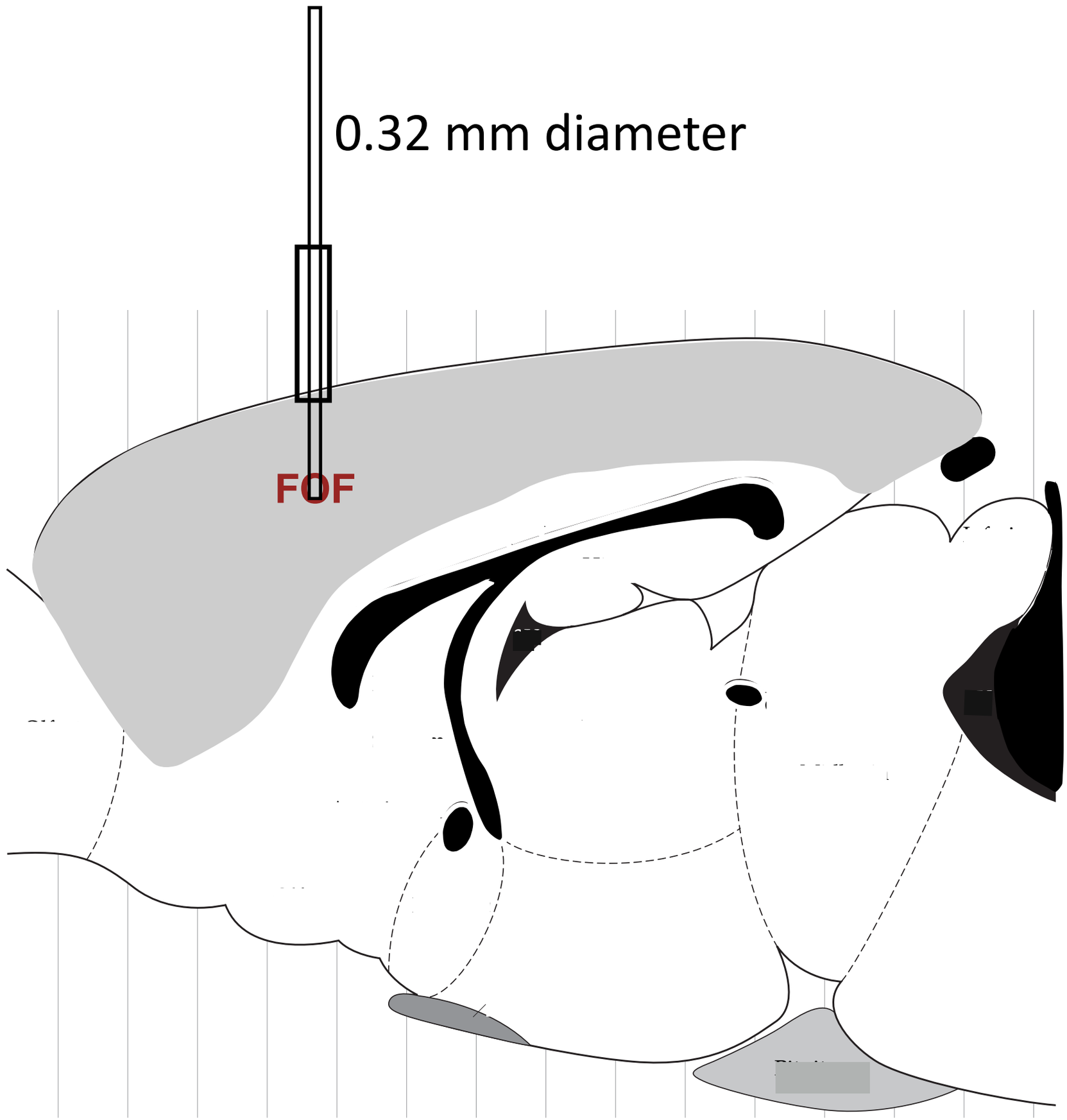


Each thin line is one rat's performance
Thick line is the mean across rats

Inactivation of FOF with muscimol




0.32 mm diameter
FOF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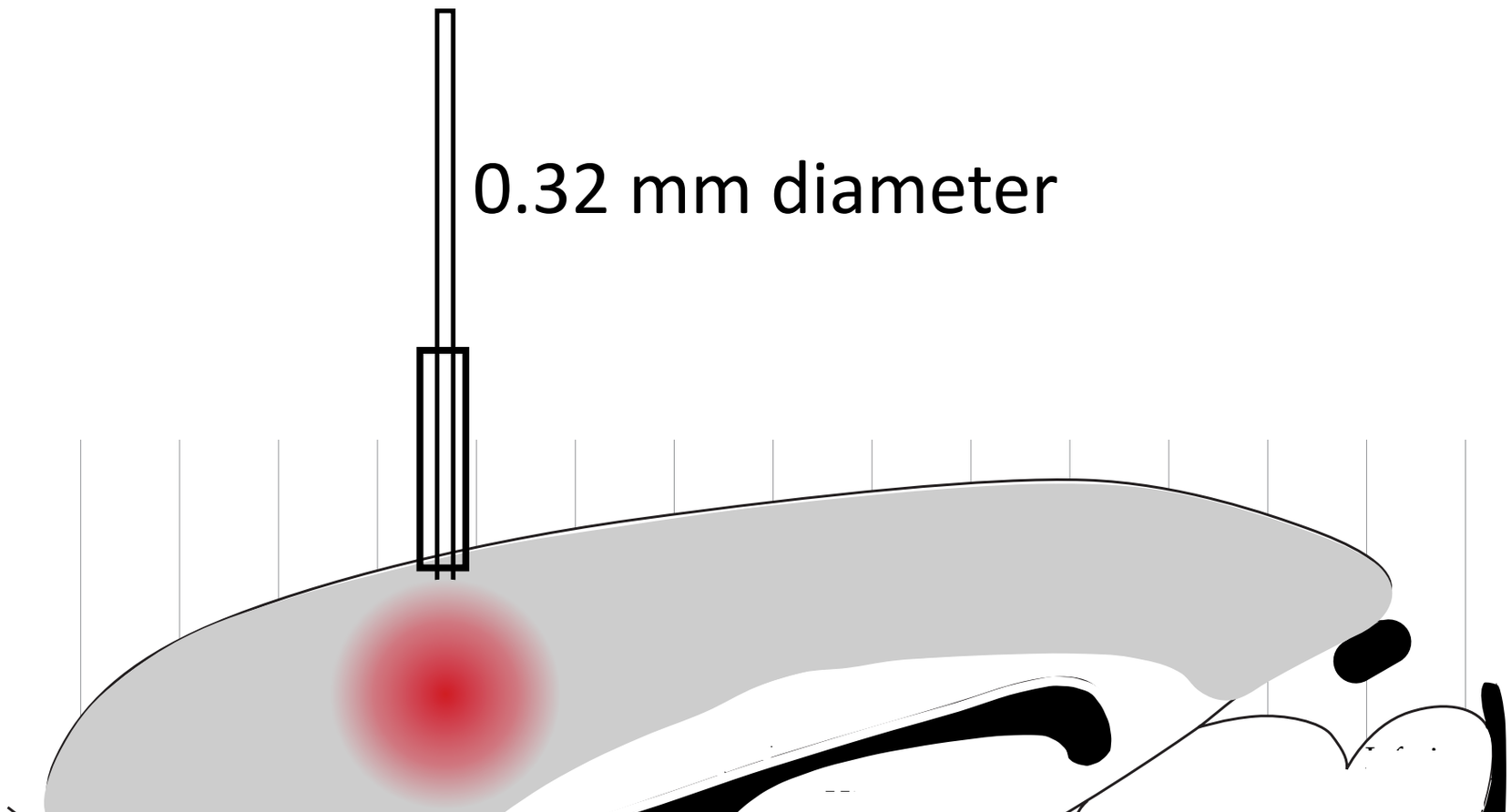
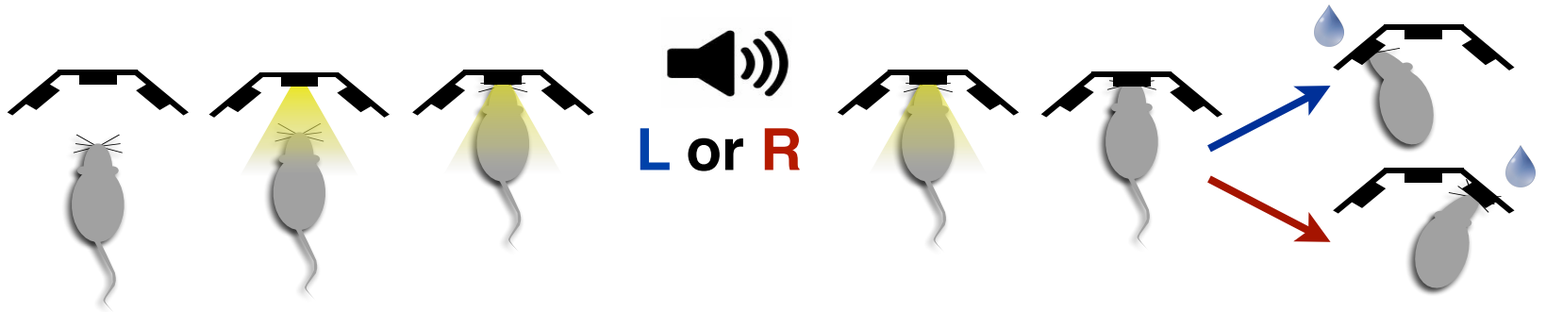
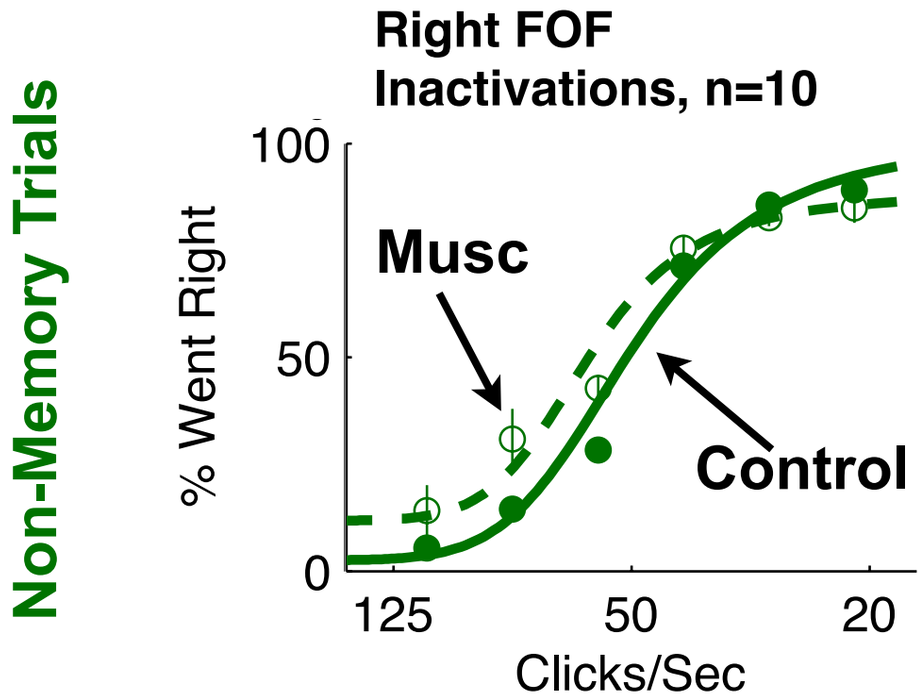


Slowly Infuse 300 nL
of 0.5mg/mL muscimol, a GABA-A agonist

Inactivation of FOF with muscimol





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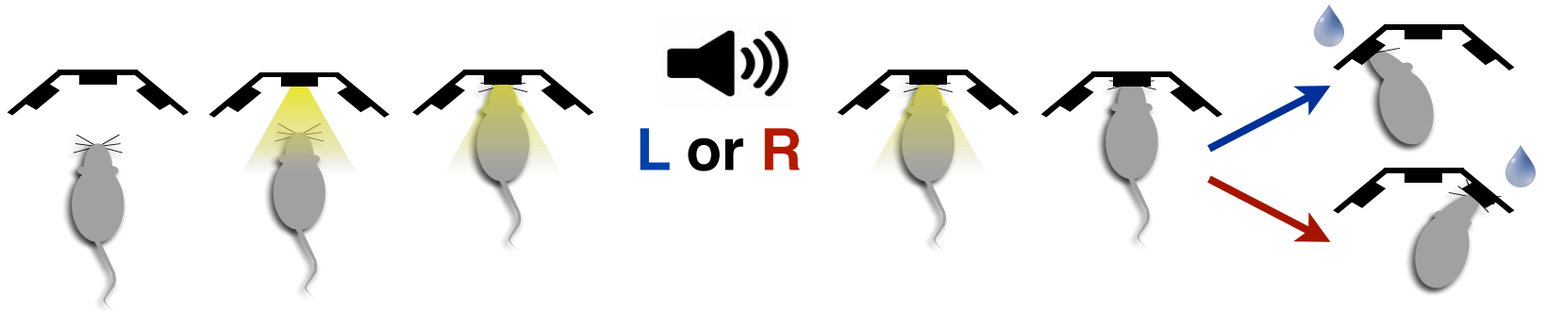
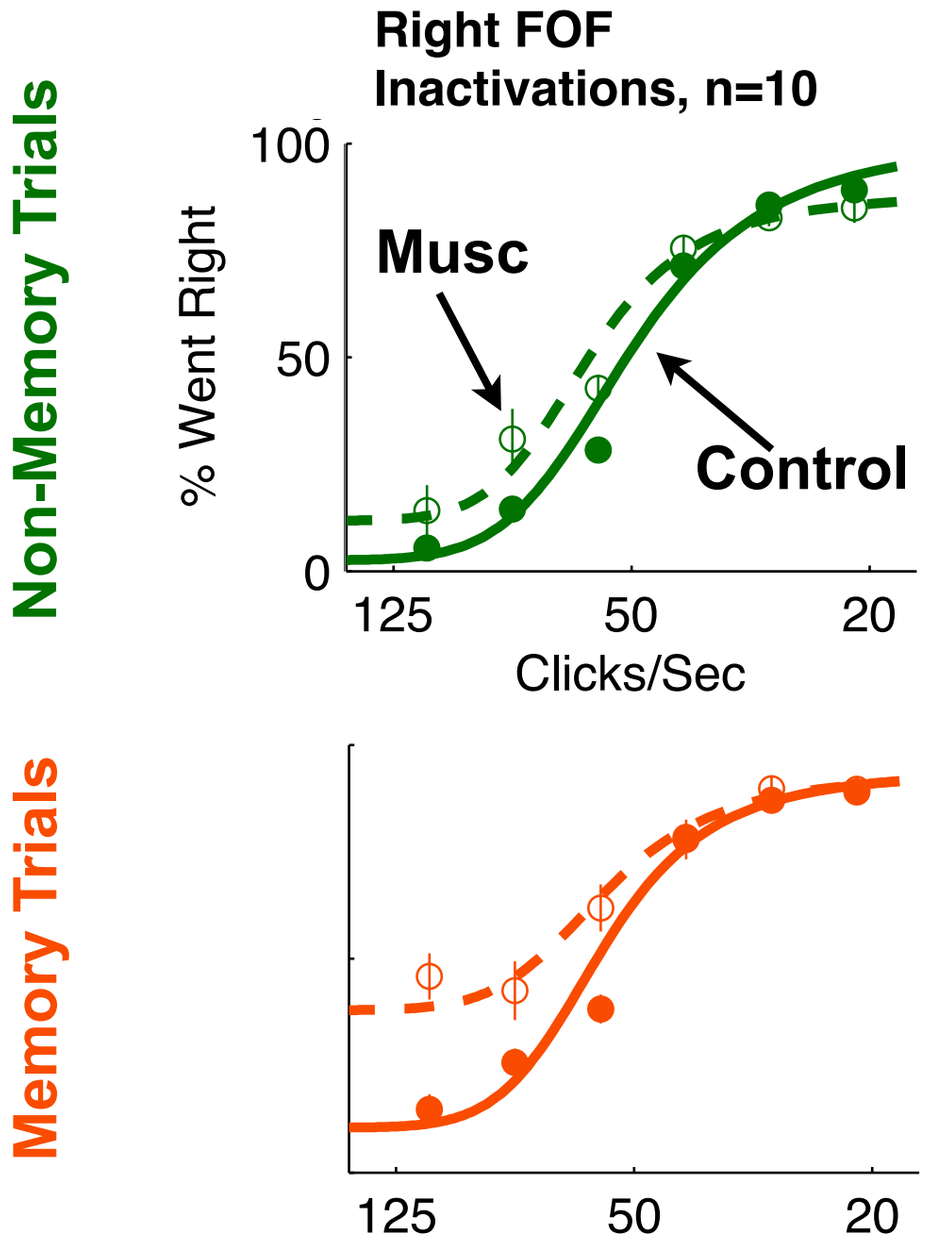
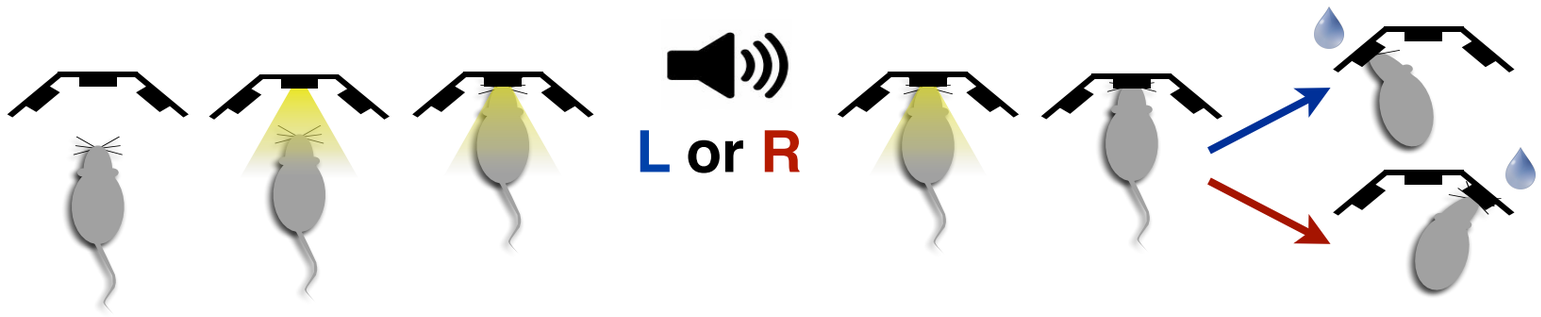




