

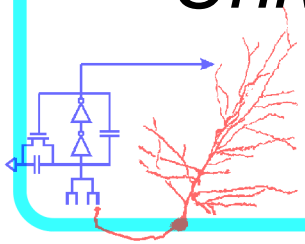
# *“Foreground and Background at the Cocktail Party”*

## *A Neural and Behavioral Study of Top-Down and Bottom-Up Auditory Attention*

Jonathan Z. Simon

*Neuroscience and Cognitive Sciences /  
Biology / Electrical & Computer Engineering*

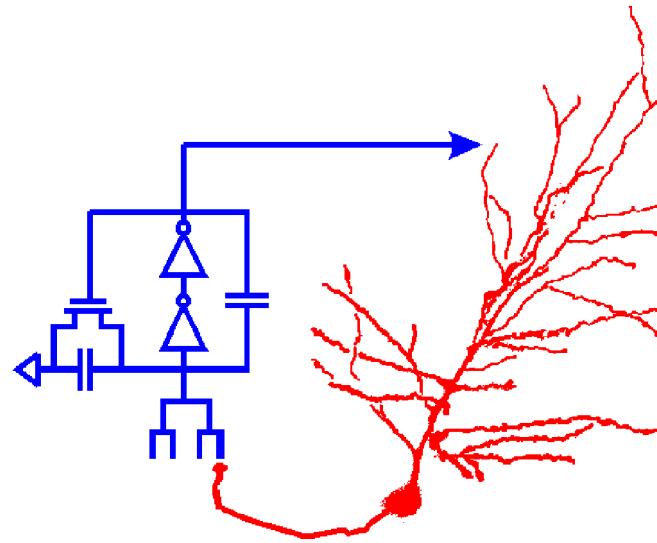
*University of Maryland, College Park*



I.U. Seminar March 20, 2008

Computational Sensorimotor Systems Laboratory

# Computational Sensorimotor Systems Laboratory



## Current & Former Students

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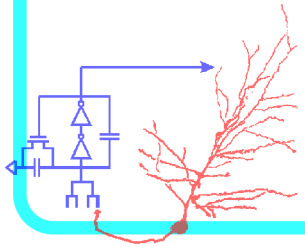
Shihab Shamma

## Supported by

NIH: NIDCD, NIBIB, NIA

# Outline

- Magnetoencephalography (MEG) as a tool of Non-Invasive Auditory Physiology
- MEG in the Frequency Domain
- Neural & Behavioral Correlates of Auditory Attention



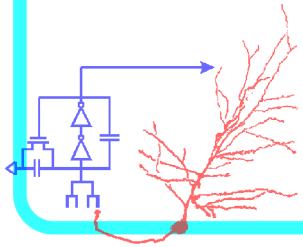
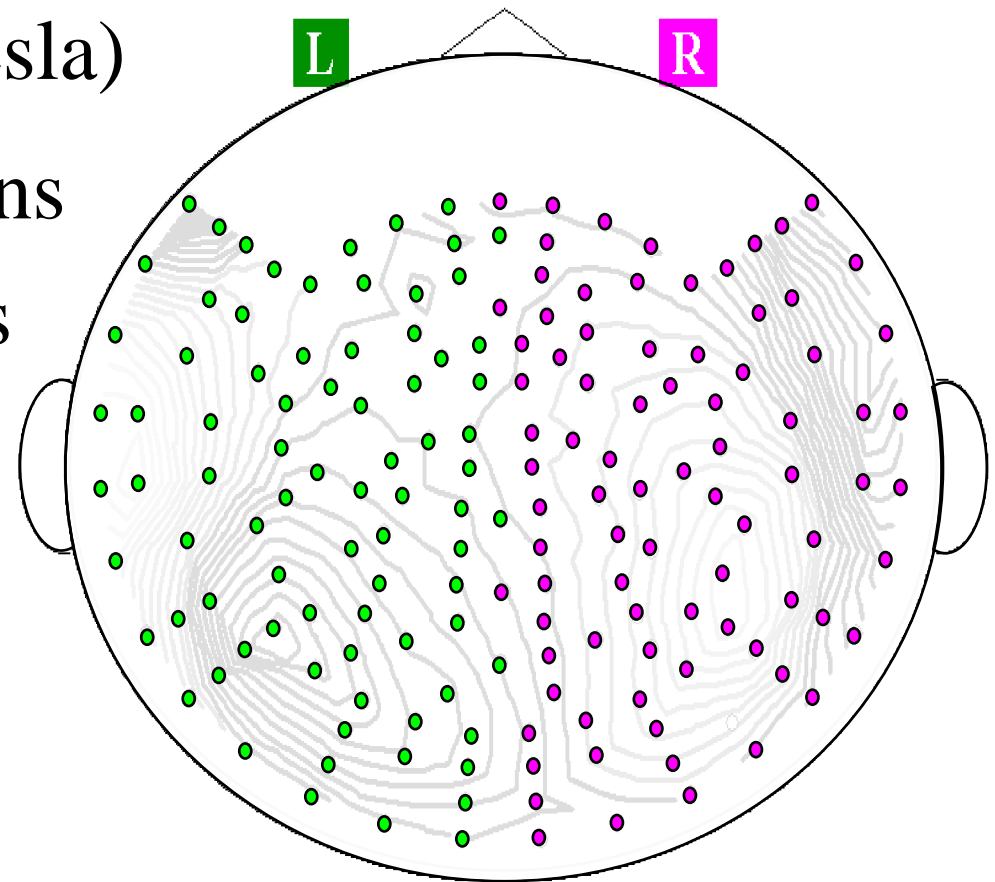
# Magnetoencephalography (MEG)

- Non-invasive, Passive, Silent Neural Recordings
- Simultaneous Whole-Head Recording (~200 sensors)
- Sensitivity

high:  $\sim 100$  fT ( $10^{-13}$  Tesla)

low:  $\sim 10^4 - \sim 10^6$  neurons

- Temporal Resolution:  $\sim 1$  ms
- Spatial Resolution  
coarse:  $\sim 1$  cm  
ambiguous





# Functional Imaging

Non-invasive recording  
from human brain  
(Functional brain imaging)

Hemodynamic  
techniques

Functional magnetic  
resonance imaging  
fMRI

Excellent *spatial resolution*  
( ~ 1-2 mm)  
Poor temporal resolution  
( ~ 1 s)

Positron emission  
tomography  
PET

PET, EEG require  
across-subject  
averaging

fMRI and MEG can  
capture effects in  
single subjects

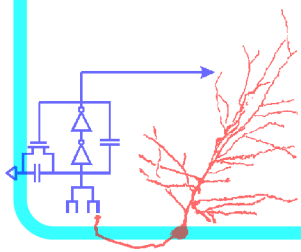
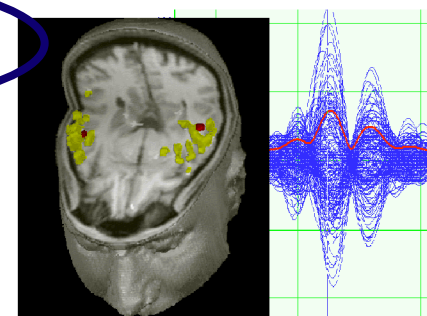
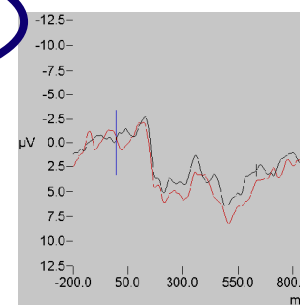
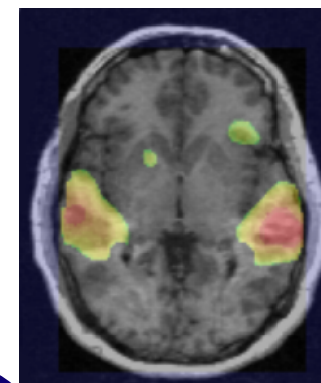
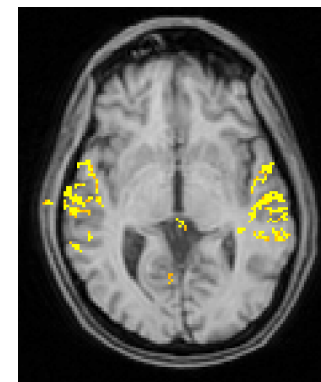
Electroencephalography  
EEG

Electromagnetic  
techniques

Poor spatial resolution  
( ~ 1 cm)

Excellent *temporal resolution*  
( ~ 1 ms)