Inactivation of FOF with muscimol

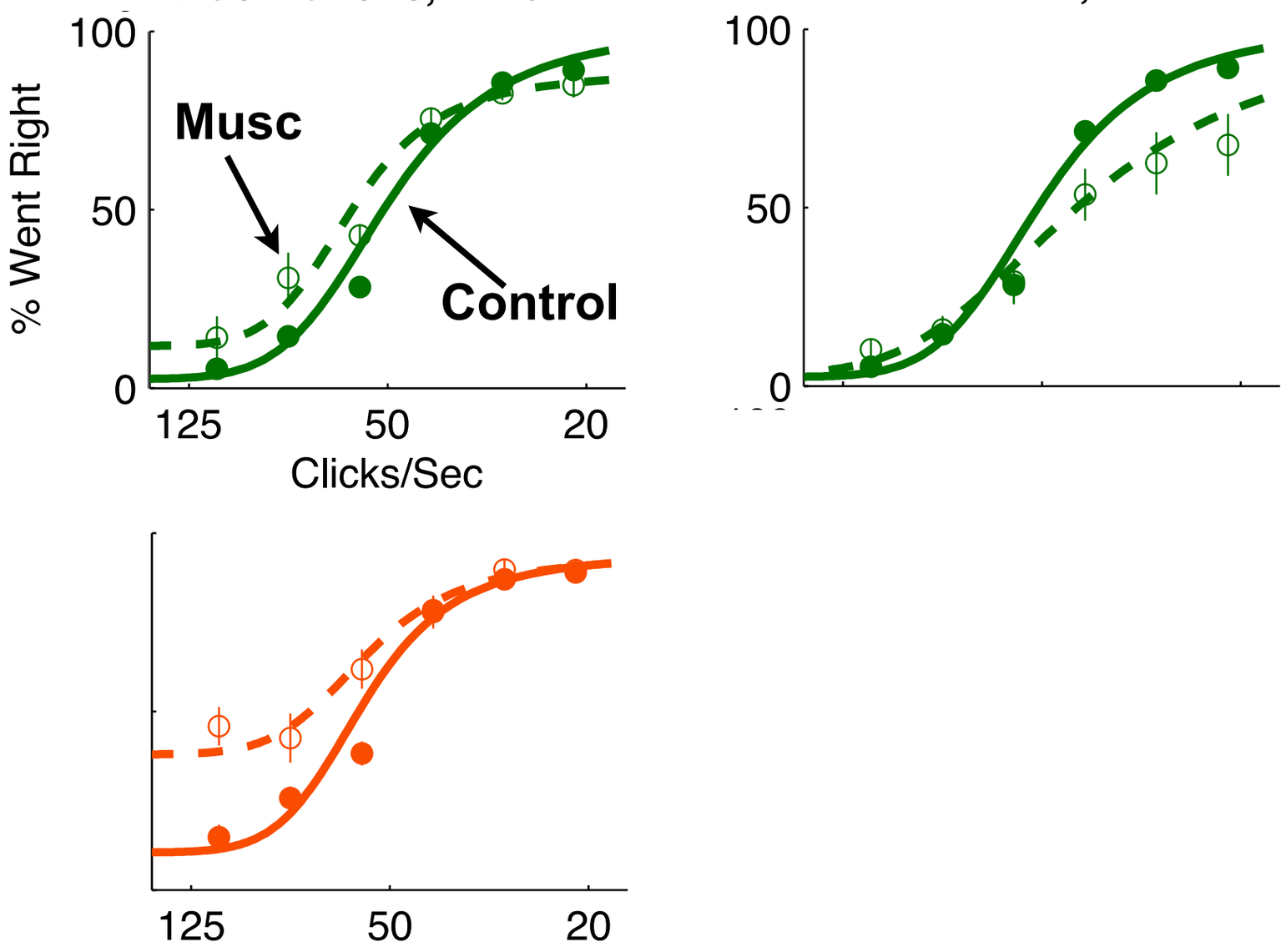


Right FOF
Inactivations, n=10

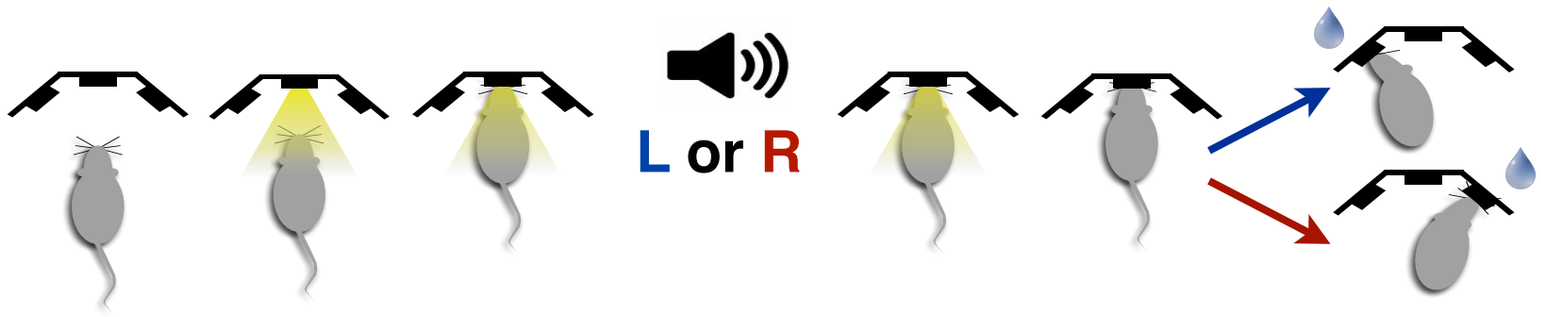
Left FOF
Inactivations, n=10

Non-Memory Trials

Memory Trials



Inactivation of FOF with muscimol



Right FOF
Inactivations, n=10

Left FOF
Inactivations, n=10

Non-Memory Trials

Memory Trials

% Went Right

100

50

0

Musc

Control

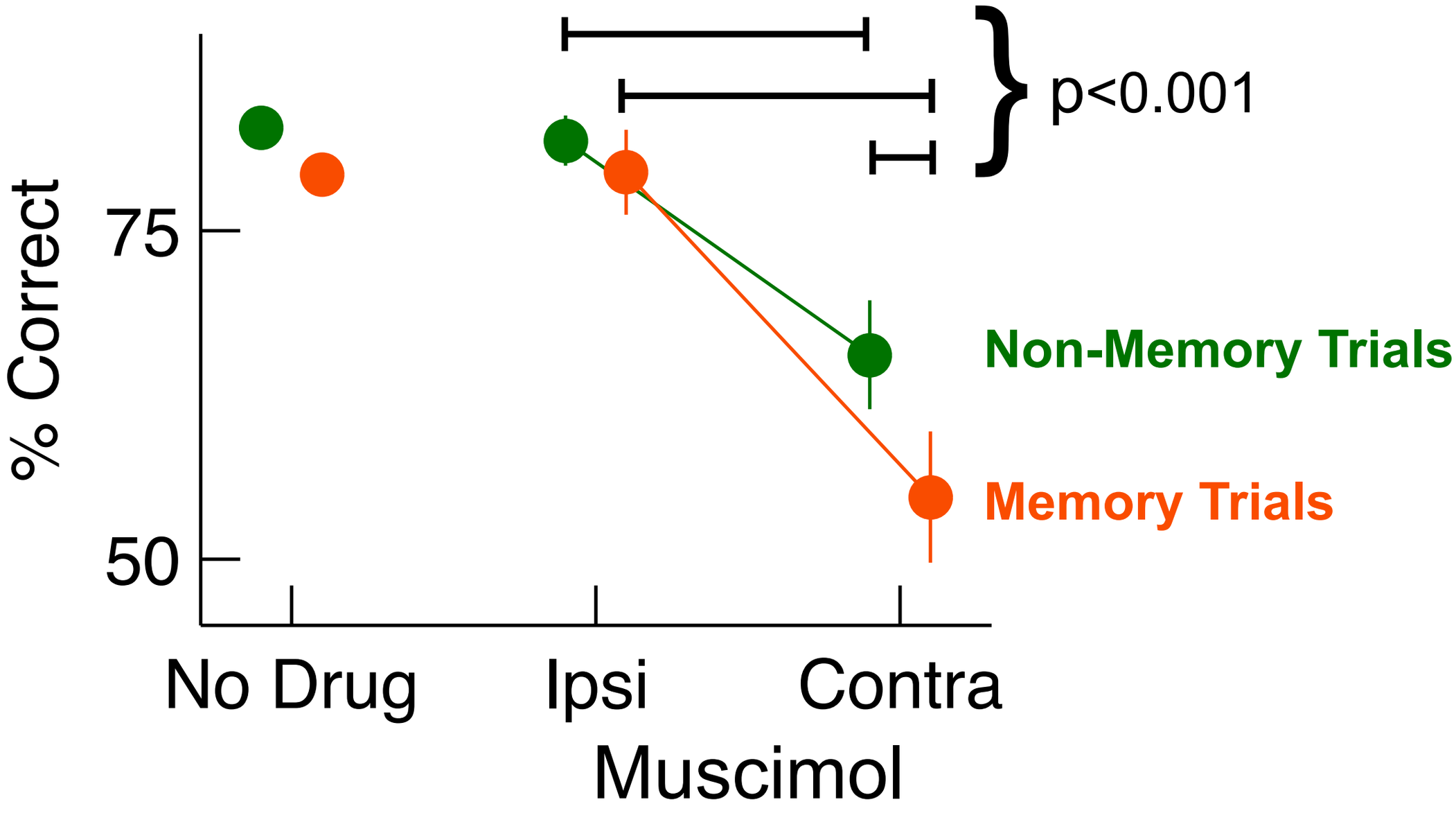
125

50

20