Magnetoencephalography  
MEG



# Primary Neural Current

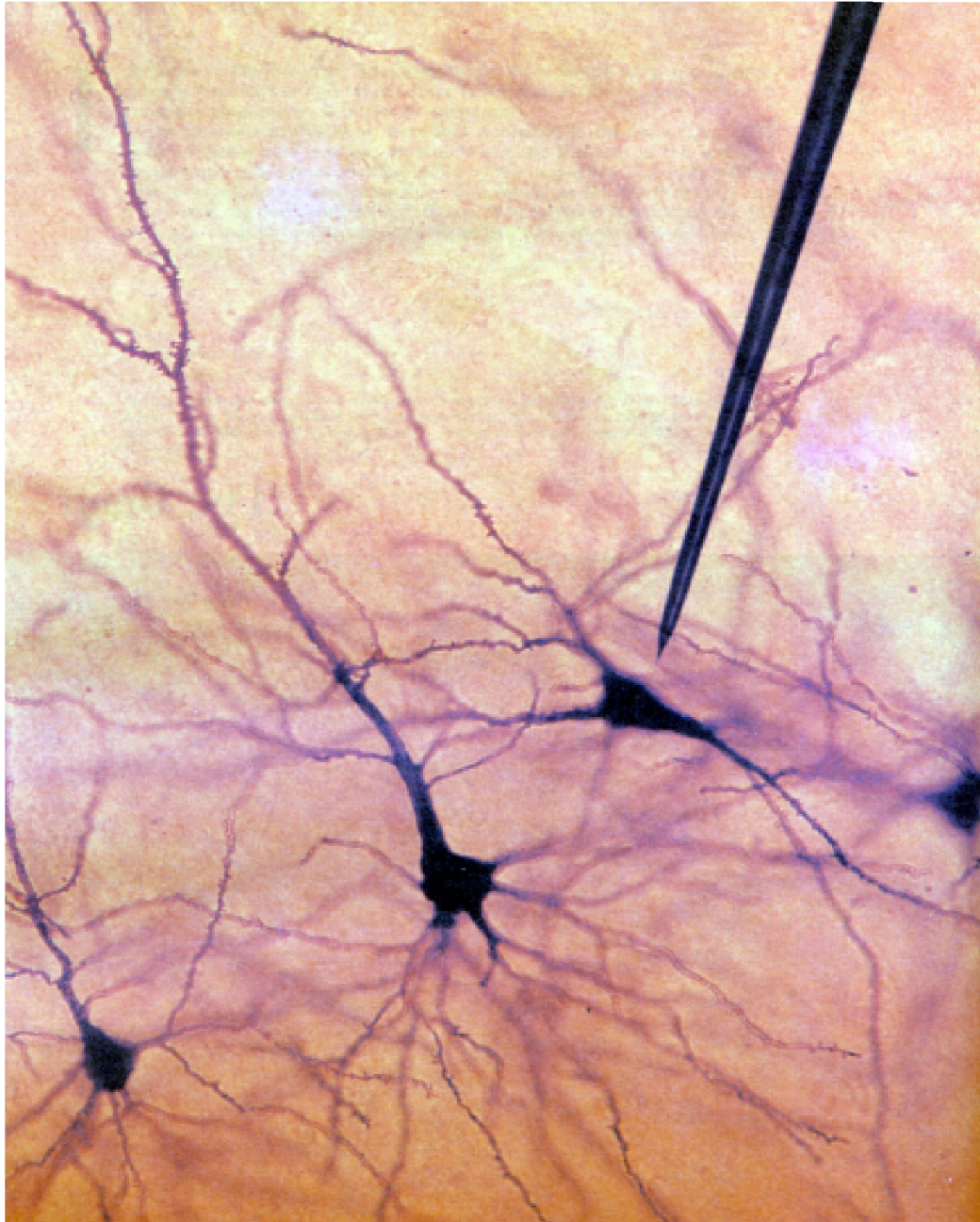
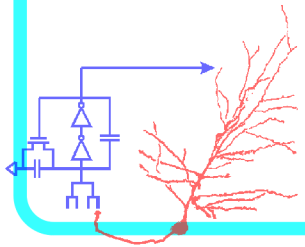


Photo by Fritz Goro



# Primary Neural Current

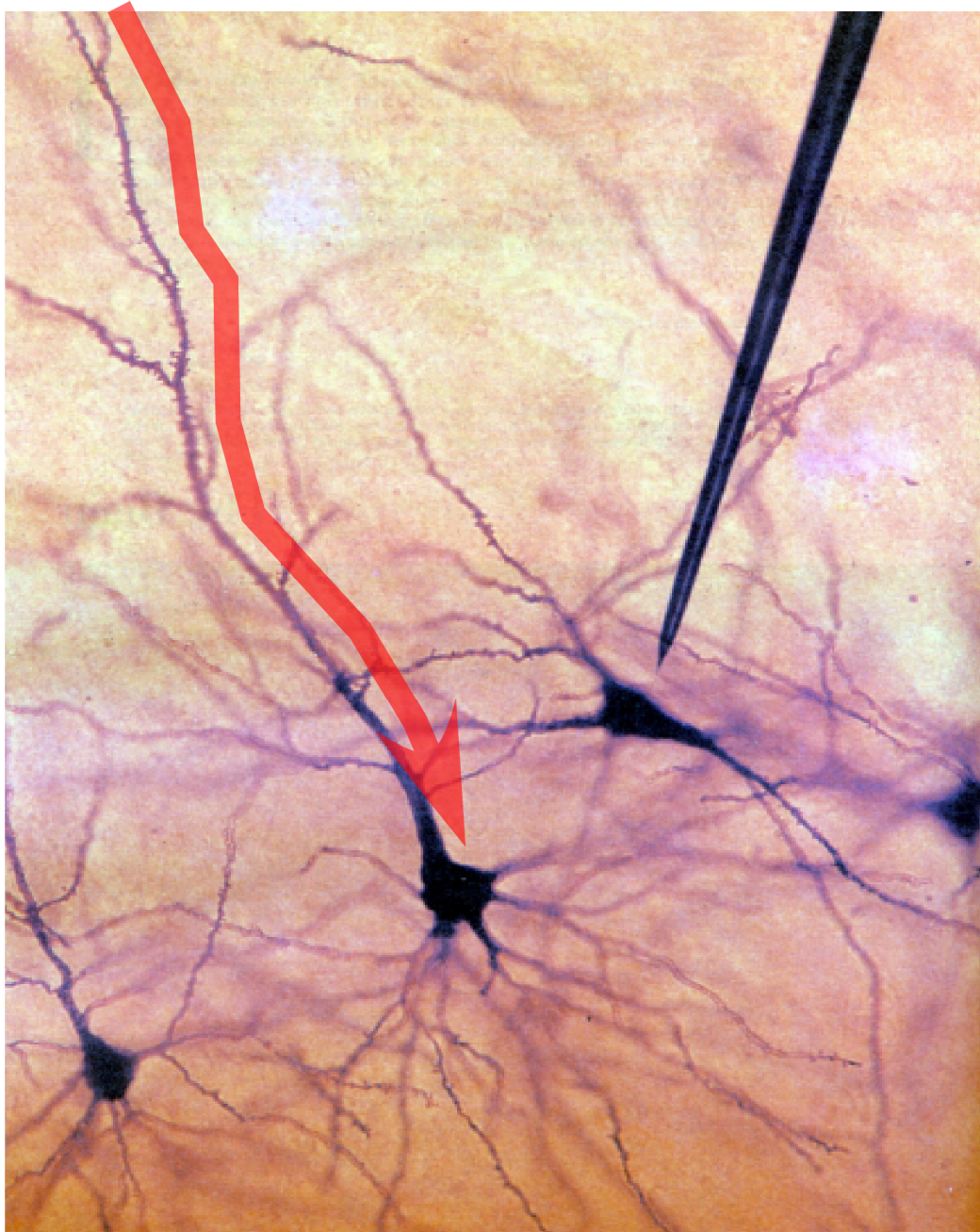
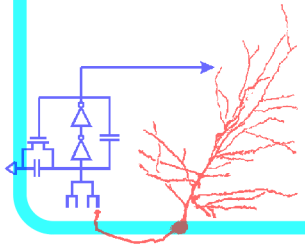
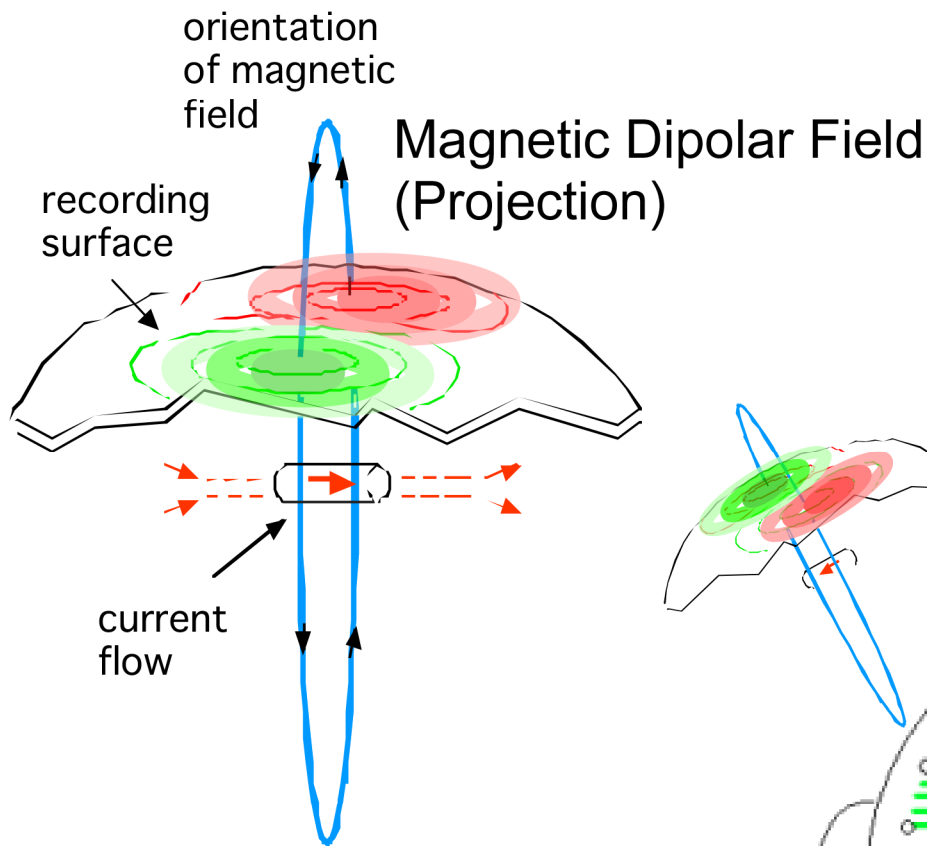