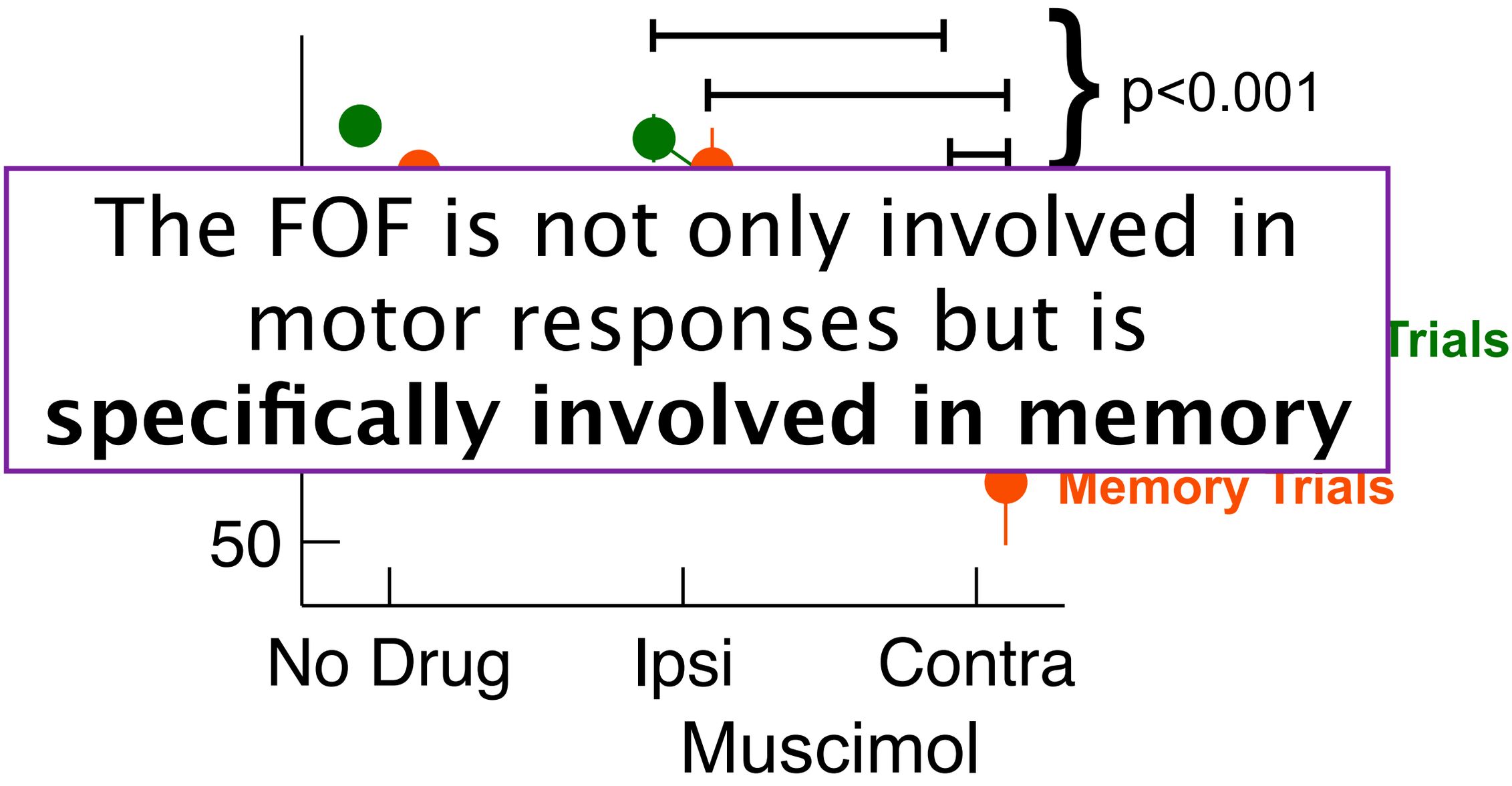
Clicks/Sec

Summary of muscimol results



n=20; 5 rats x 4 sessions per rat

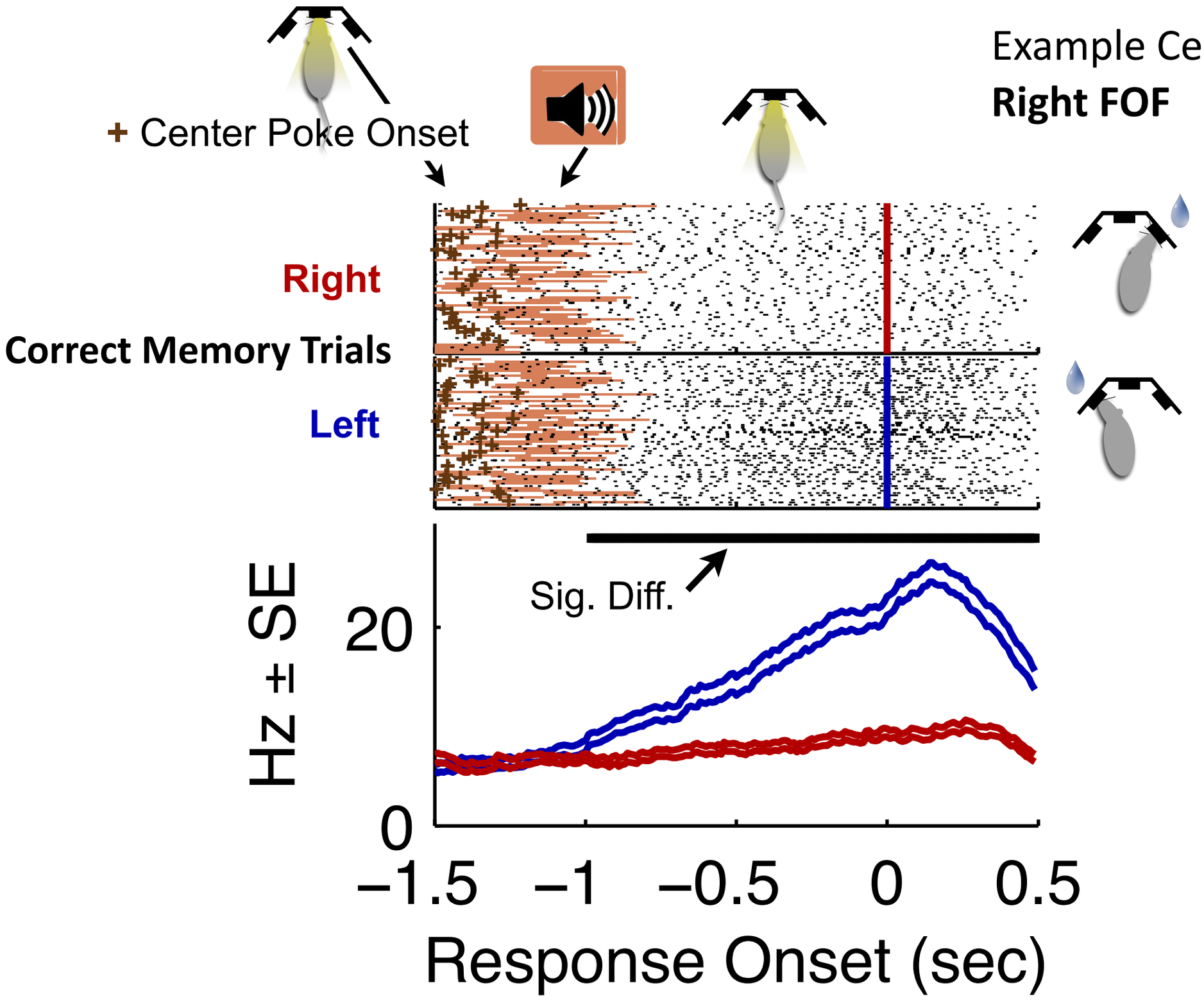
Summary of muscimol results



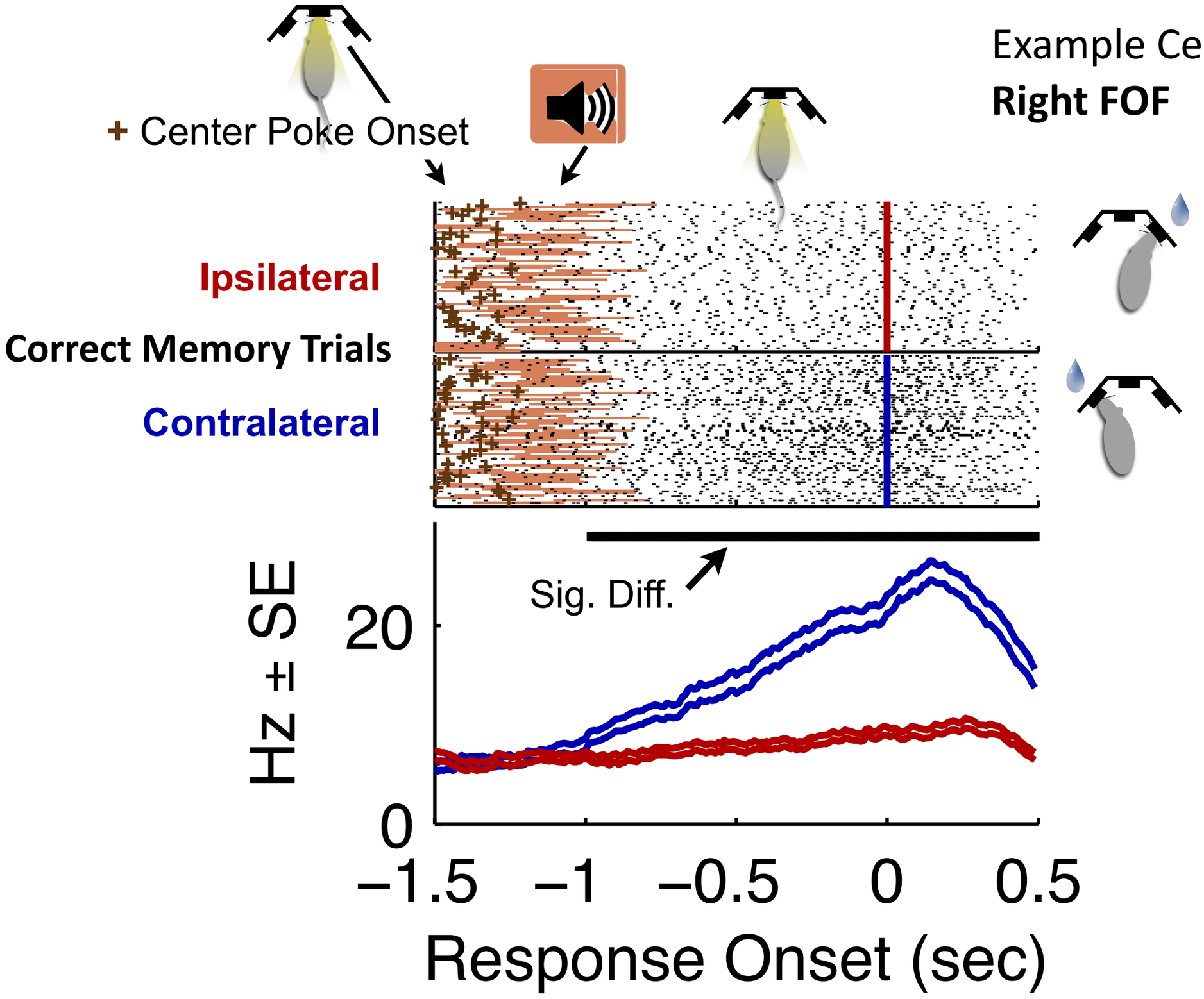
The FOF is not only involved in motor responses but is **specifically involved in memory**

n=20; 5 rats x 4 sessions per rat

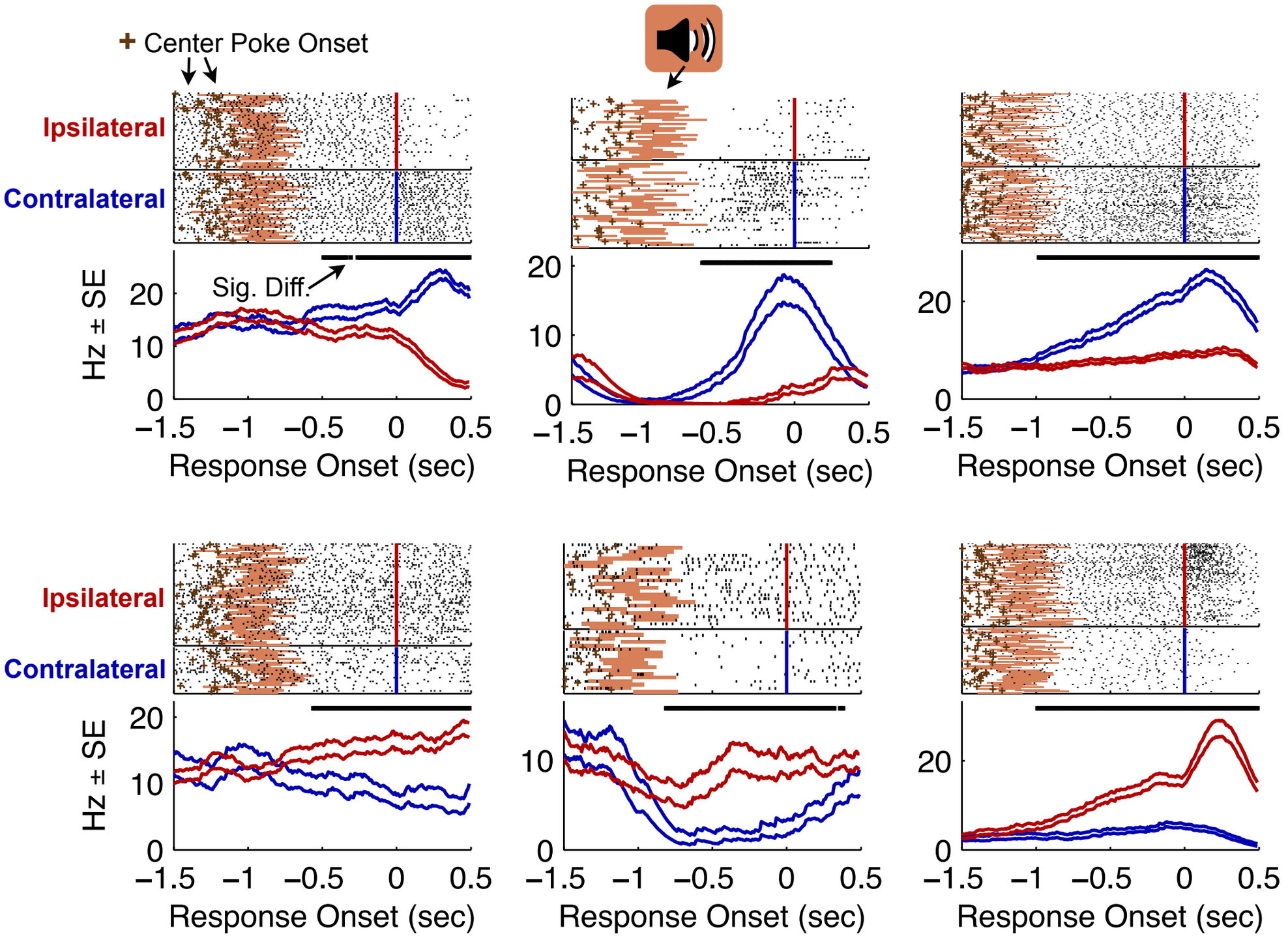
Spatially selective delay activity in FOF



Spatially selective delay activity in FOF

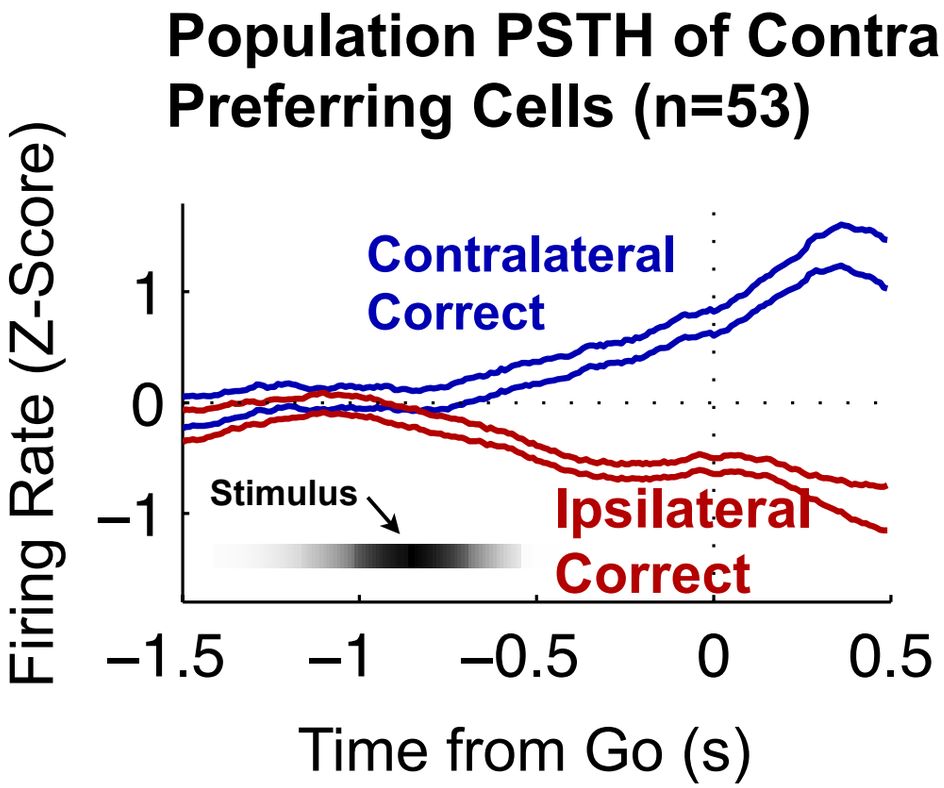


Spatially selective delay activity in FOF

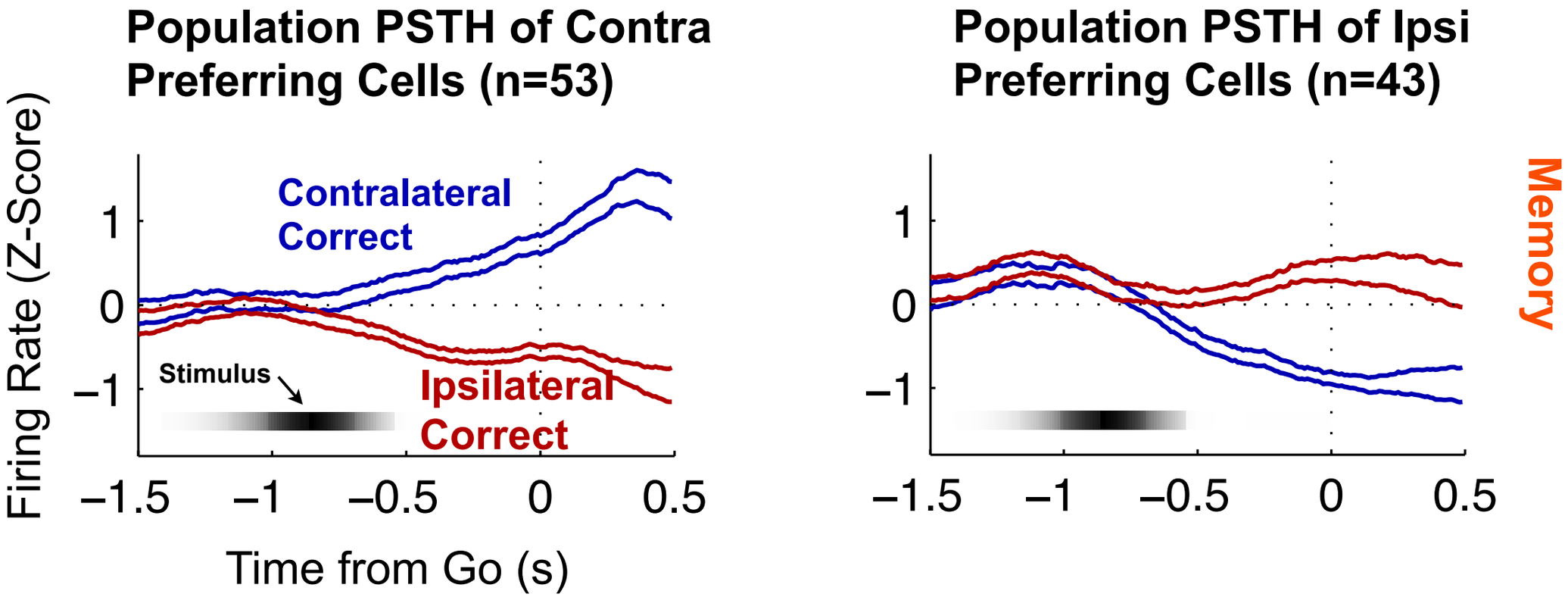


Spatially selective delay activity in FOF

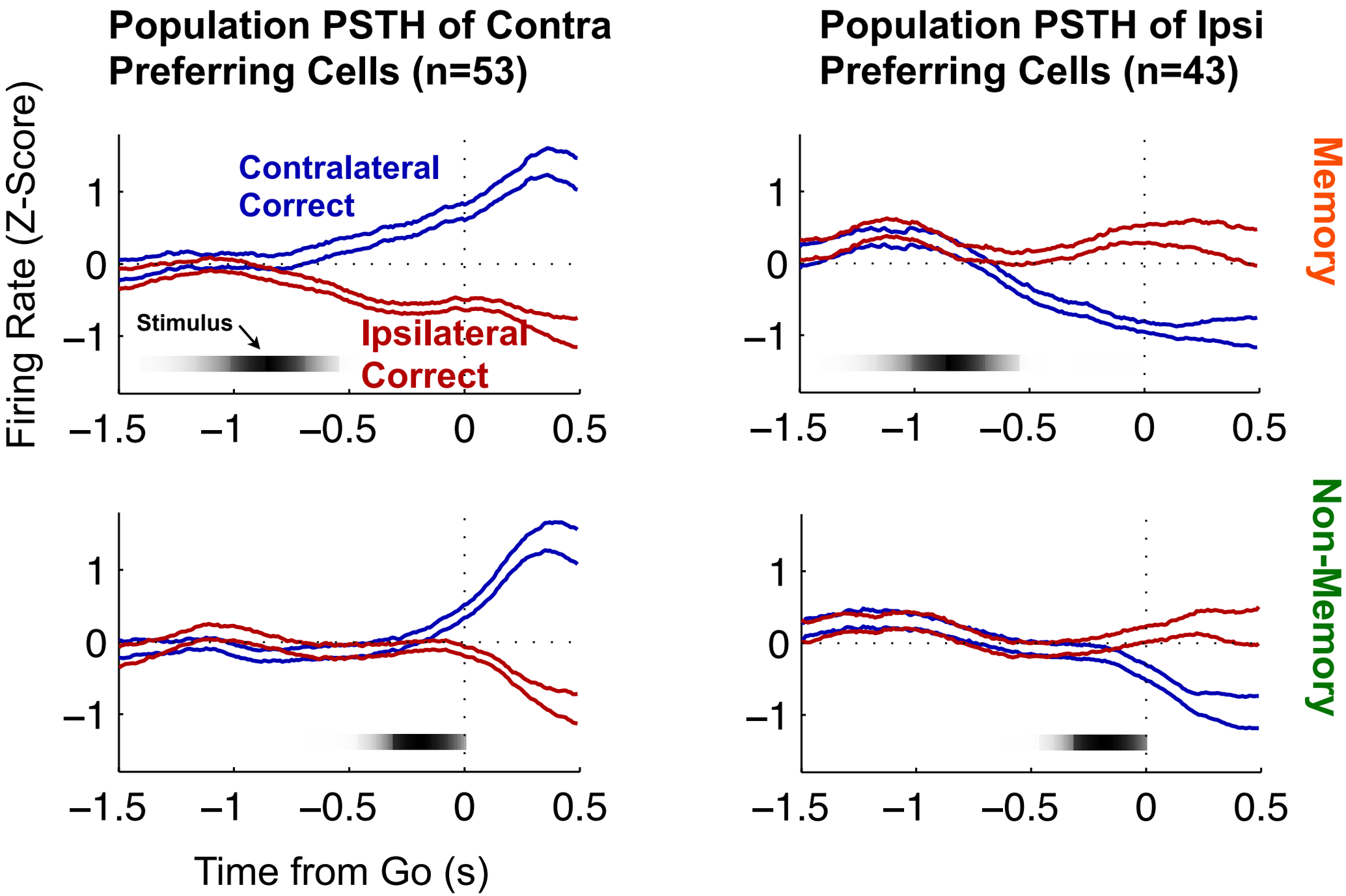
Spatially selective delay activity in FOF



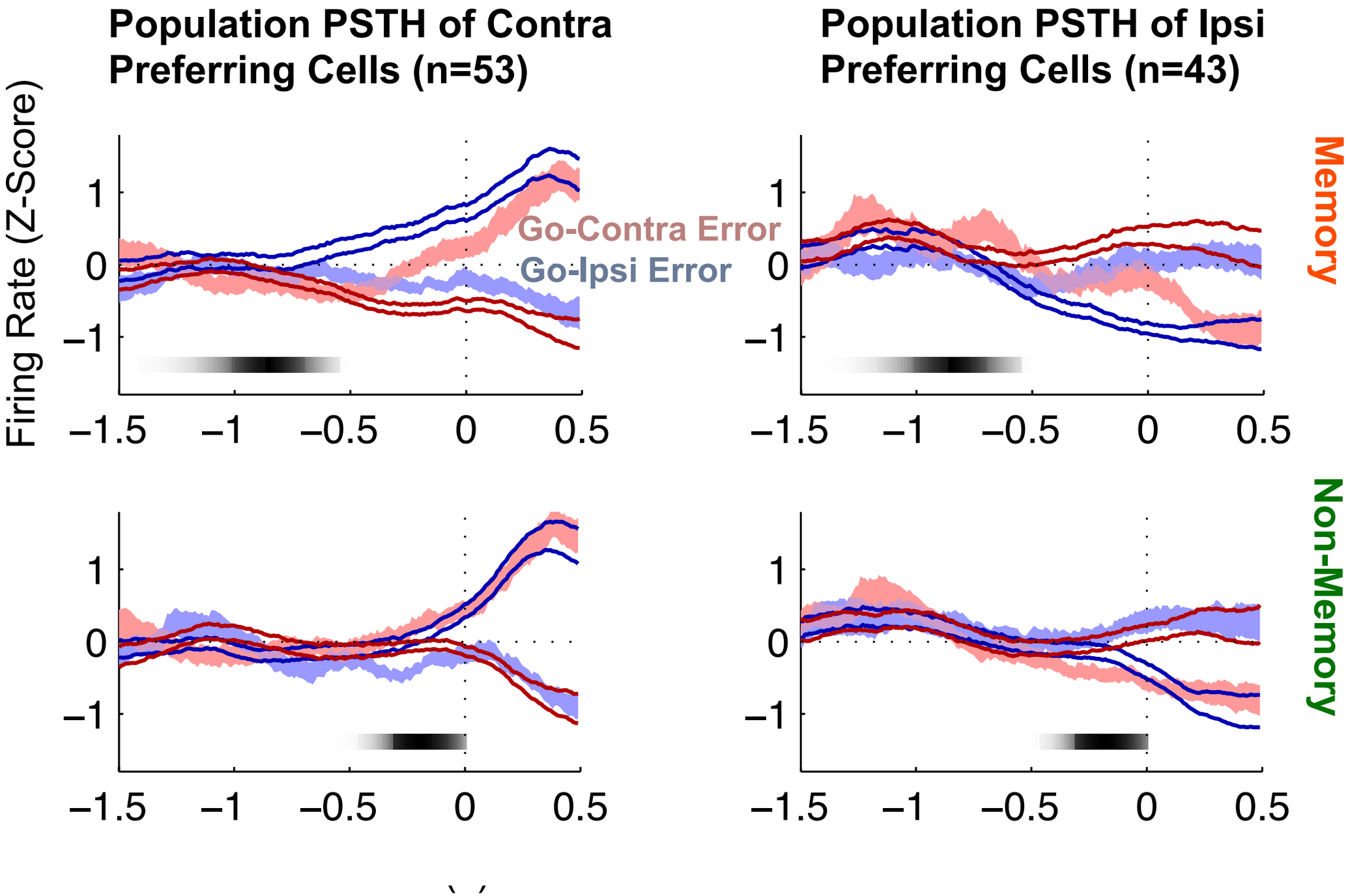
Spatially selective delay activity in FOF



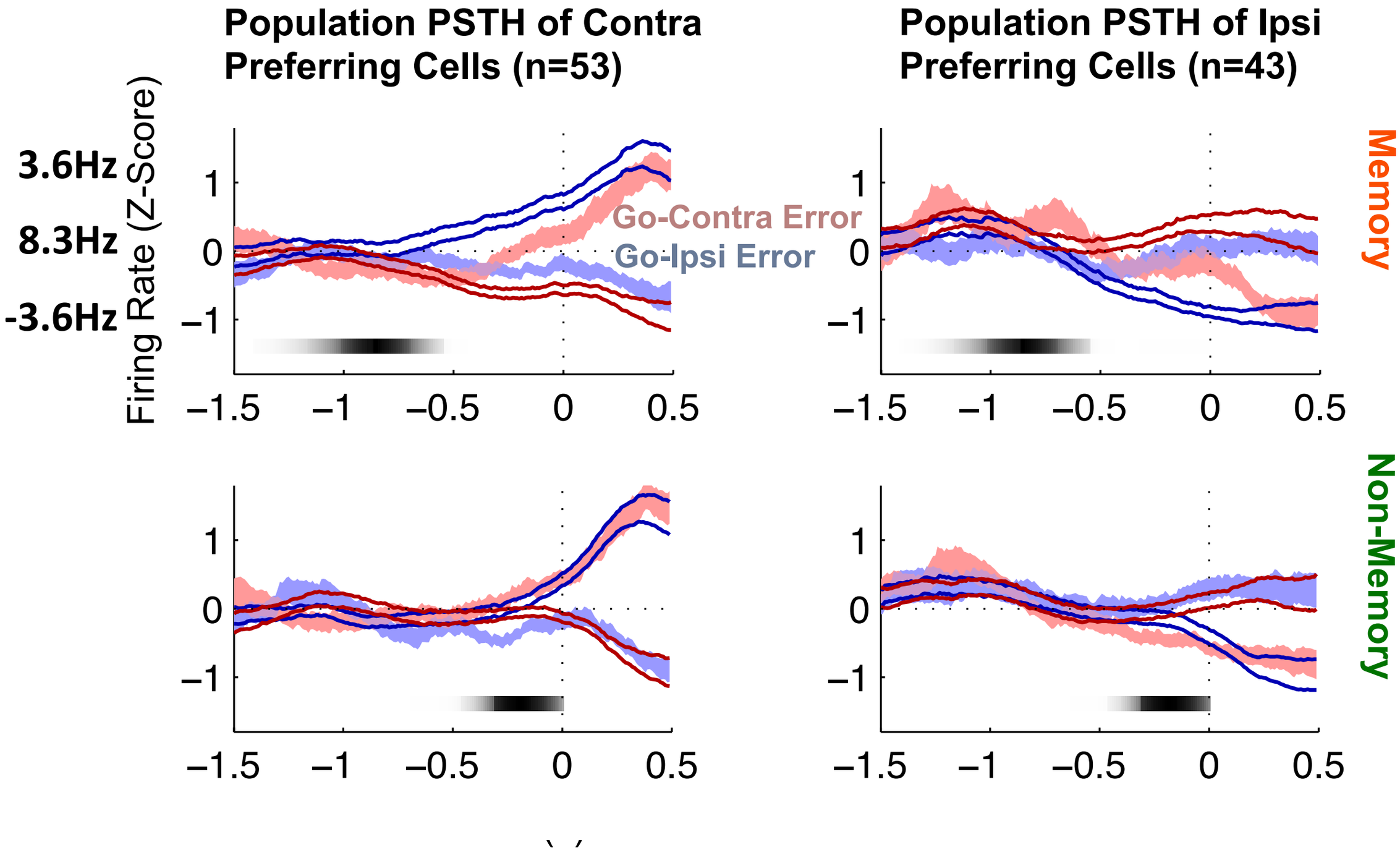
Spatially selective delay activity in FOF



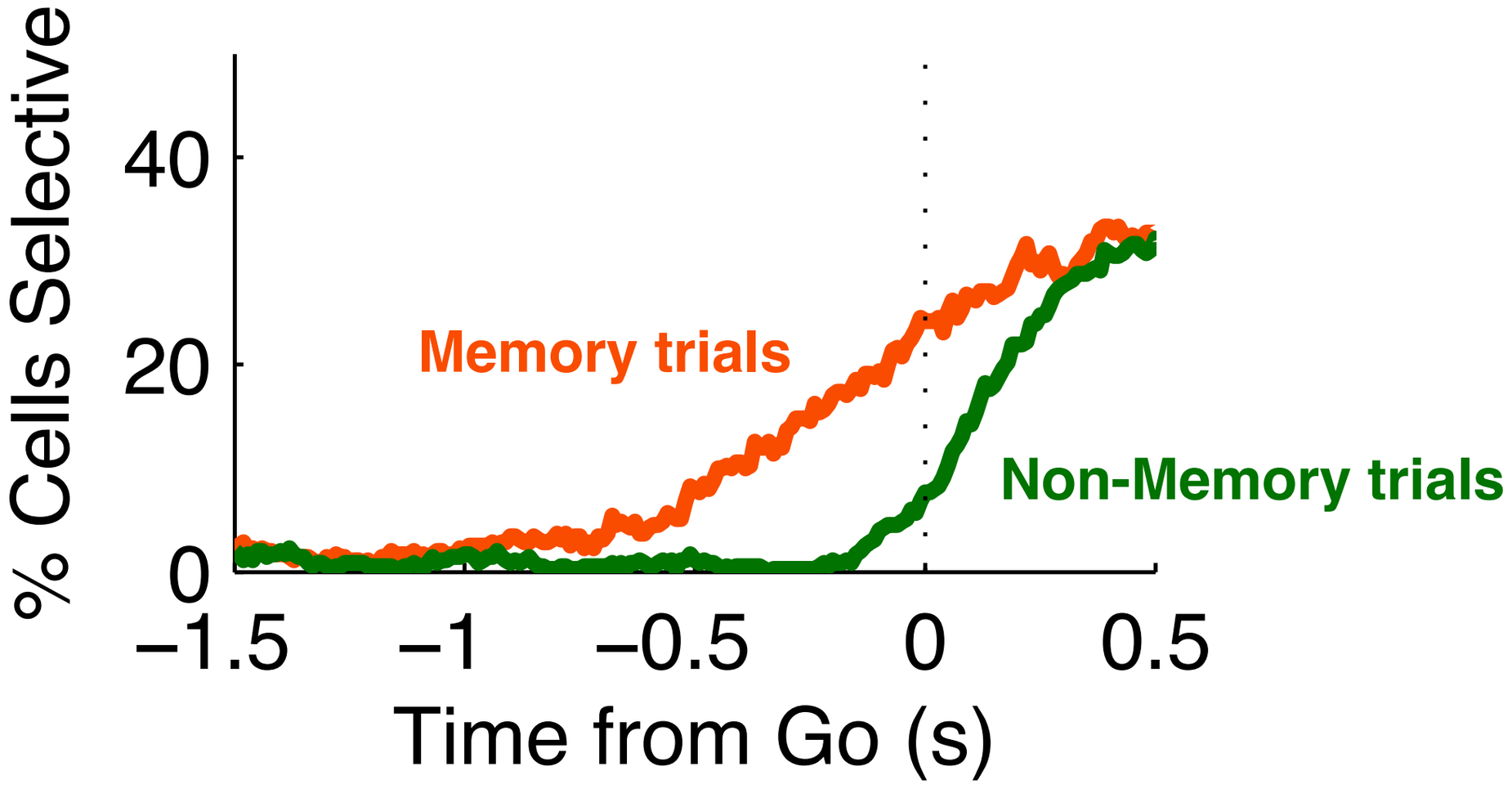
Spatially selective delay activity in FOF