Photo by Fritz Goro

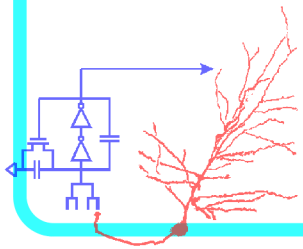
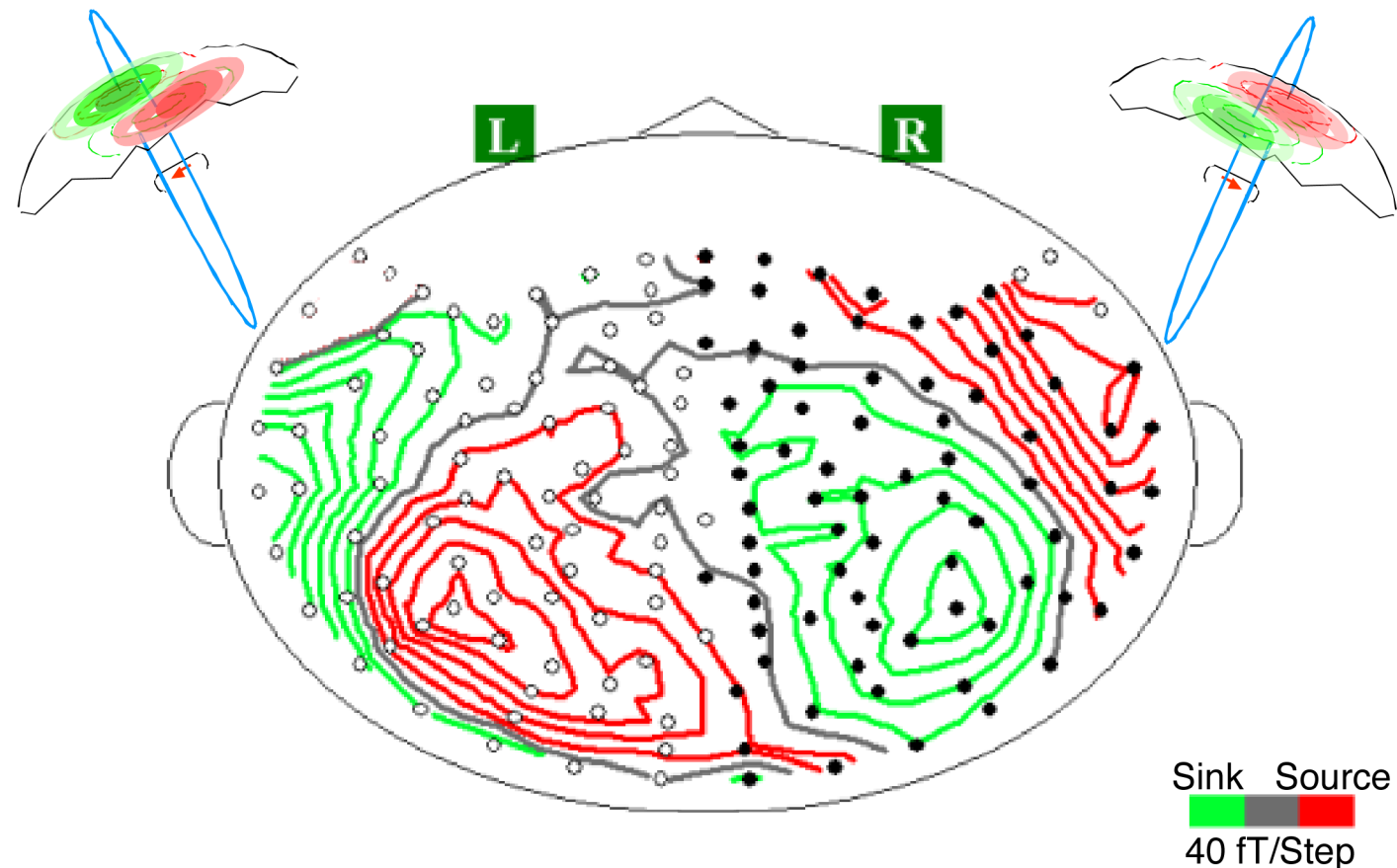




# MEG Measures Neural Currents



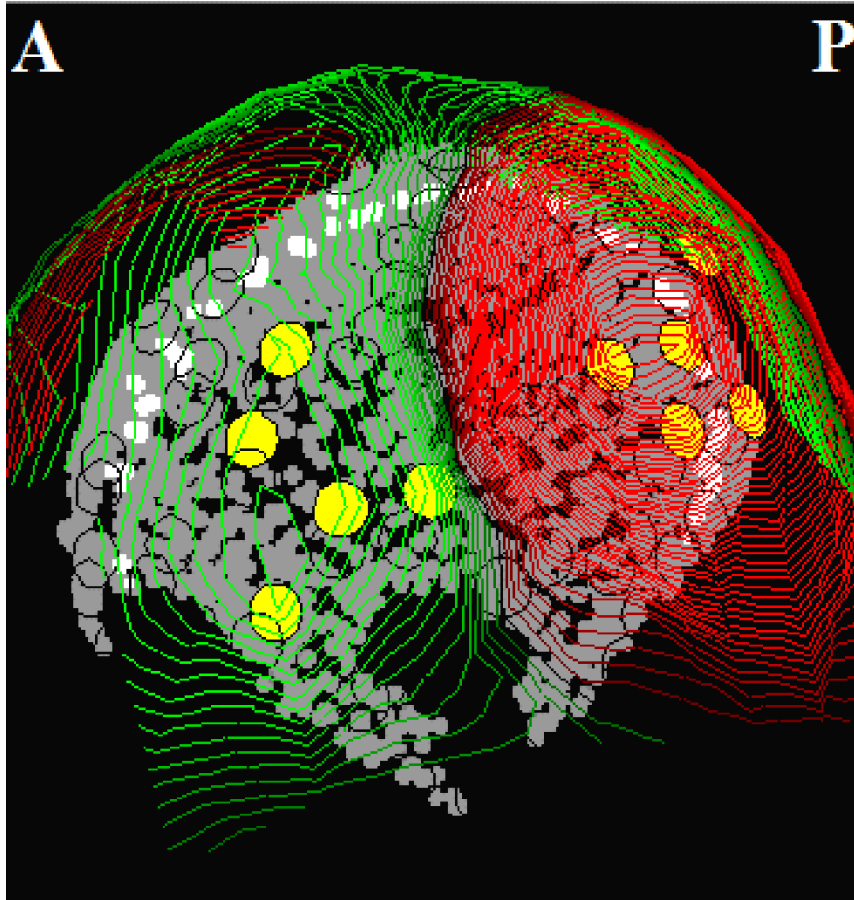
- MEG = Magnetoencephalography
- Direct electrophysiological measurement
  - not hemodynamic
  - real-time
- No unique solution for distributed source



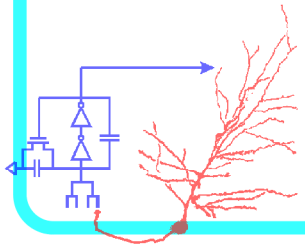
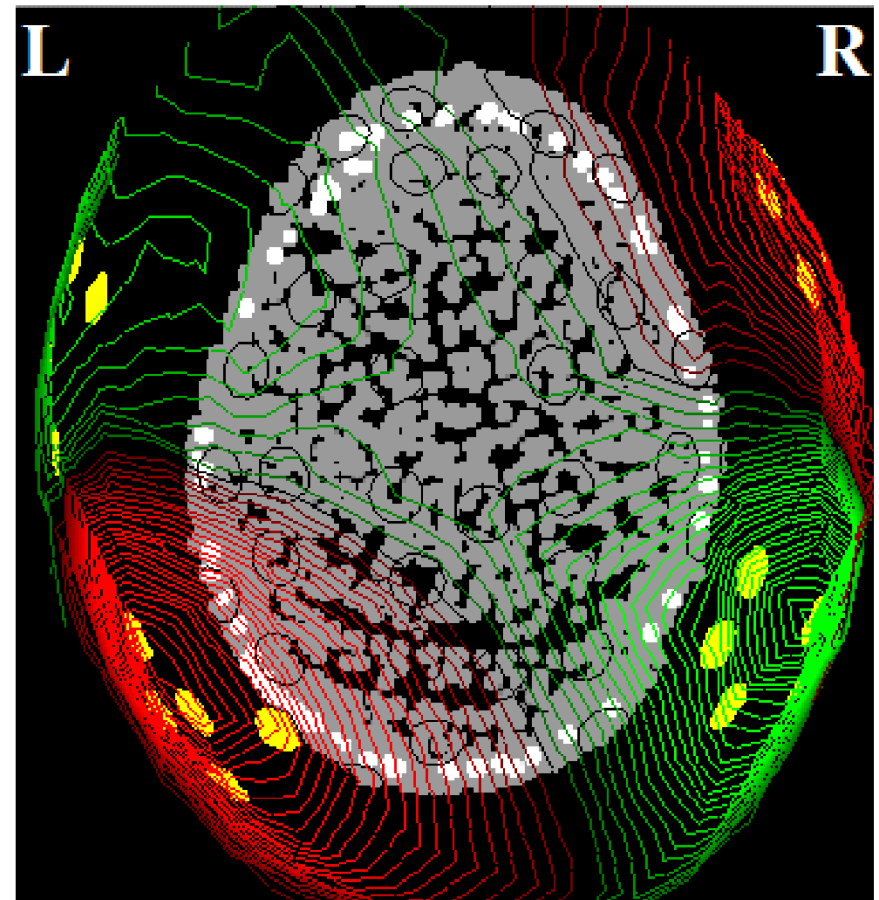
# MEG Response