Spatially selective delay activity in FOF

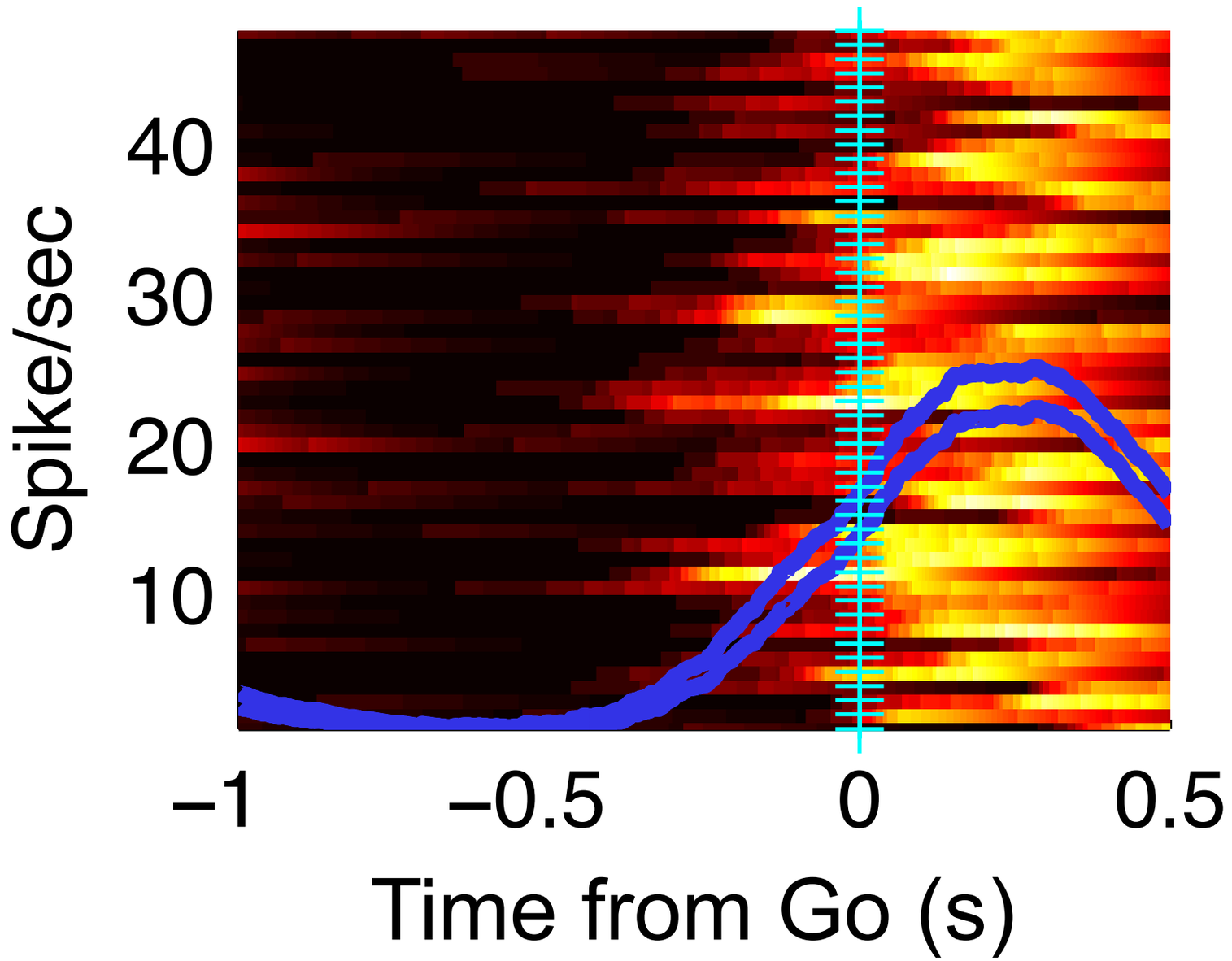


Spatially selective delay activity in FOF



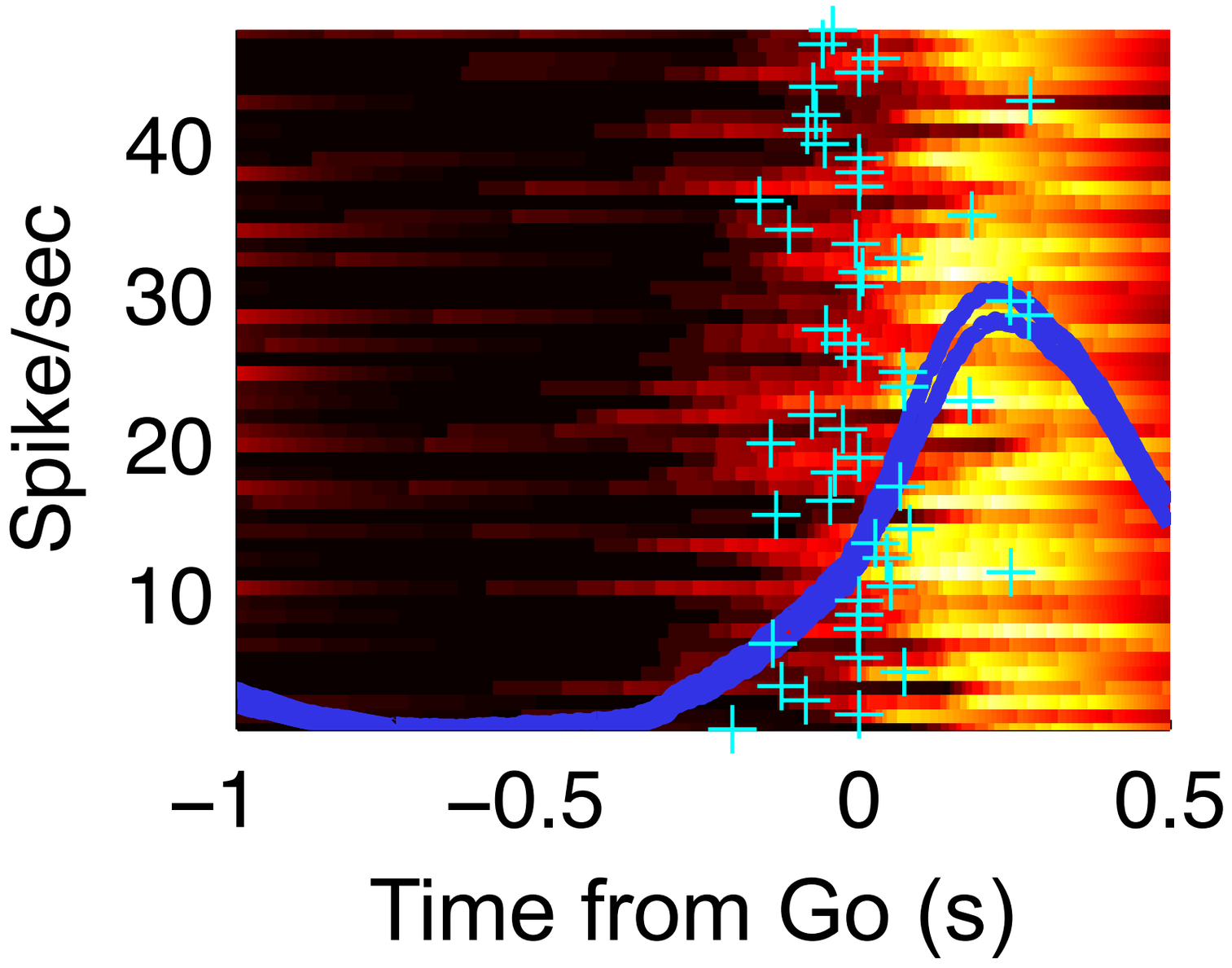
36% of 262 cells in FOF show delay period selectivity