## 3-D Isofield Contour Map

Sagittal View



Axial View

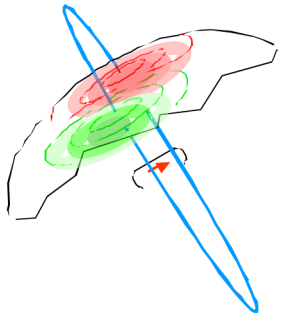


Chait et al.,  
Cerebral Cortex 2006

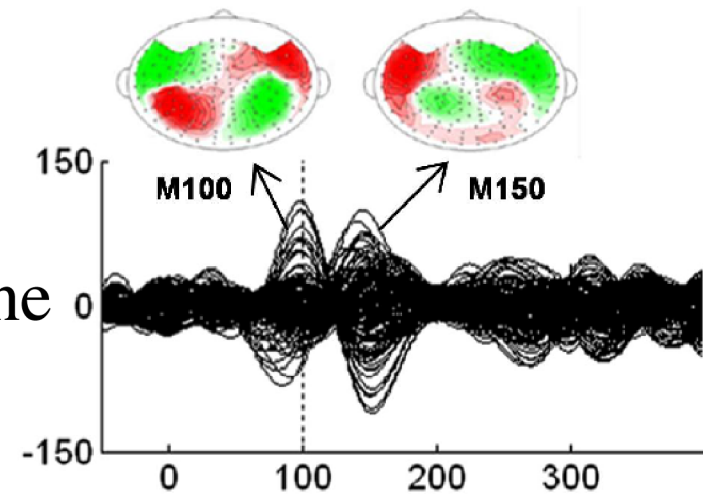
# Time Course of MEG Responses

## Evoked Responses

MEG Events Time-Locked  
to Stimulus Event

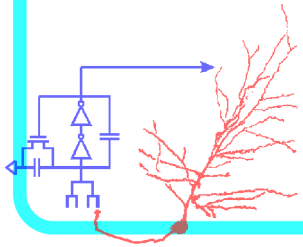
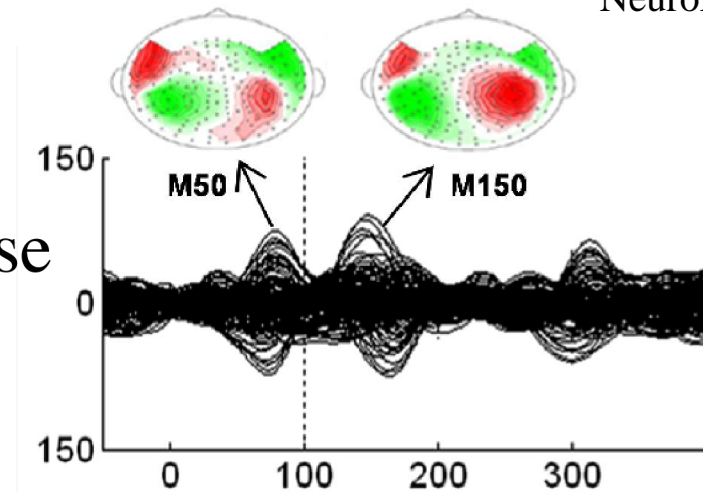


Pure Tone

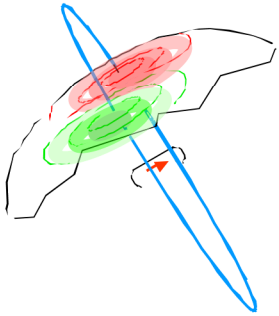


Chait et al.,  
NeuroReport 2004

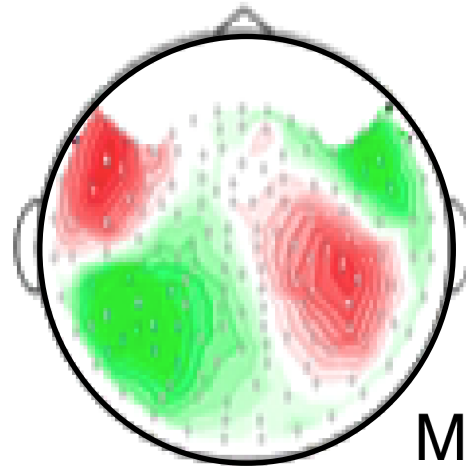
Broadband Noise



# Spatial Auditory MEG Responses

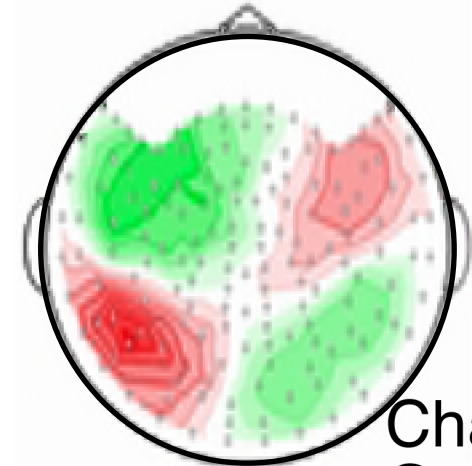


Auditory Responses  
*Robust*  
*Strongly Lateralized*



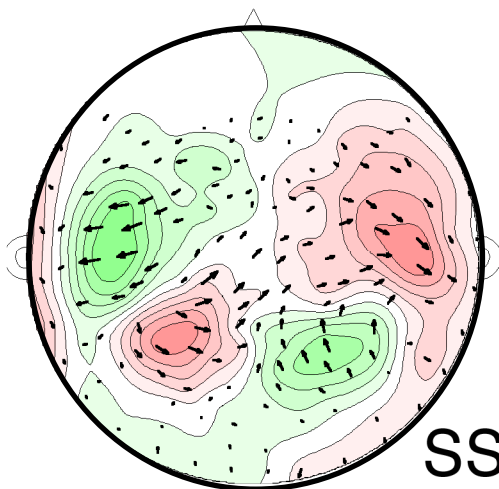
M50

Chait et al.,  
NeuroReport 2004



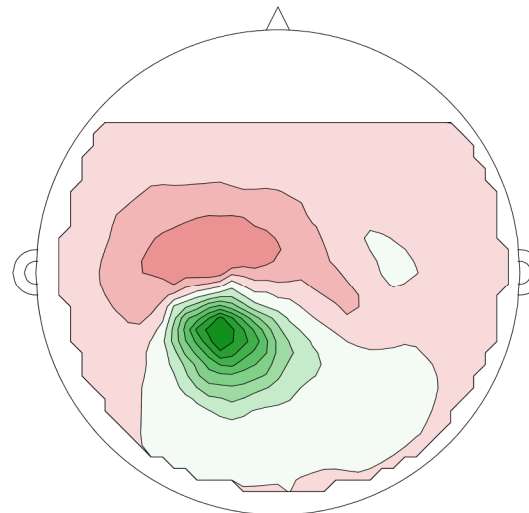
Change  
Onset

Chait et al.,  
J. Neuroscience 2007



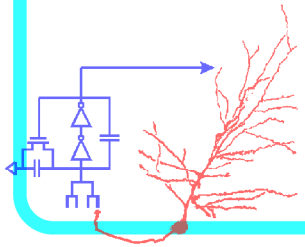
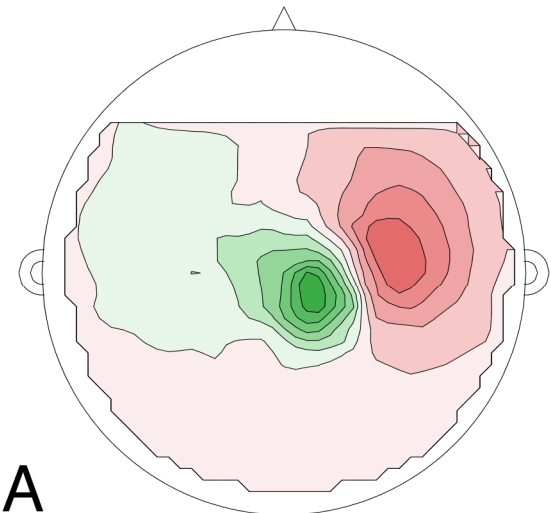
SSR

Simon & Wang  
J. Neuroscience Methods 2005



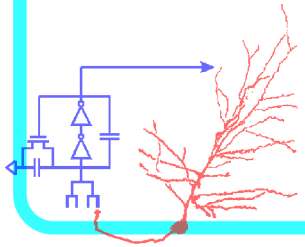
ICA

Xiang et al.,  
Neural Engineering 2005



# *MEG as Auditory Physiology Tool*

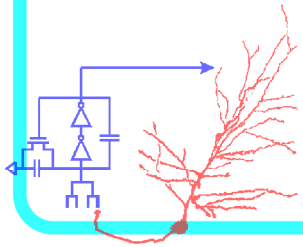
- Advantages of humans over animals
  - Subjects can be rented (by the hour)
  - Subjects can be trained in minutes
  - Better grasp of subjects' perceptual space (?)
  - Access to Speech & Language processing (?)
- Advantage of Whole Head Recording
- Disadvantage of Neural Source Localization
  - Coarseness/Ambiguity in Source Location
  - Blindness to Many Kinds of Coding
- Neutral Aspects
  - Neural Source is Dendritic Current (not Spikes)
  - Humans not typical mammals (?)
  - New Technique/Immature Analysis Tools





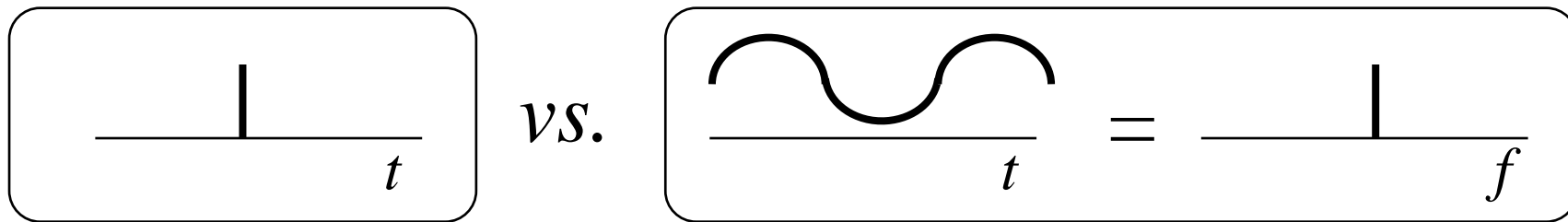
# Outline

- Magnetoencephalography (MEG) as a tool of Non-Invasive Auditory Physiology
- **MEG in the Frequency Domain**
- Neural & Behavioral Correlates of Auditory Attention

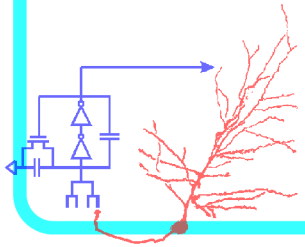


# *An Alternative to Time: Frequency*

- Use Stimuli localized in Frequency, not time

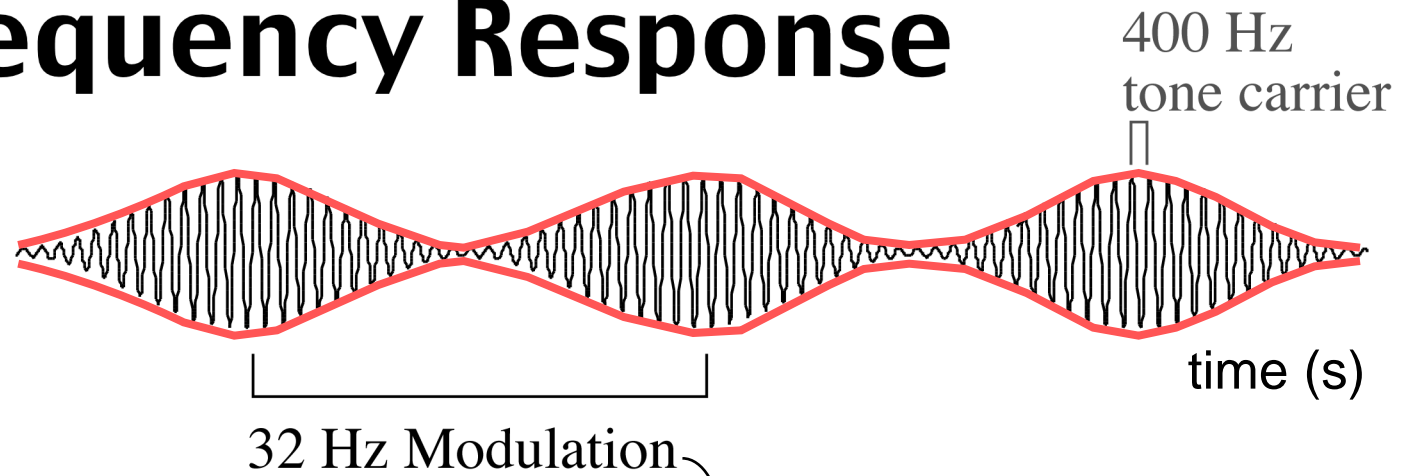


- Examine Response at Same Frequency
- Steady State Response (SSR)
- Frequency Response/Transfer Function

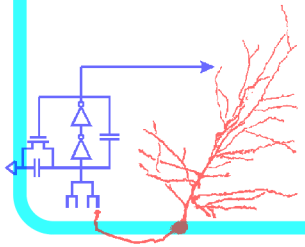
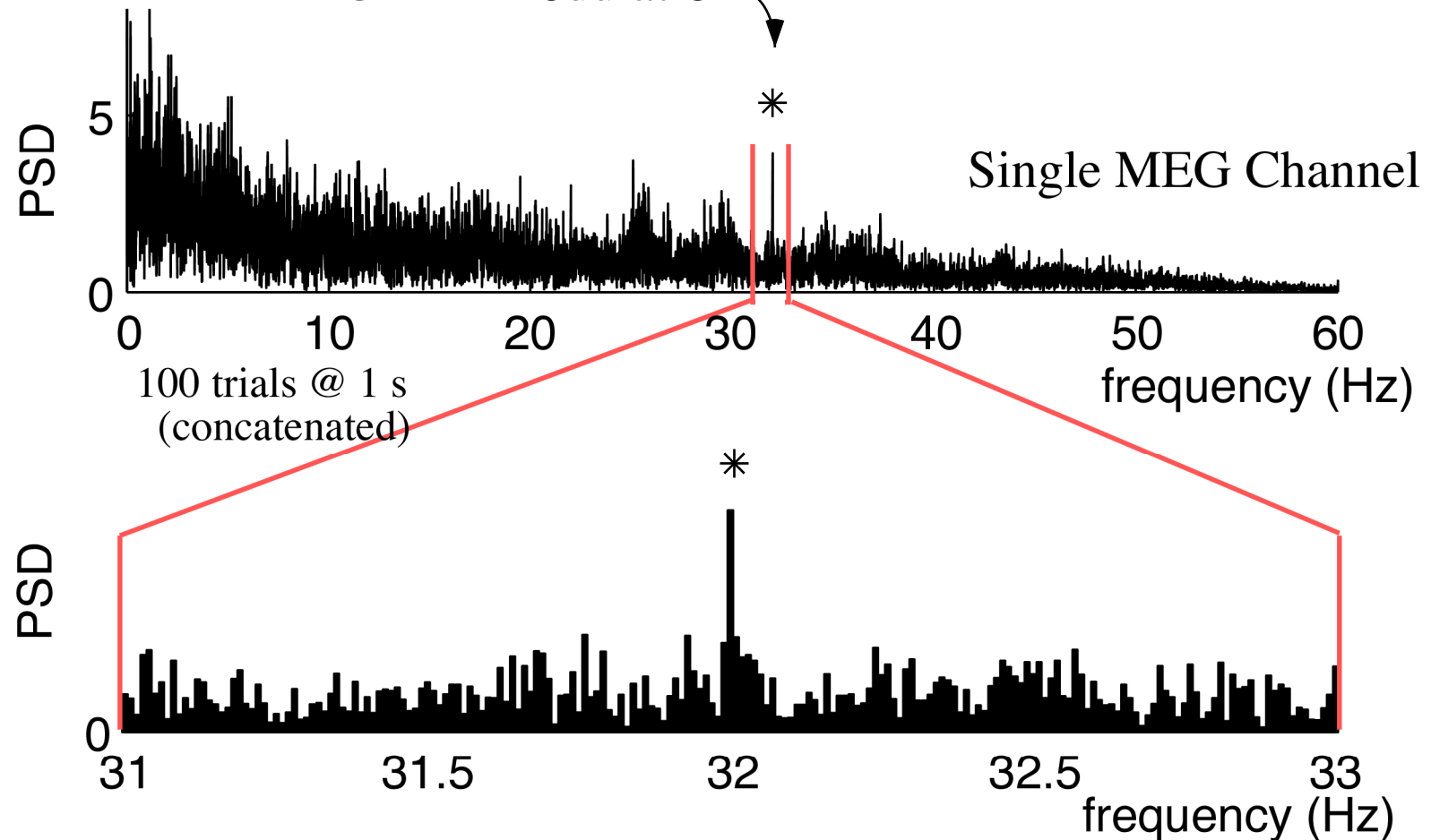


# Frequency Response

Stimulus

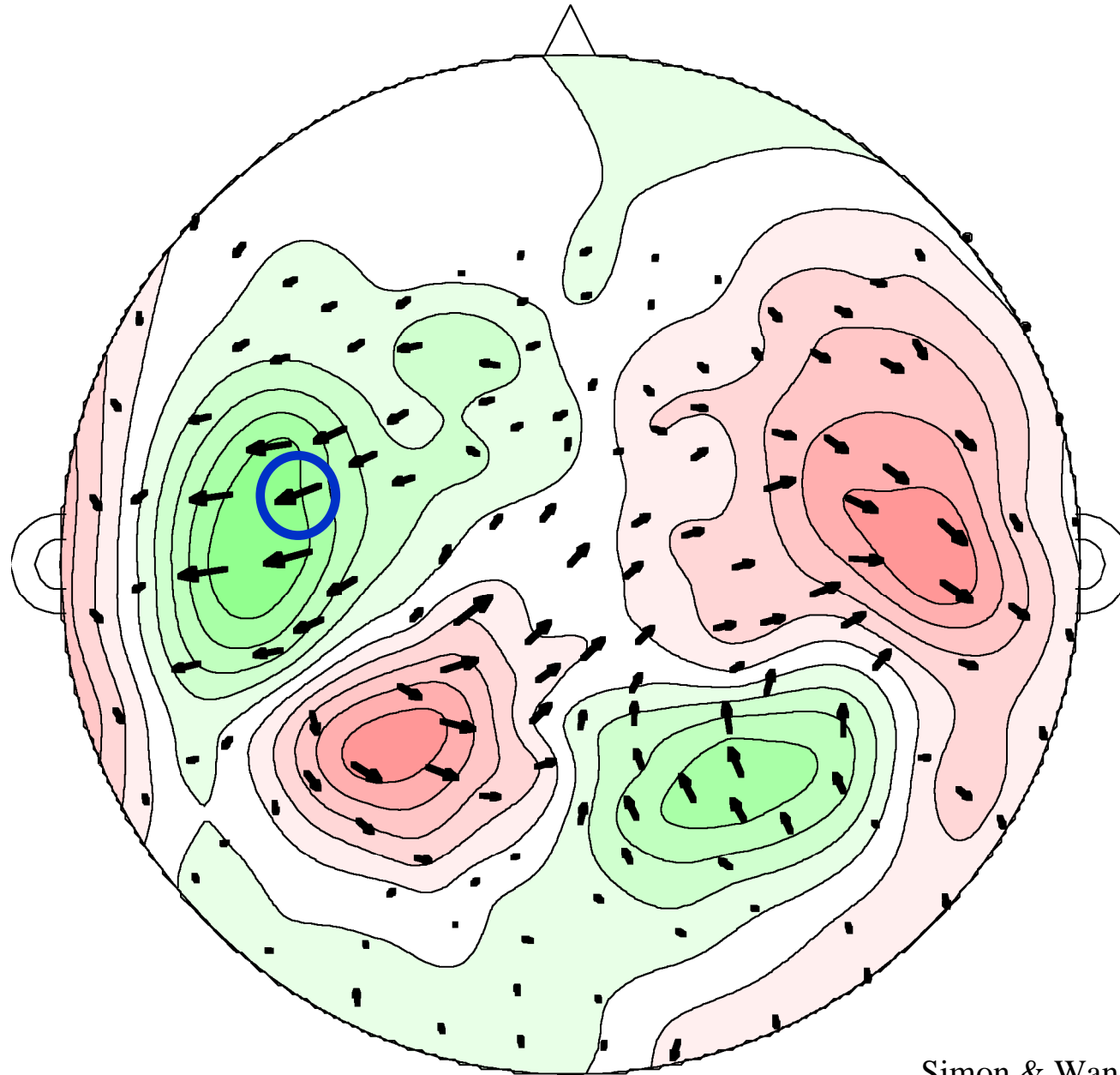


Response

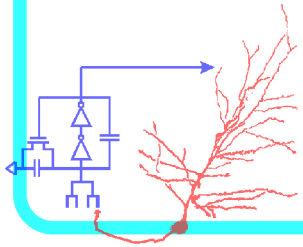


Precise Phase-Locking: 0.01 Hz  
Little trial-to-trial jitter

# Whole Head Steady State Response



32 Hz

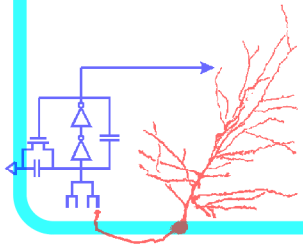


Simon & Wang  
J. Neuroscience Methods 2005

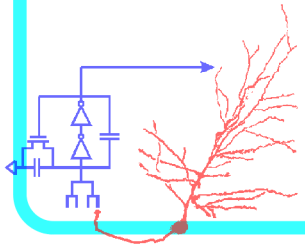
Computational Sensorimotor Systems Laboratory