Computing neural latency



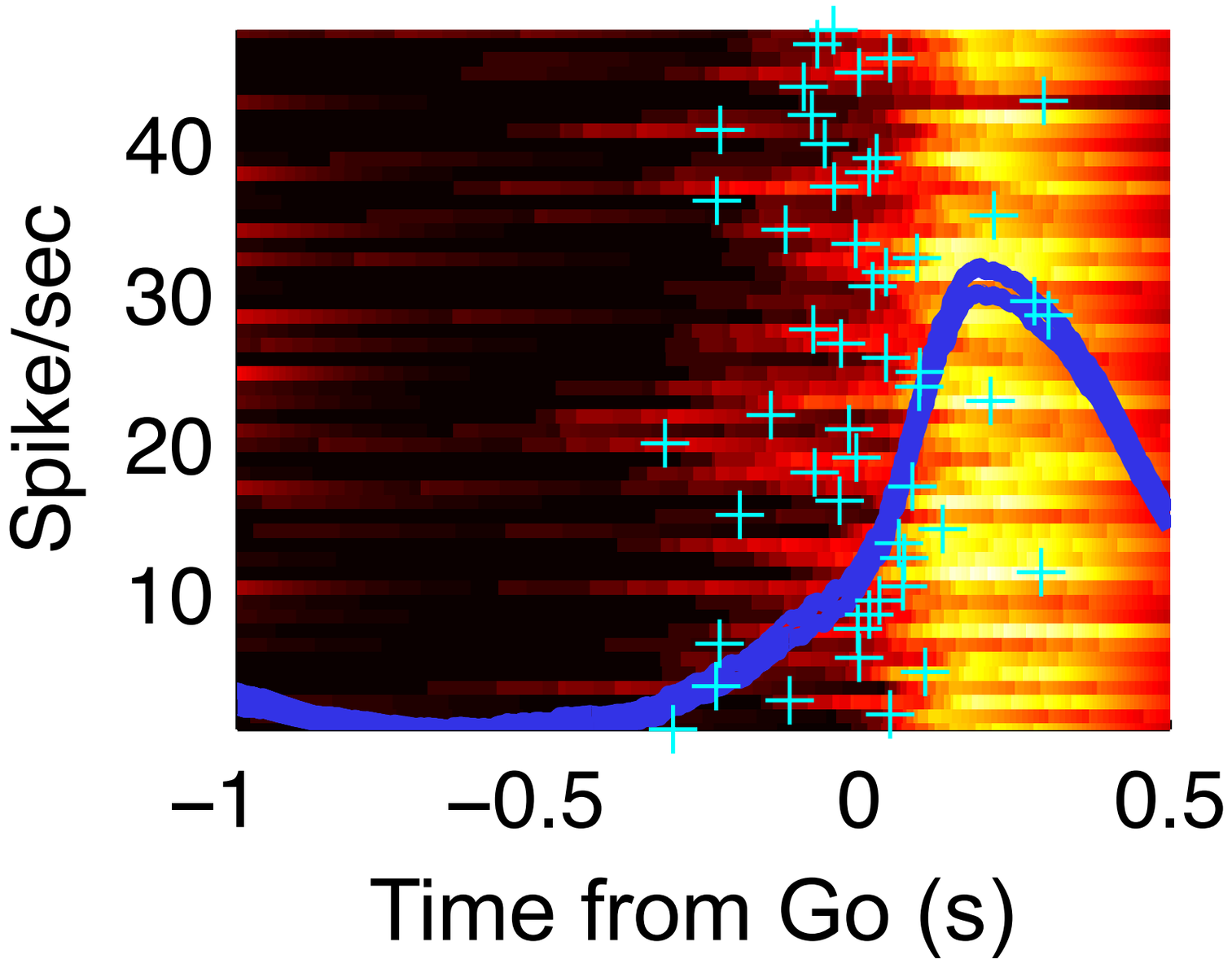
inspired by DiCarlo and Maunsell, 2005

Computing neural latency



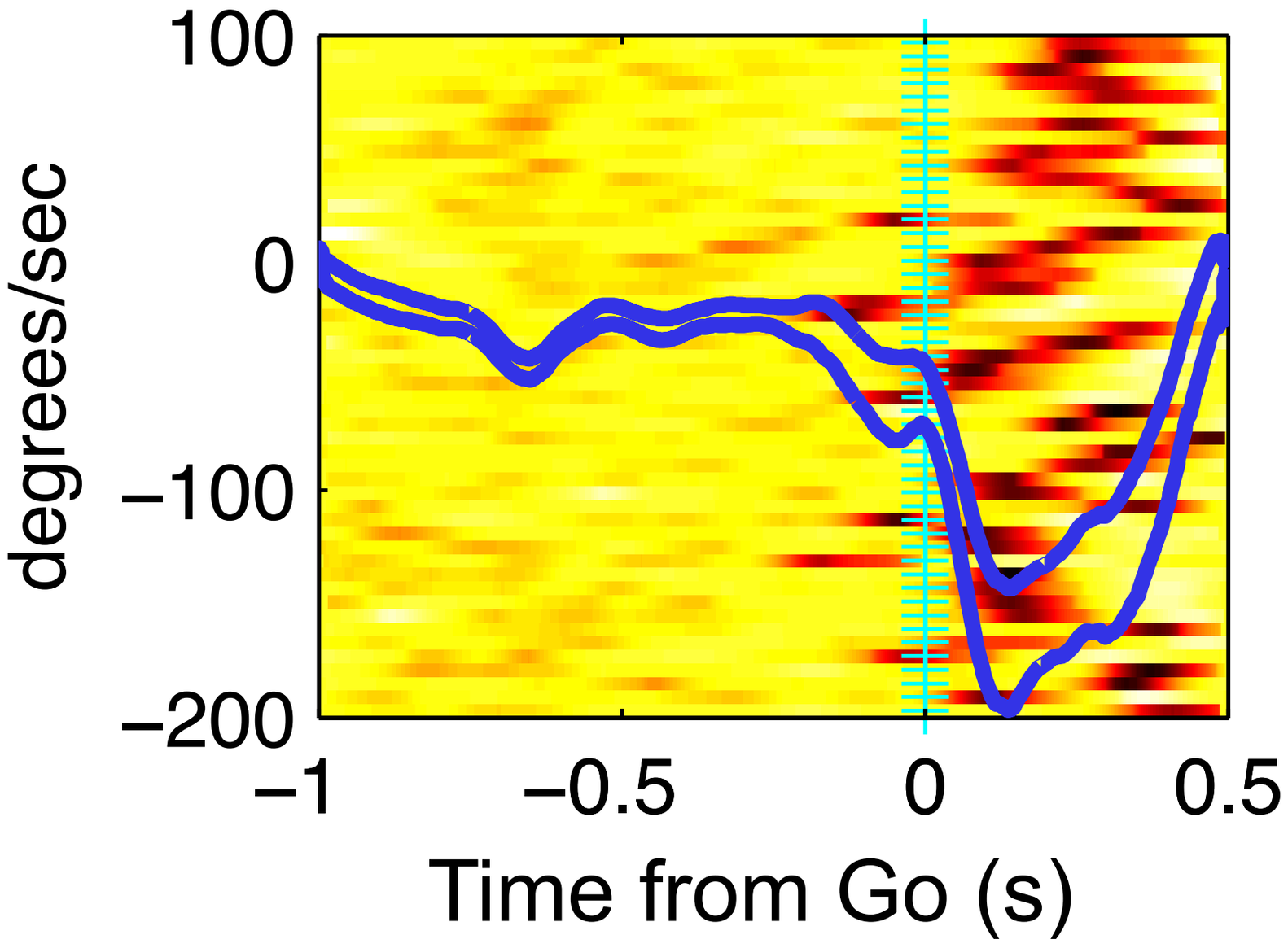
inspired by DiCarlo and Maunsell, 2005

Computing neural latency

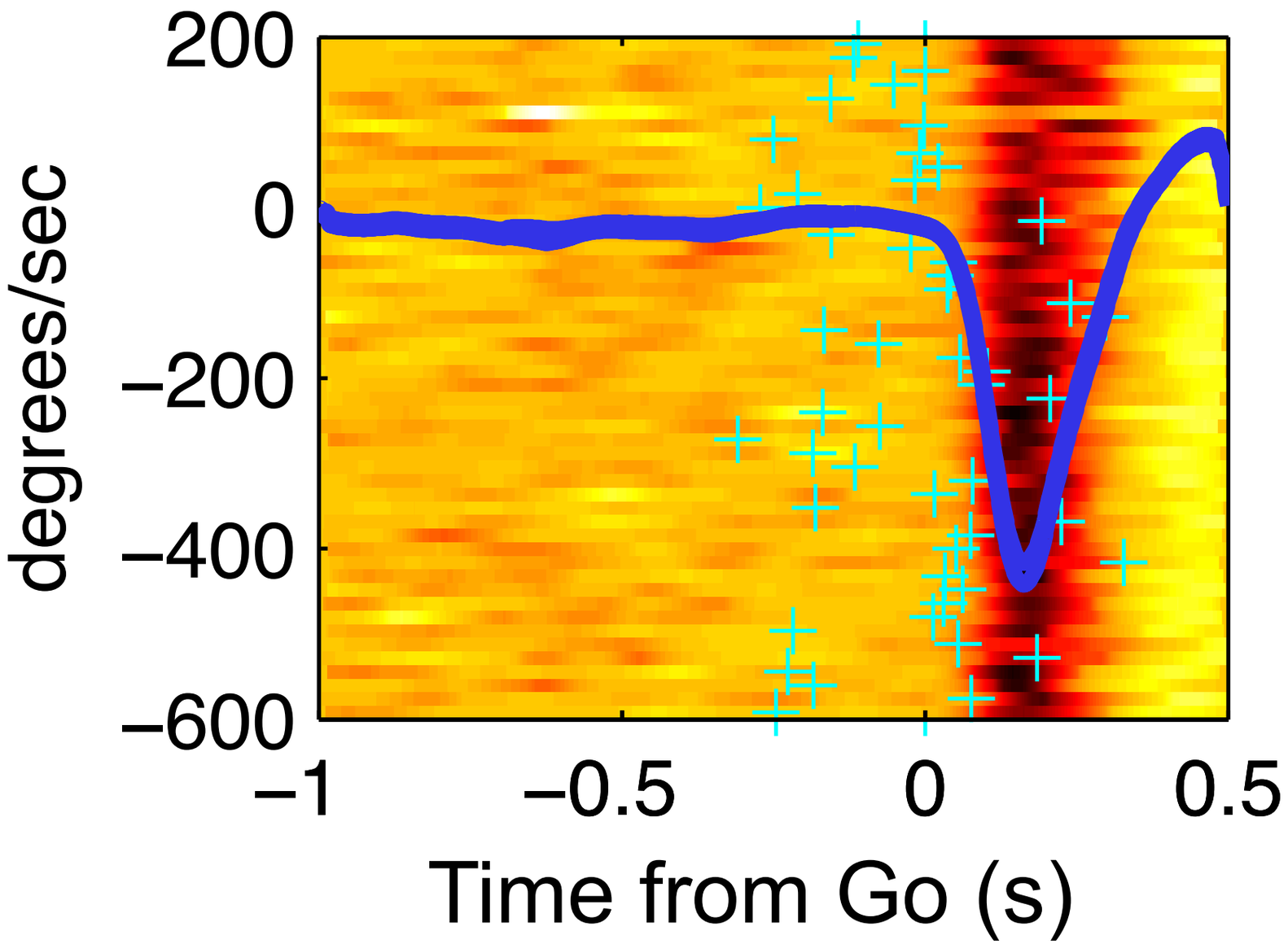


inspired by DiCarlo and Maunsell, 2005

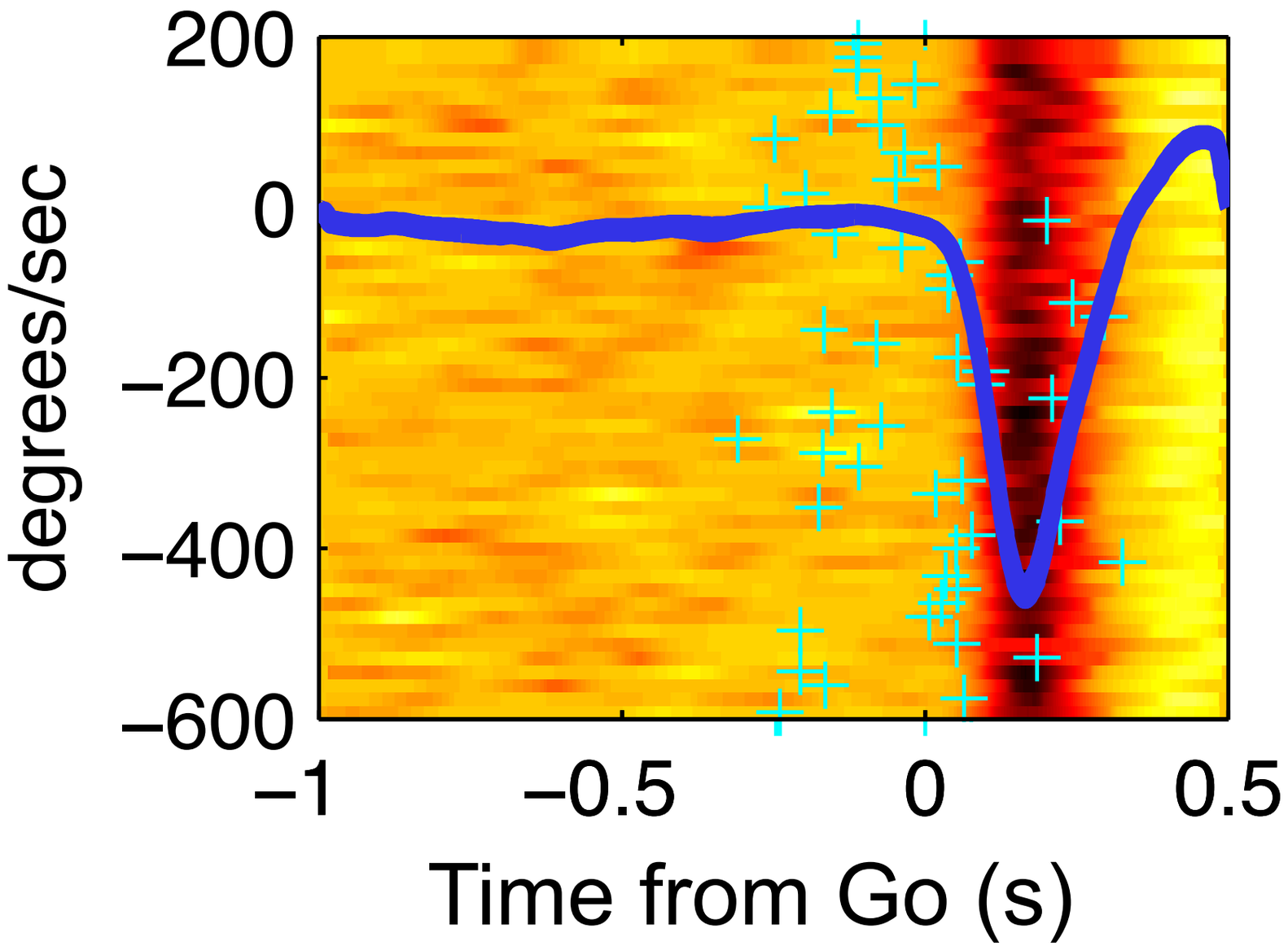
Computing behavioral latency



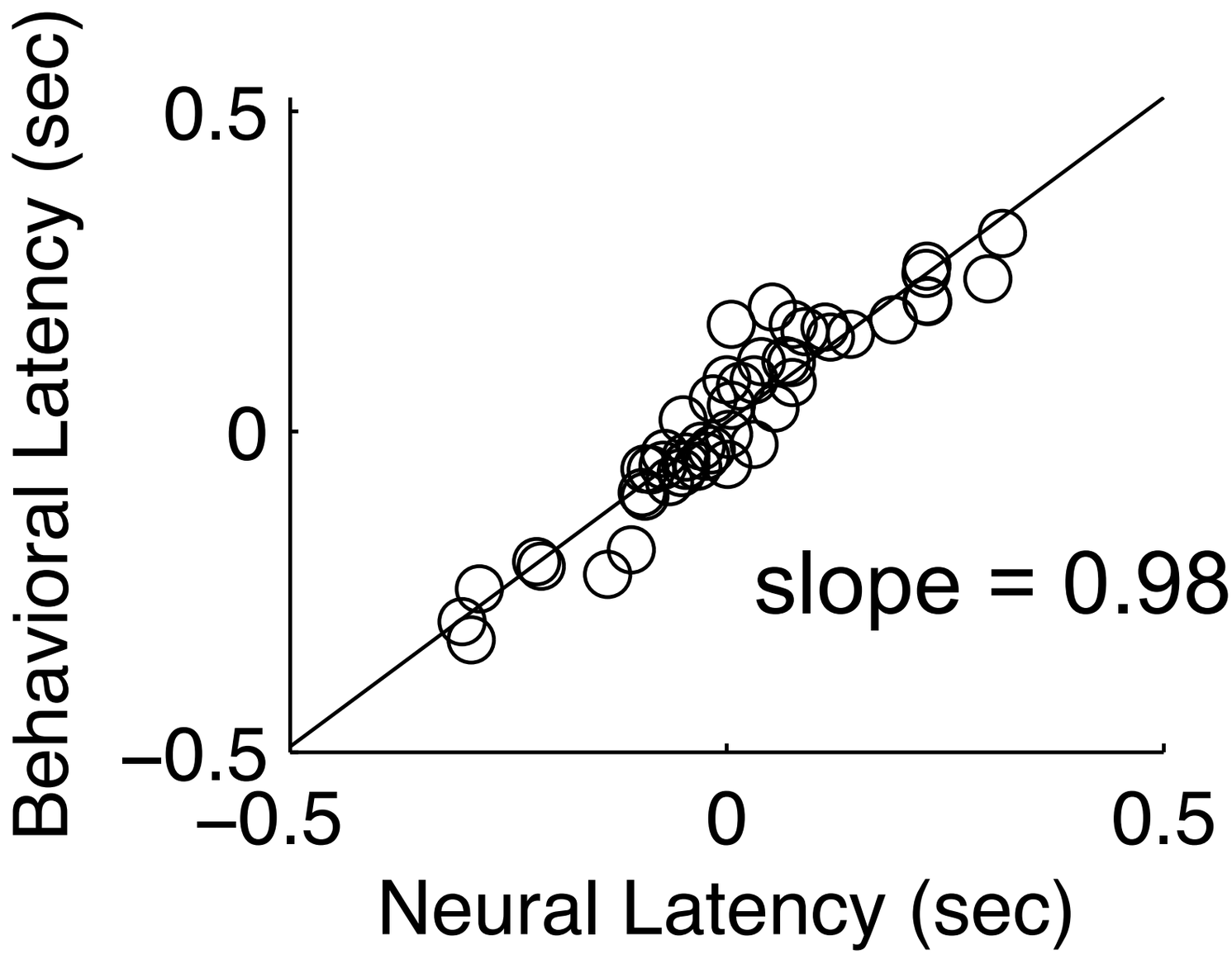
Computing behavioral latency



Computing behavioral latency

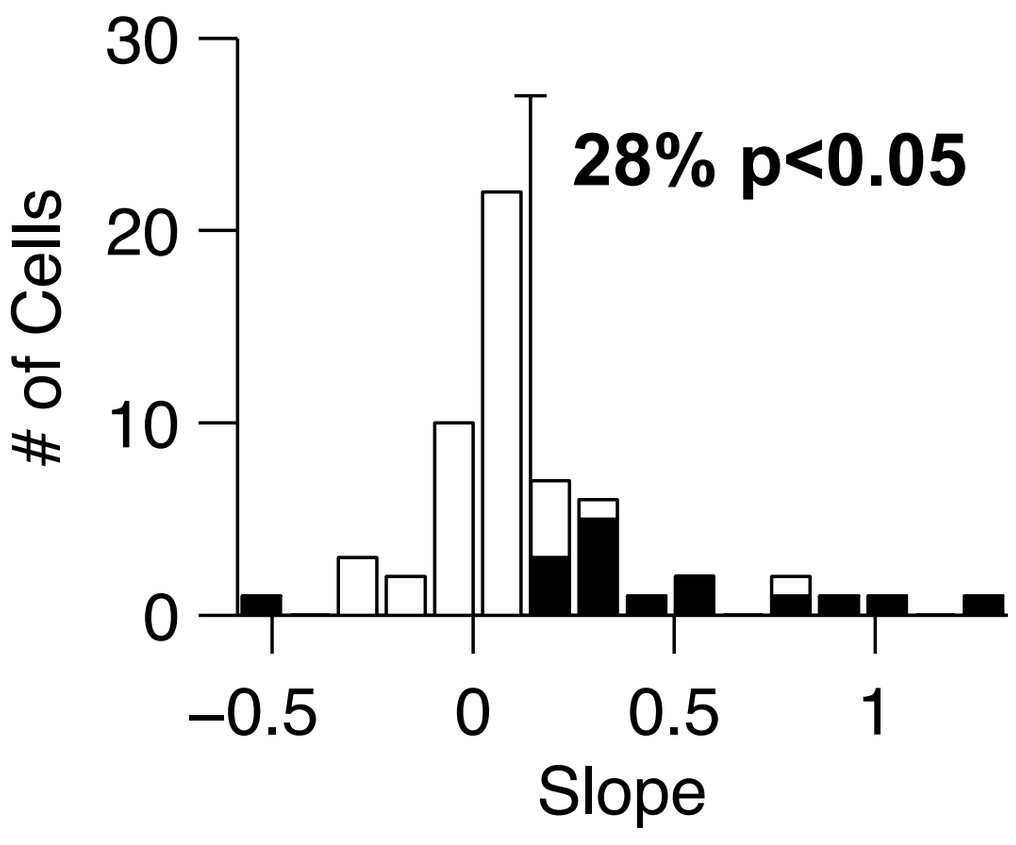


Best example of highly correlated neural and behavioral latency

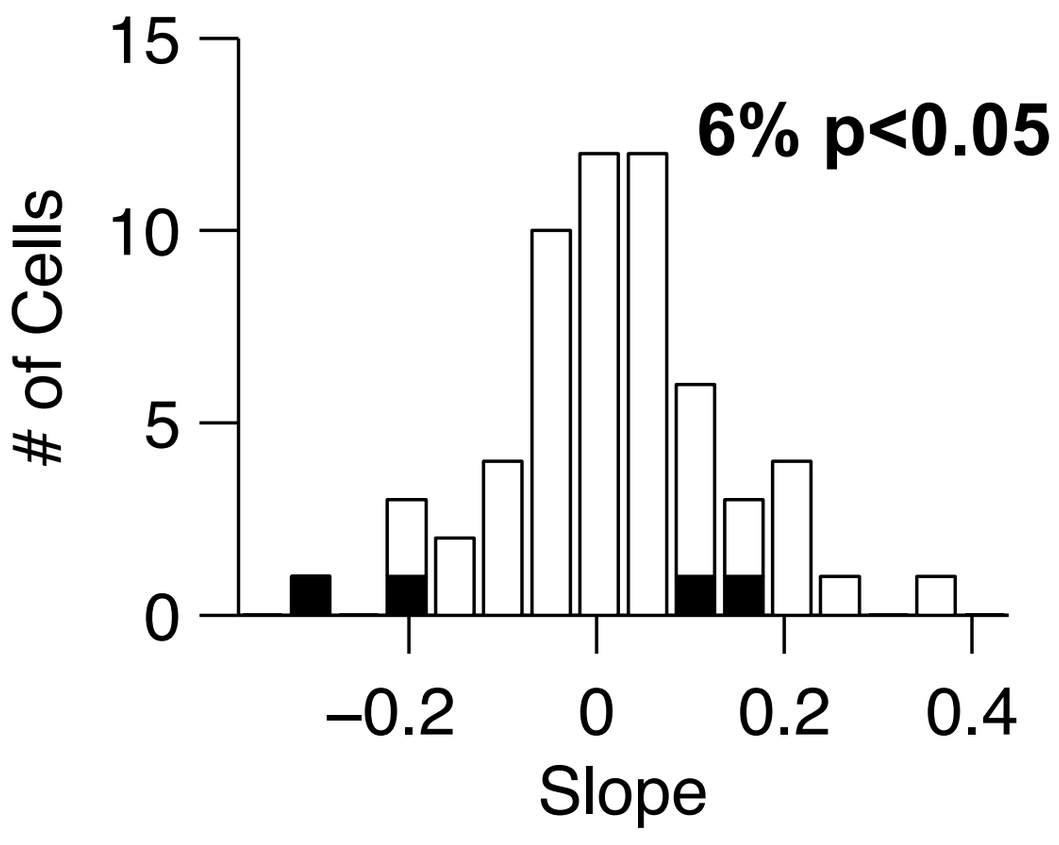


Neural / behavioral latency population summary