# Outline

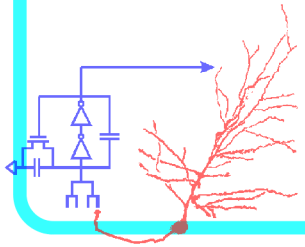
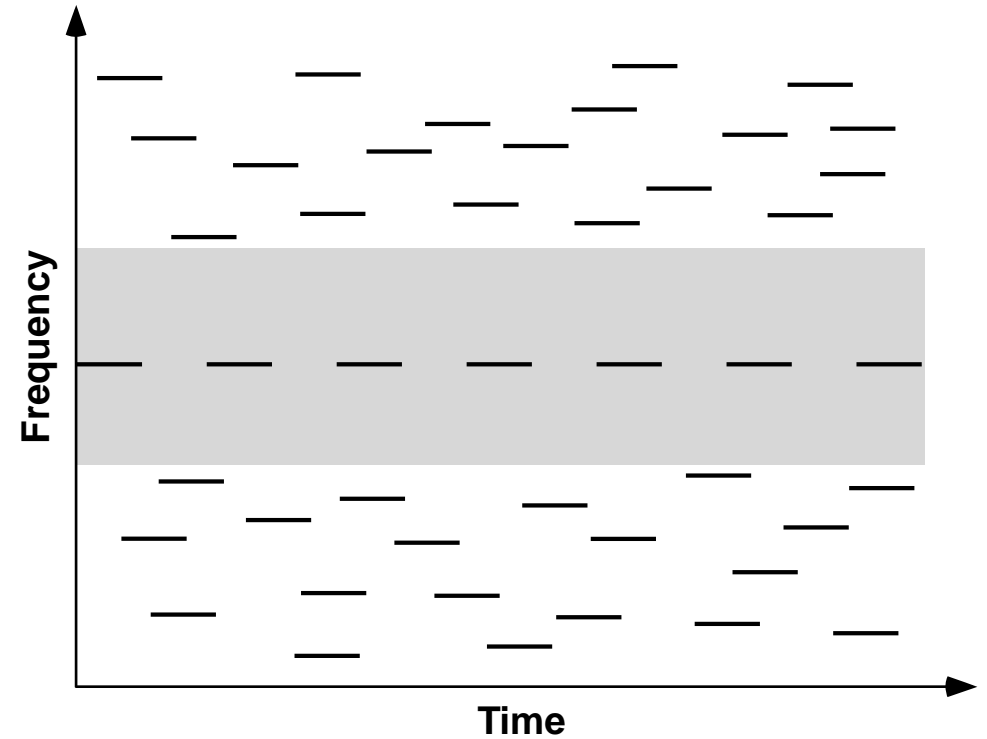
- Magnetoencephalography (MEG) as a tool of Non-Invasive Auditory Physiology
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# *Foreground & Background*

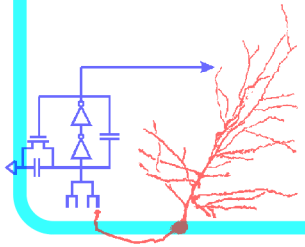
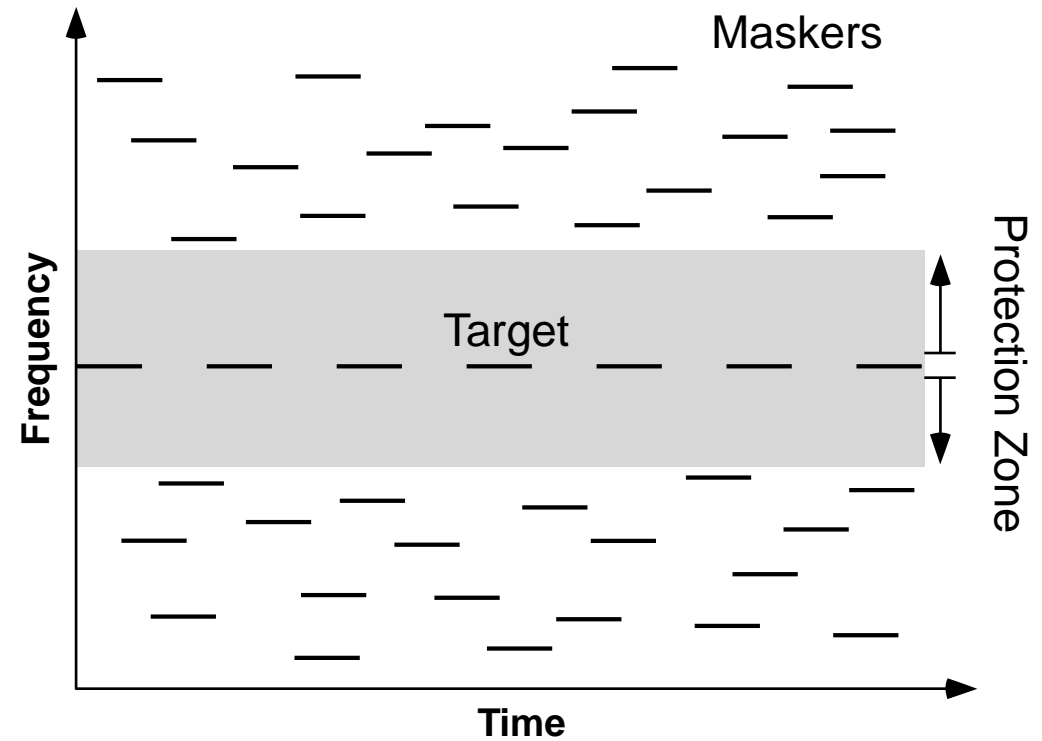


# Foreground & Background



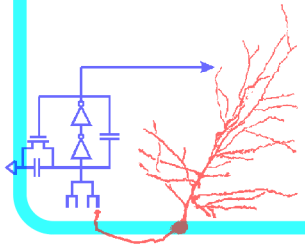
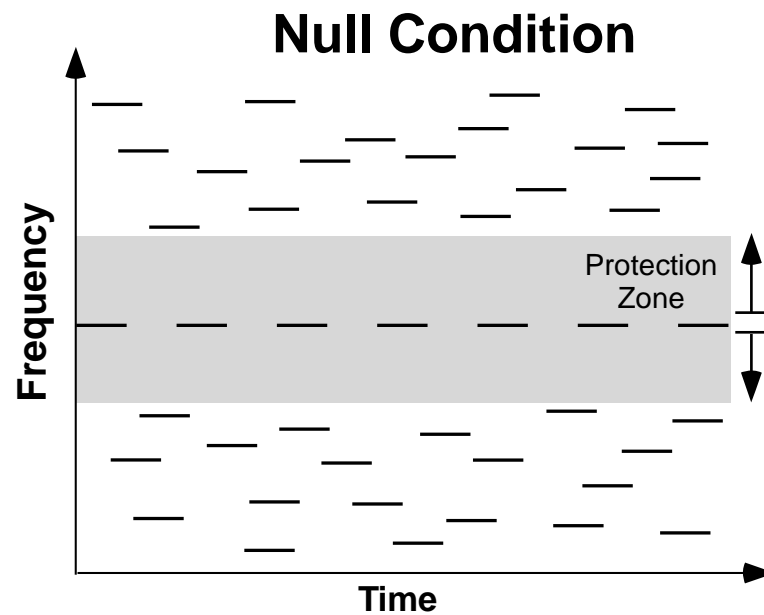