Correct Contra Memory Trials

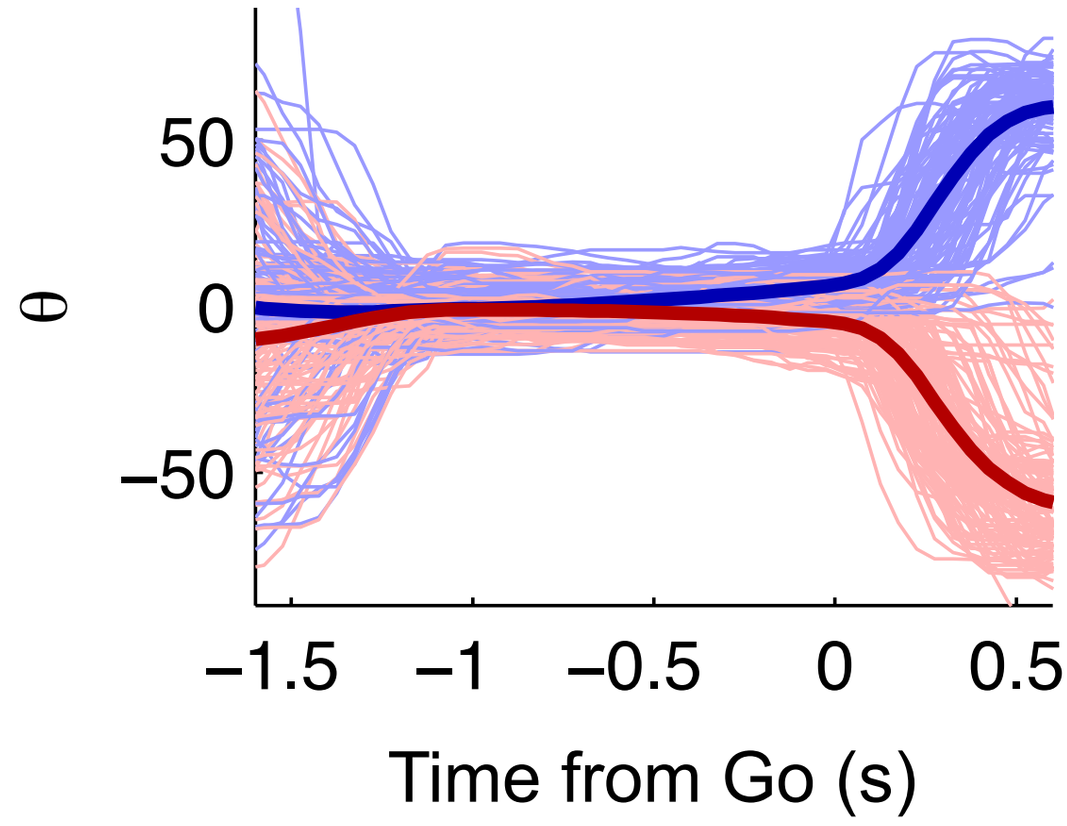


Shuffled Correct Contra Memory Trials



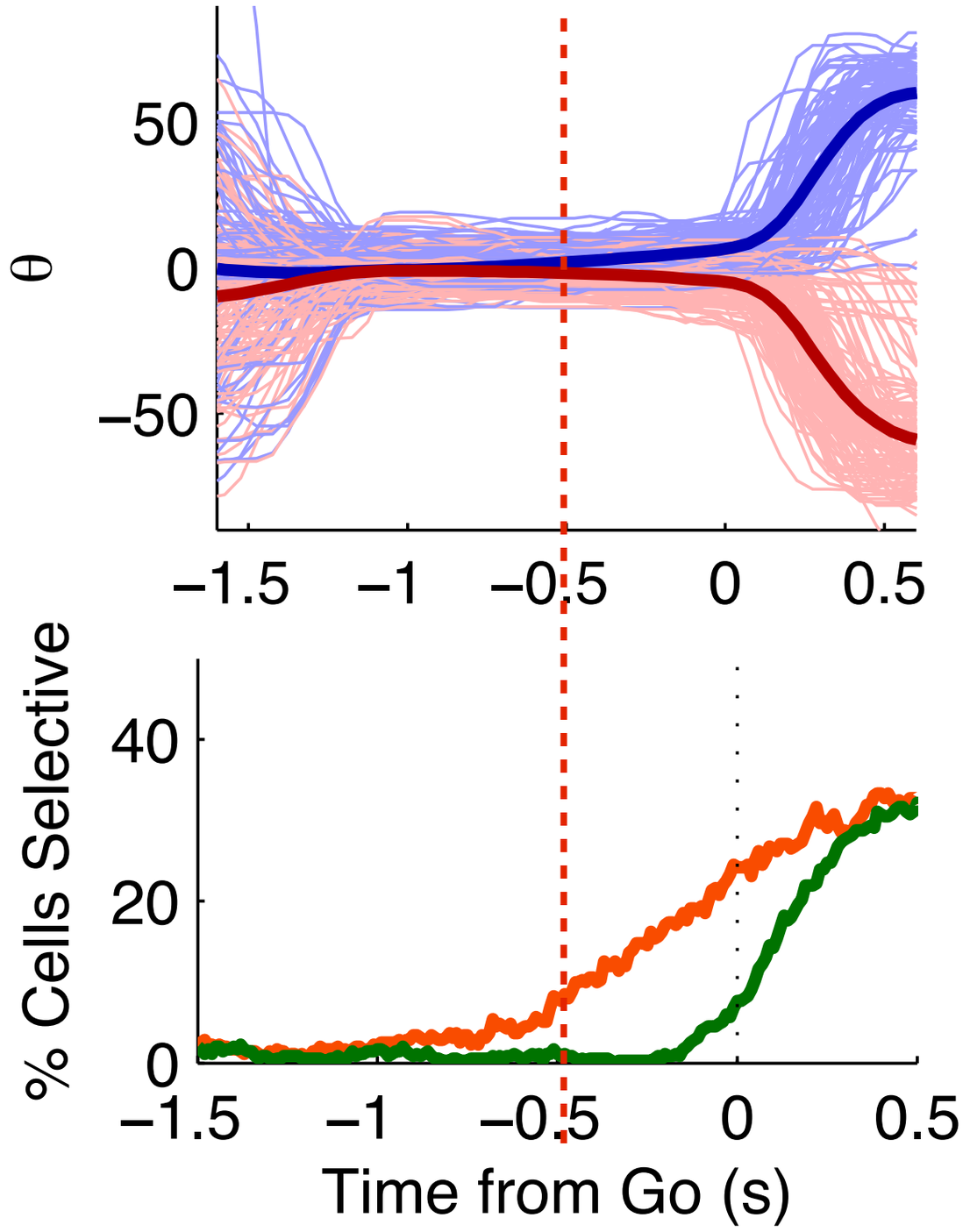
Behavioral evidence of planning

Head orientation θ, correct Mem trials only



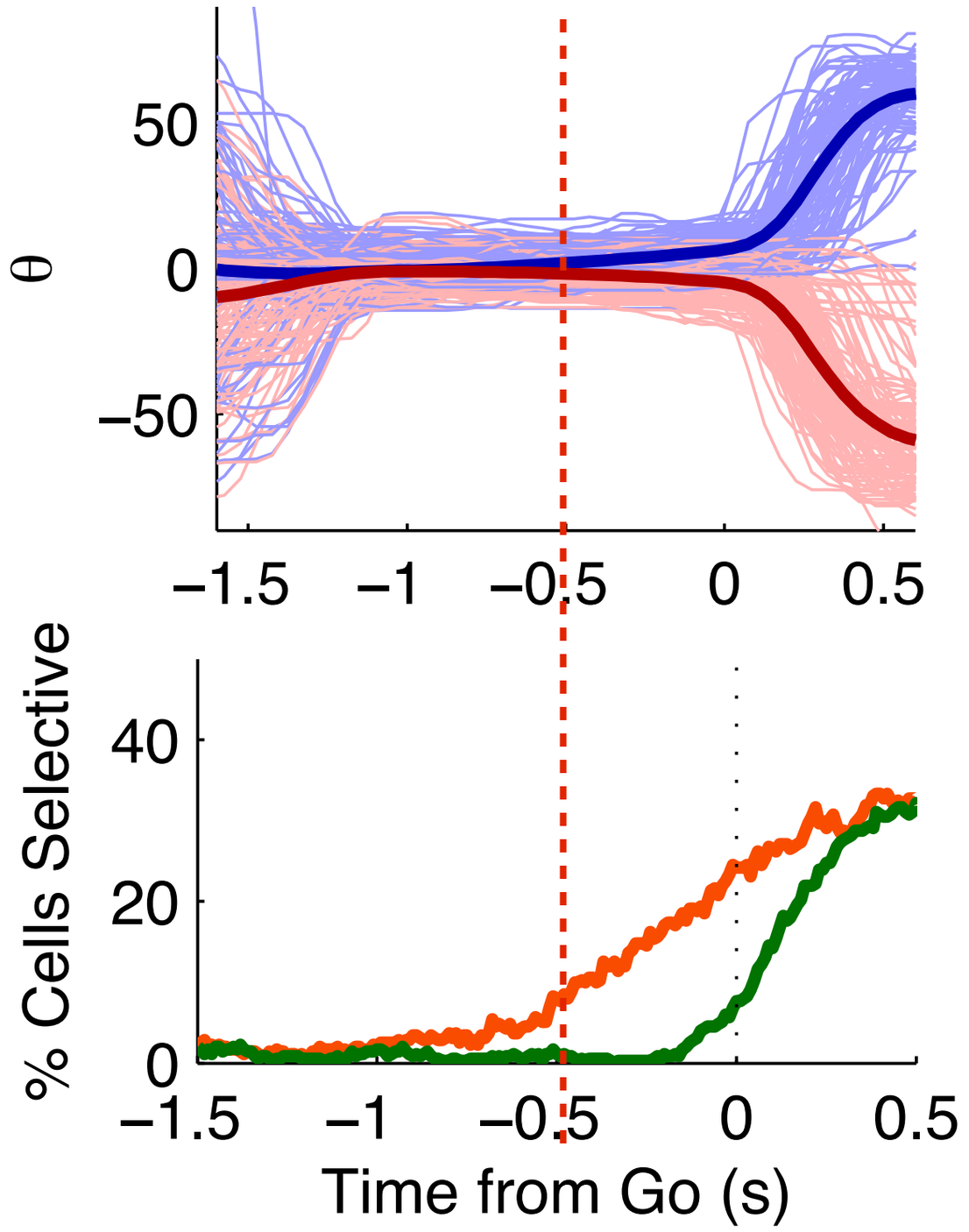
Behavioral evidence of planning

Head orientation θ, correct Mem trials only



Behavioral evidence of planning

Head orientation θ, correct Mem trials only



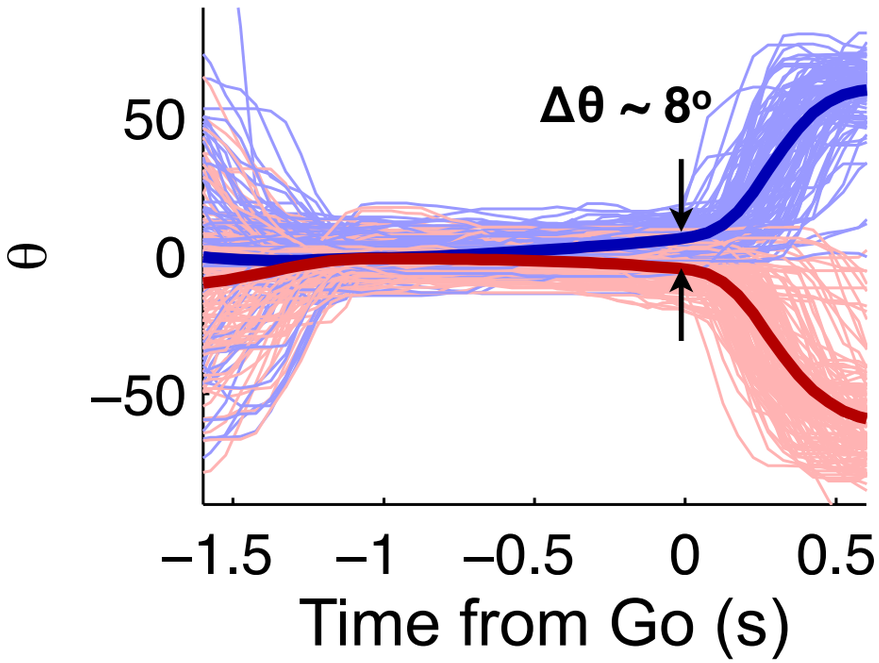
Timing of significant firing rate signal coincides with timing of significant differences in head orientation --

Is the FOF a simple motor area, encoding current head orientation?