# Foreground & Background

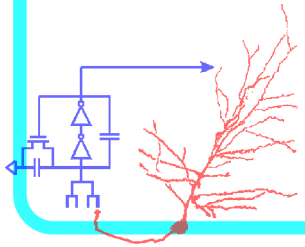
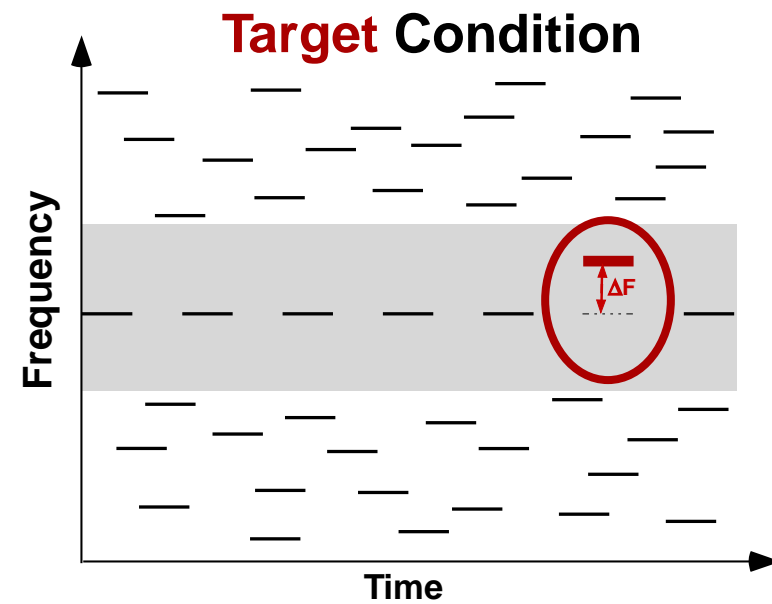
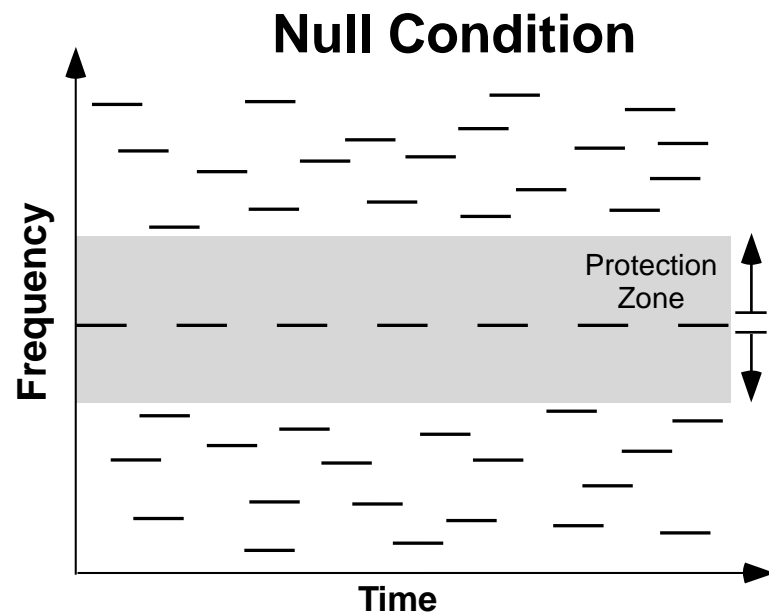




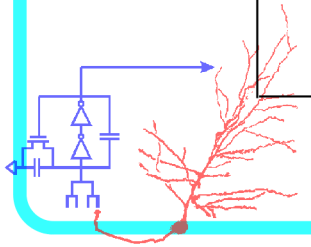
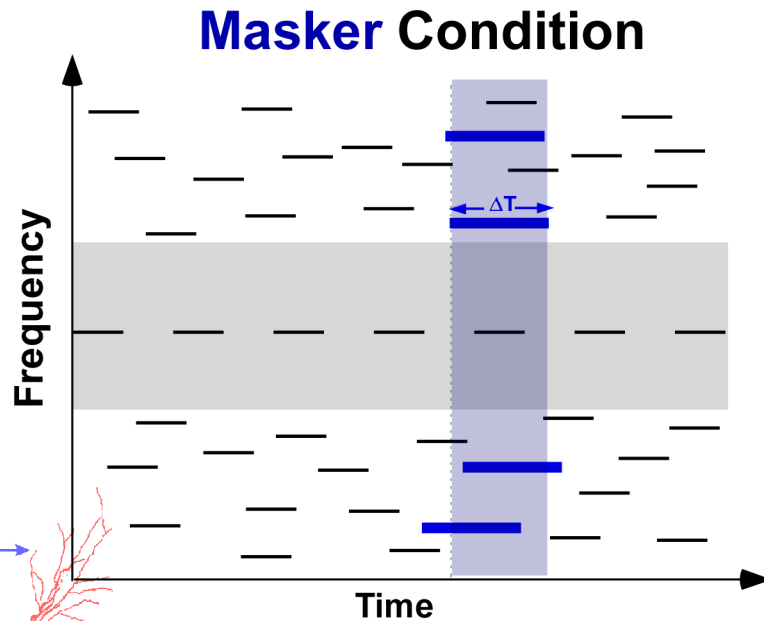
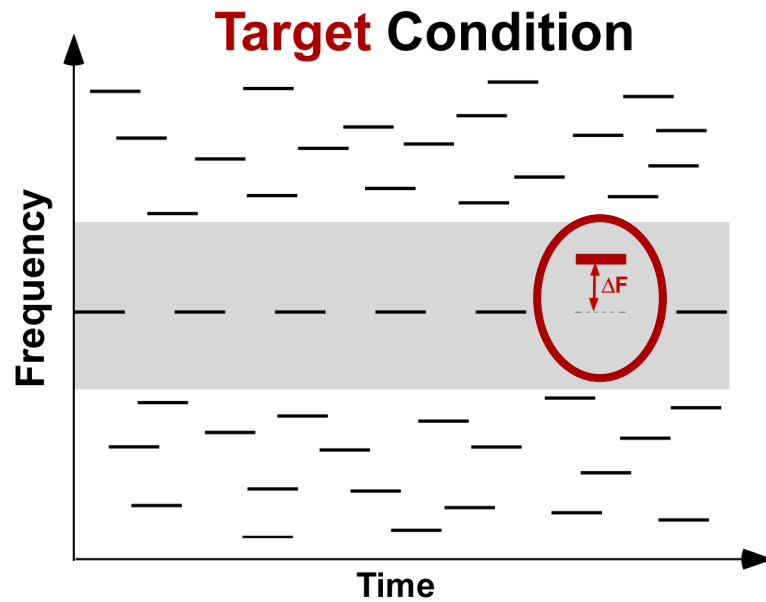
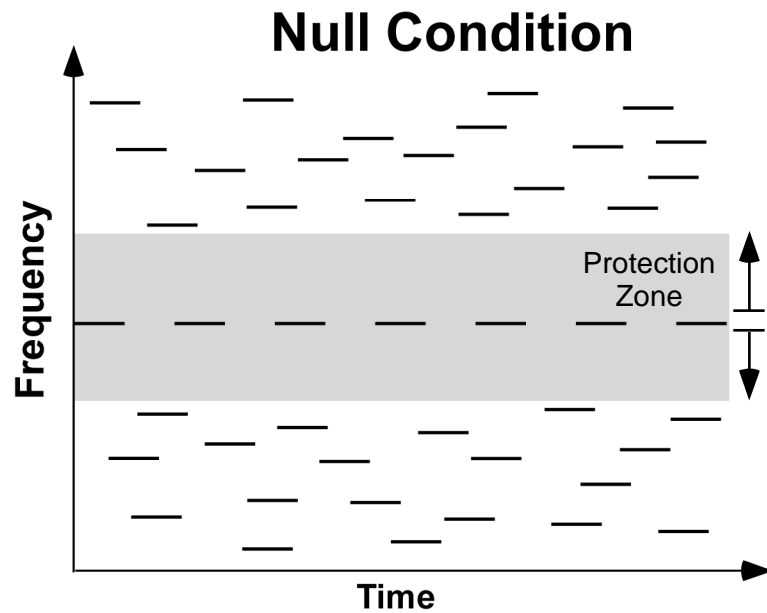
# *Experimental Paradigm*