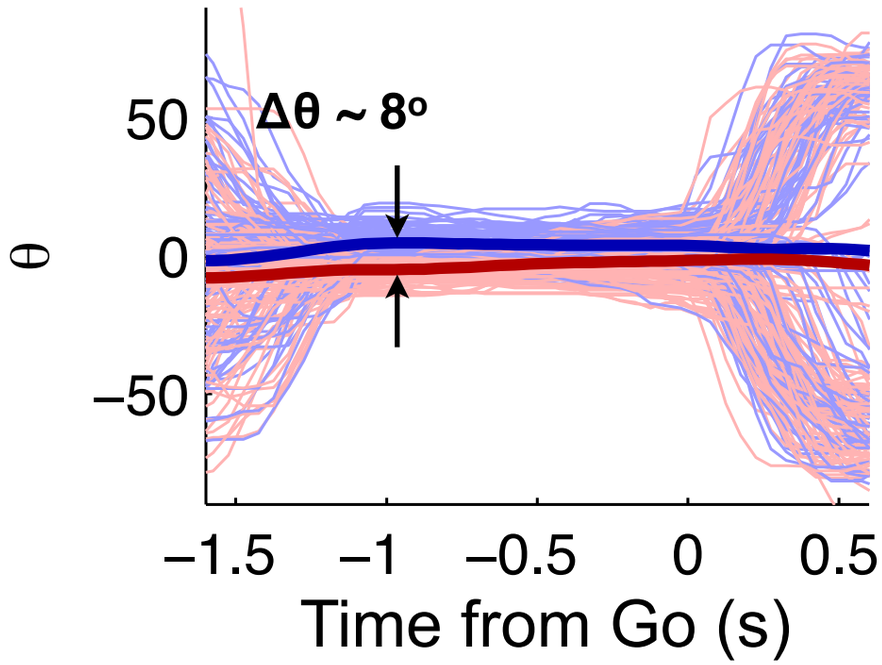
Variance in head angle to the rescue

Head orientation θ, correct Mem trials only

select by θ at t=+0.6



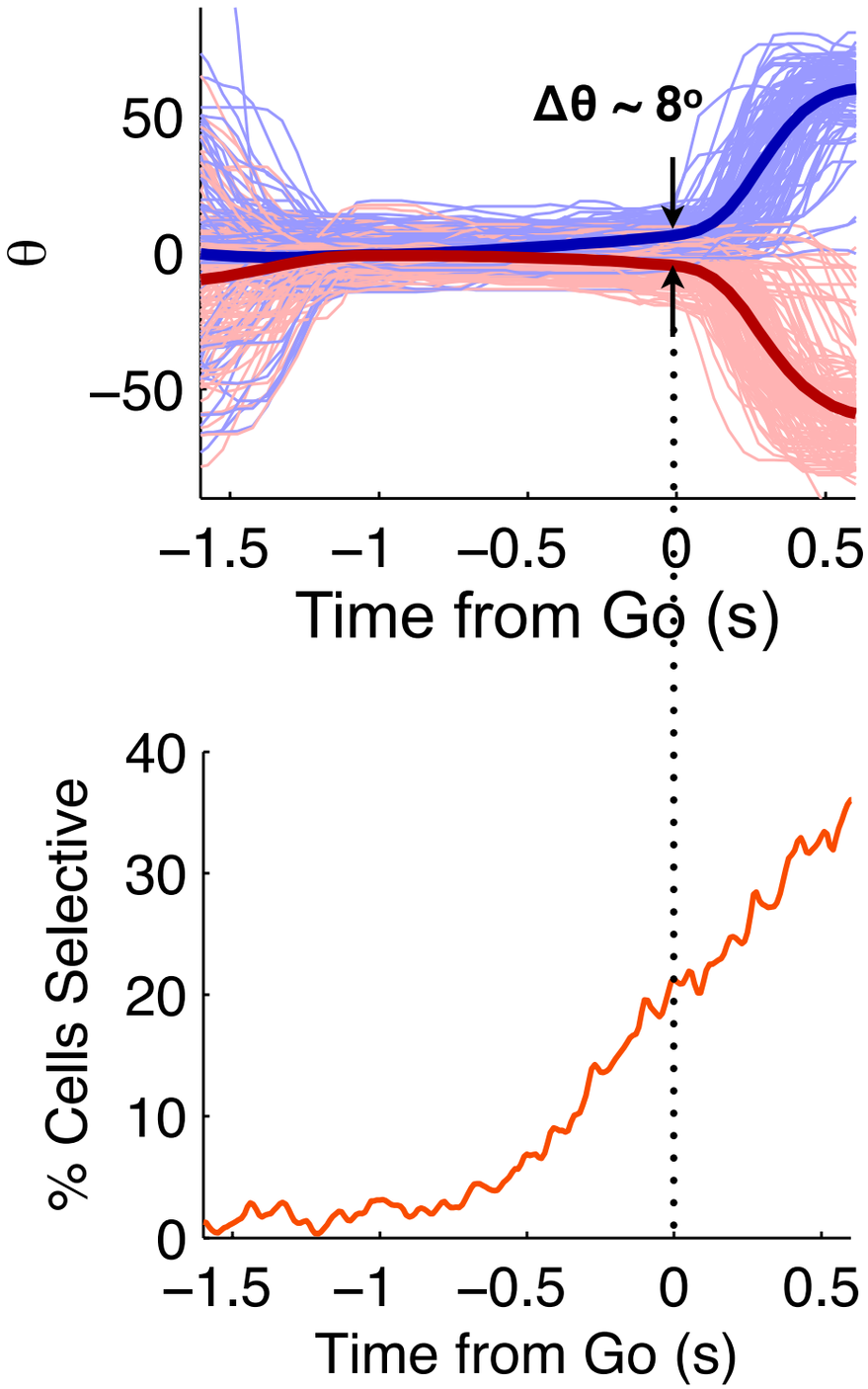
select by θ at t=–0.9



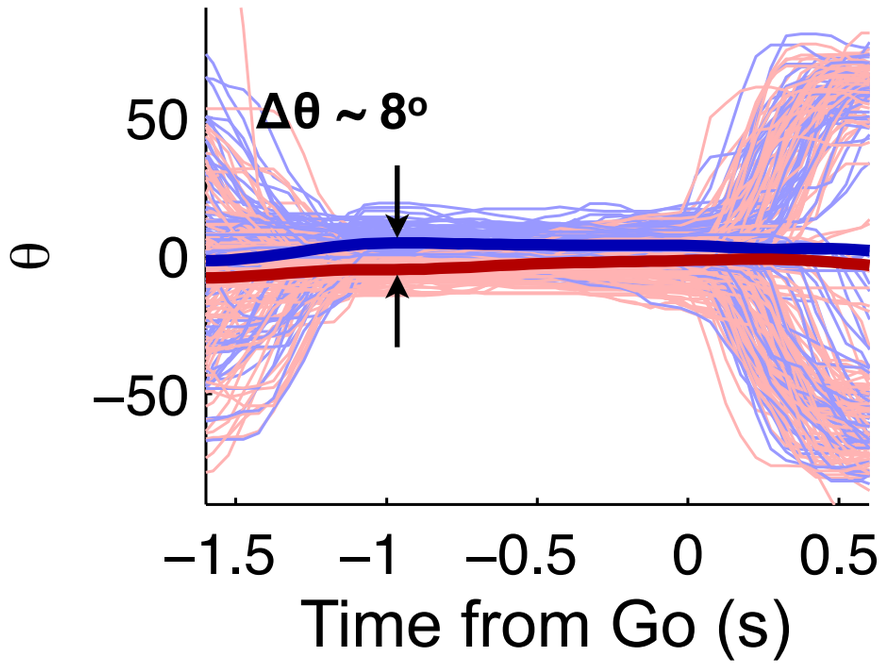
Variance in head angle to the rescue

Head orientation θ, correct Mem trials only

select by θ at t=+0.6



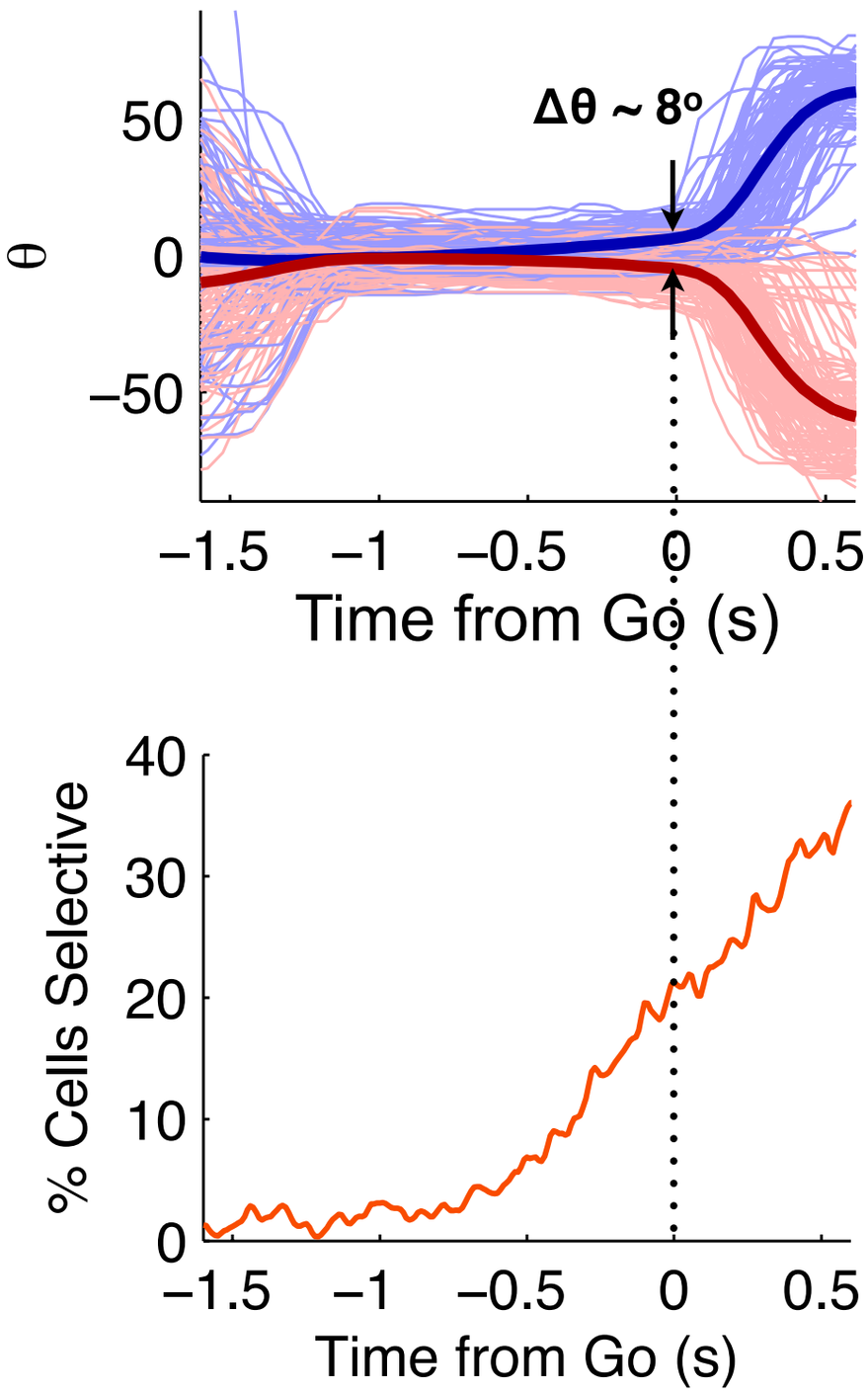
select by θ at t=–0.9



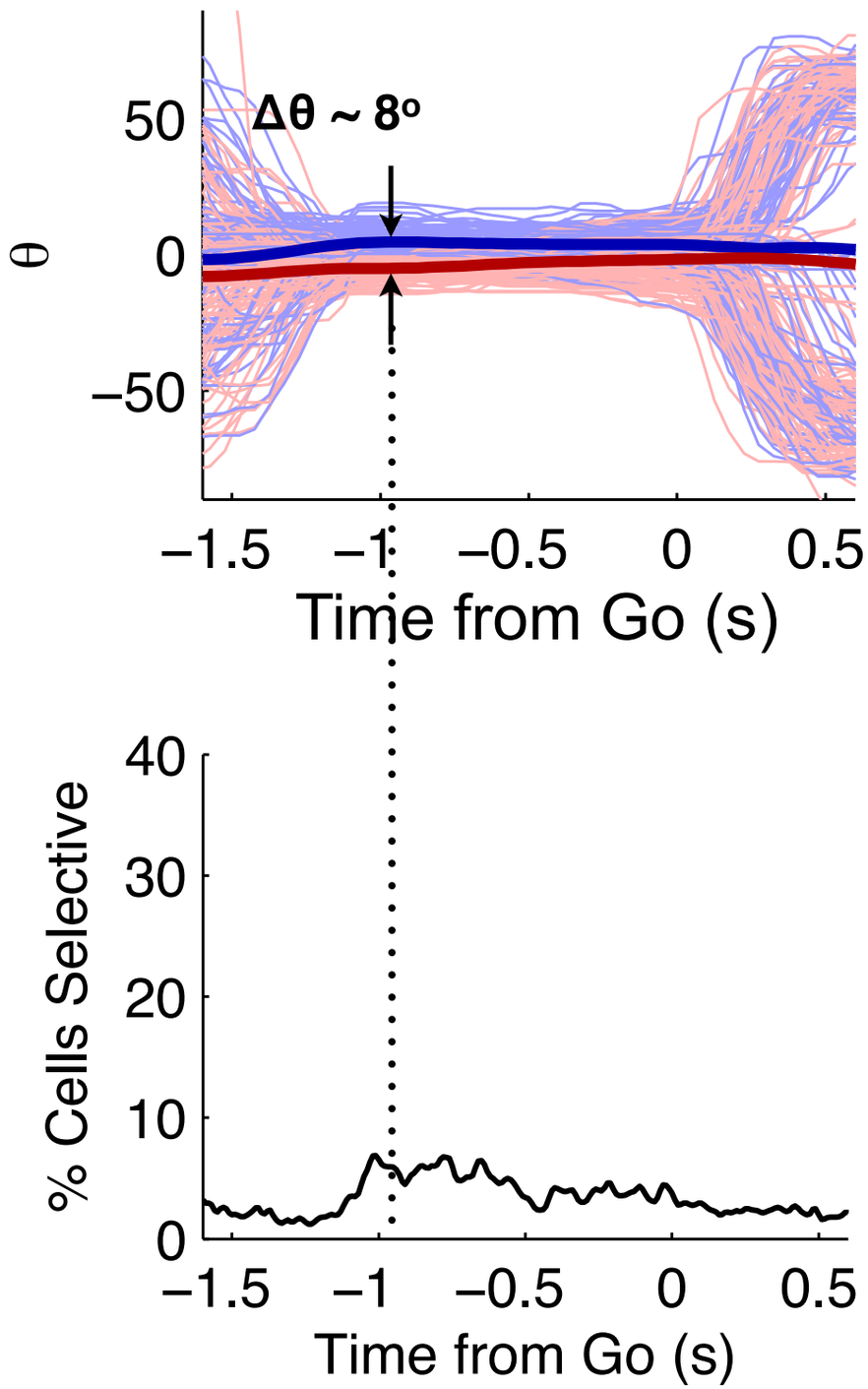
Variance in head angle to the rescue

Head orientation θ, correct Mem trials only

select by θ at t=+0.6

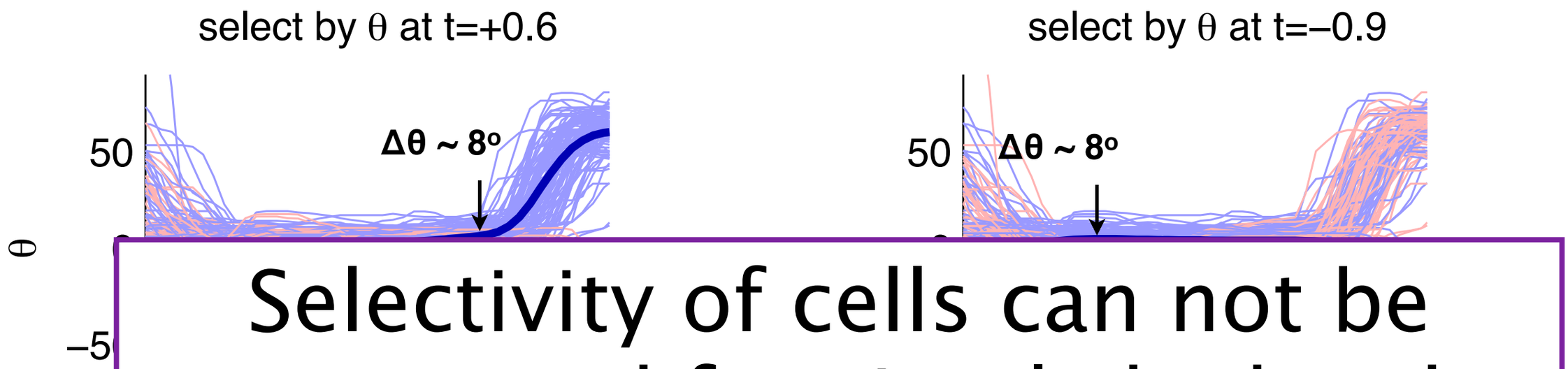


select by θ at t=–0.9

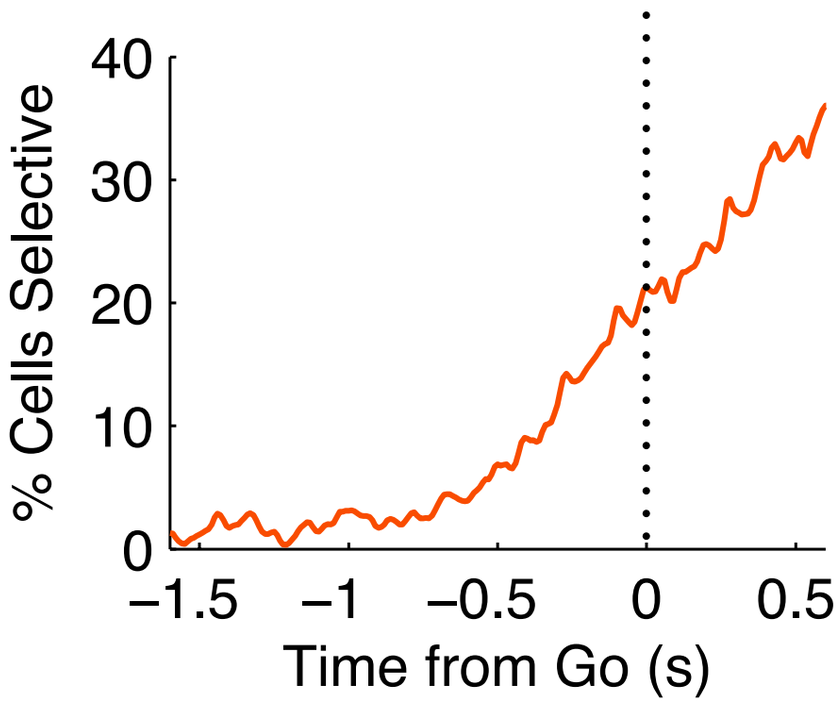


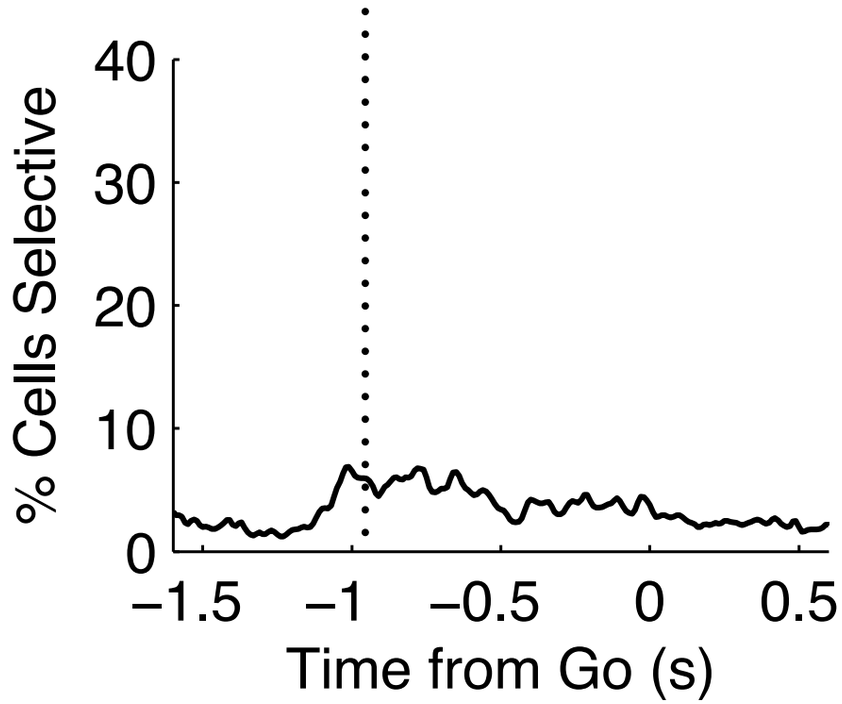
Variance in head angle to the rescue

Head orientation θ, correct Mem trials only



Selectivity of cells can not be accounted for simply by head angle during the delay period.





Summary

- Rats can be trained on “cognitive control” tasks like memory-guided orienting
- Inactivation of activity in FOF with muscimol disrupts contralateral responding, **especially on memory trials**
- FOF neurons **prospectively** encode the rats response during the delay period.
- **The FOF is a key cortical region for the memory/ planning of orienting head movements**
- **Studying decision-making in rats should allow us to bridge the gap between knowledge about rat navigation and primate decision-making**

Work (ongoing and future)

- Modeling: muscimol results, contra/ipsi asymmetry
- What is the source/purpose of the heterogeneity in responses?
- How does the rat inhibit responses during the delay? Where is the sensorimotor transformation? Role for PFC?
- Saccades? **Whiskers**?
- Tasks to disassociate attention from responses

Acknowledgements

Carlos Brody
Max Bialek

Joe Jun
Bing Brunton
Filip Ponulak
Chuck Kopec
Tim Hanks

Glyn Brown
Klaus Osorio
Sergei Karnup

Happy Canada Day!