# Experimental Paradigm

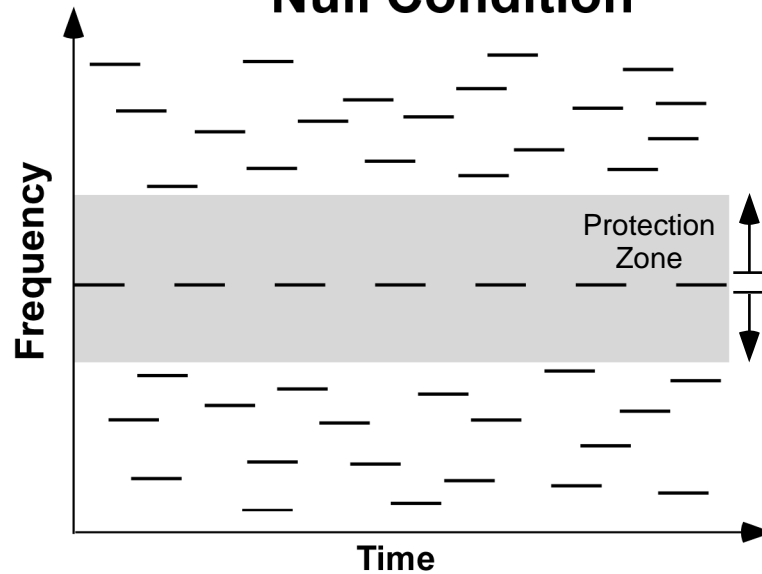


# Experimental Paradigm

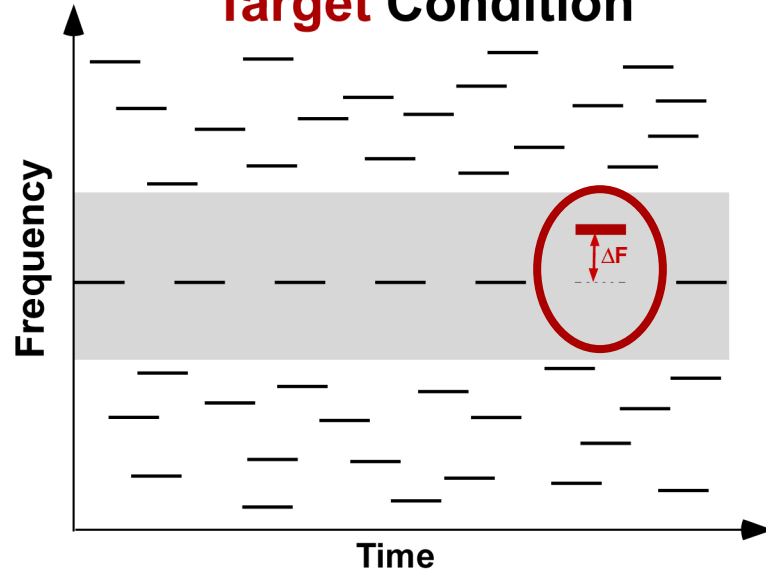


# Experimental Paradigm

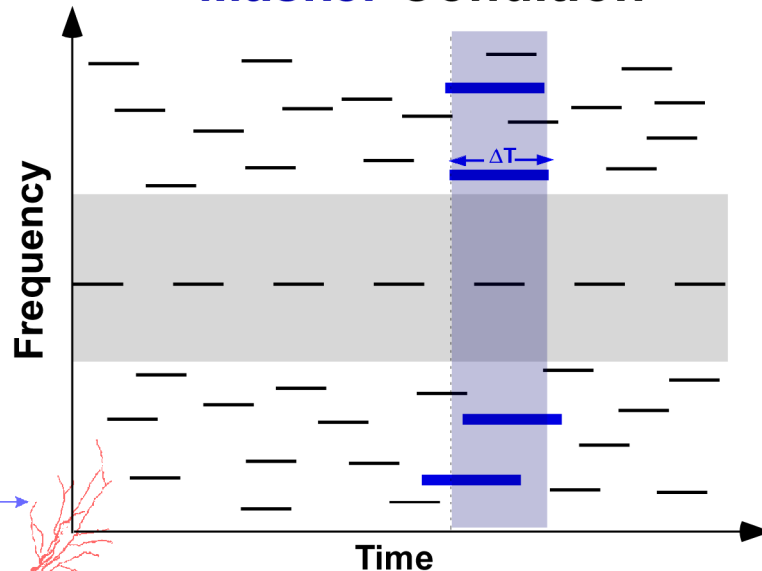
## Null Condition



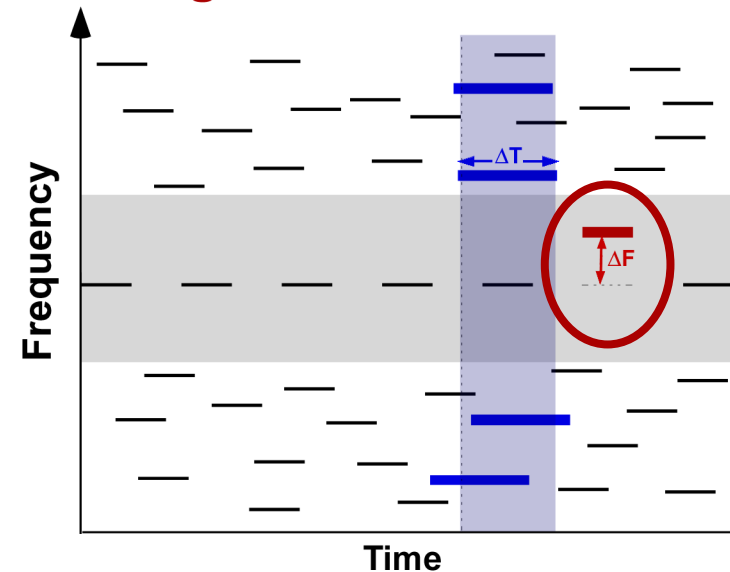
## Target Condition



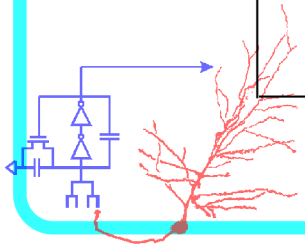
## Masker Condition



## Target & Masker Condition

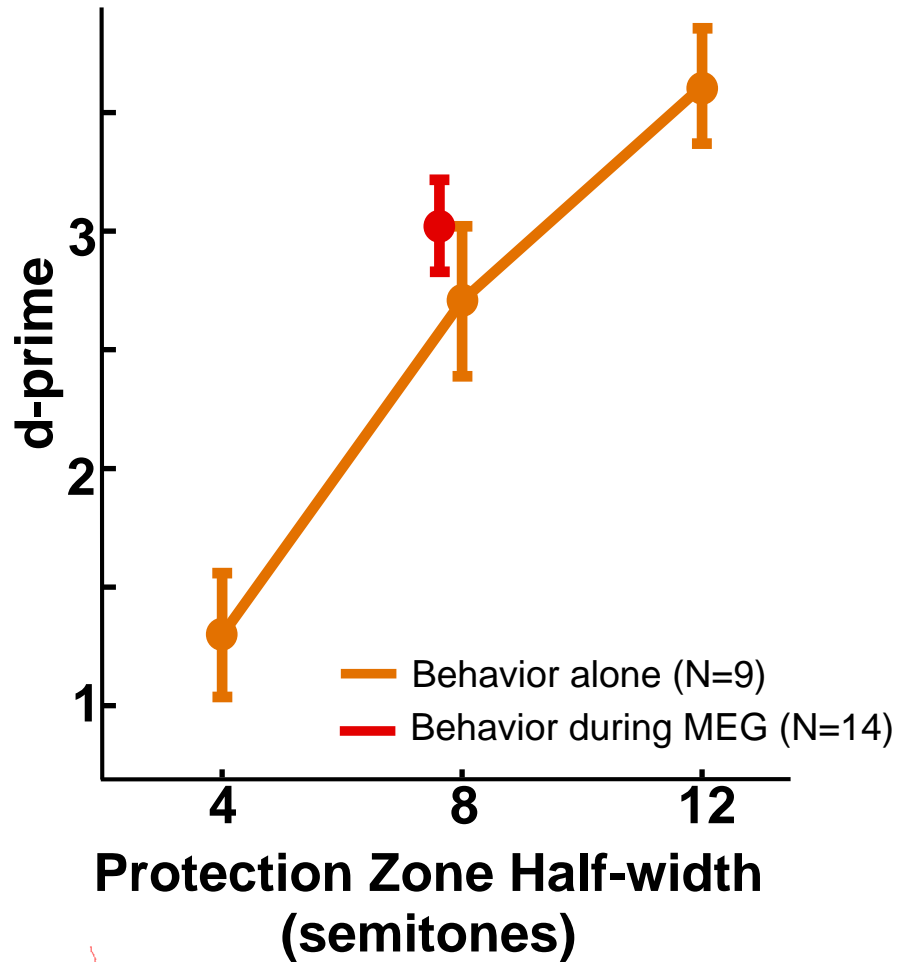


Target rate: 4Hz  
 Target rove: 250-500 Hz  
 Duration: 5.5 s  
 Protection Zone:  
 4, 8, 12 st/ 8 st  
 Band: 5 Oct @ 353 Hz  
 Tone dur: 75 ms  
 Target dev:  $\pm 2$  st  
 Masker dev: 400 ms

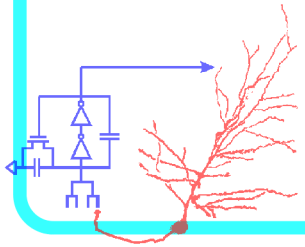
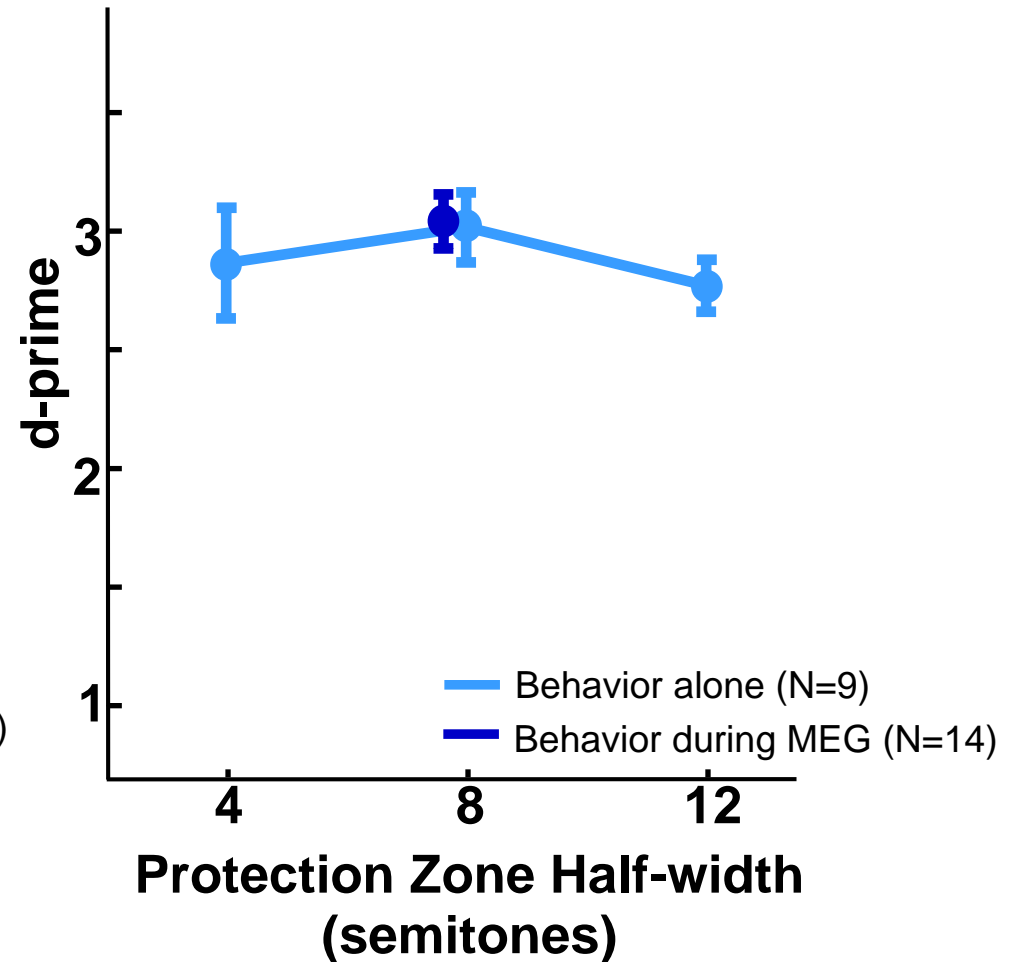


# Behavior

## Behavioral Performance for Target Task



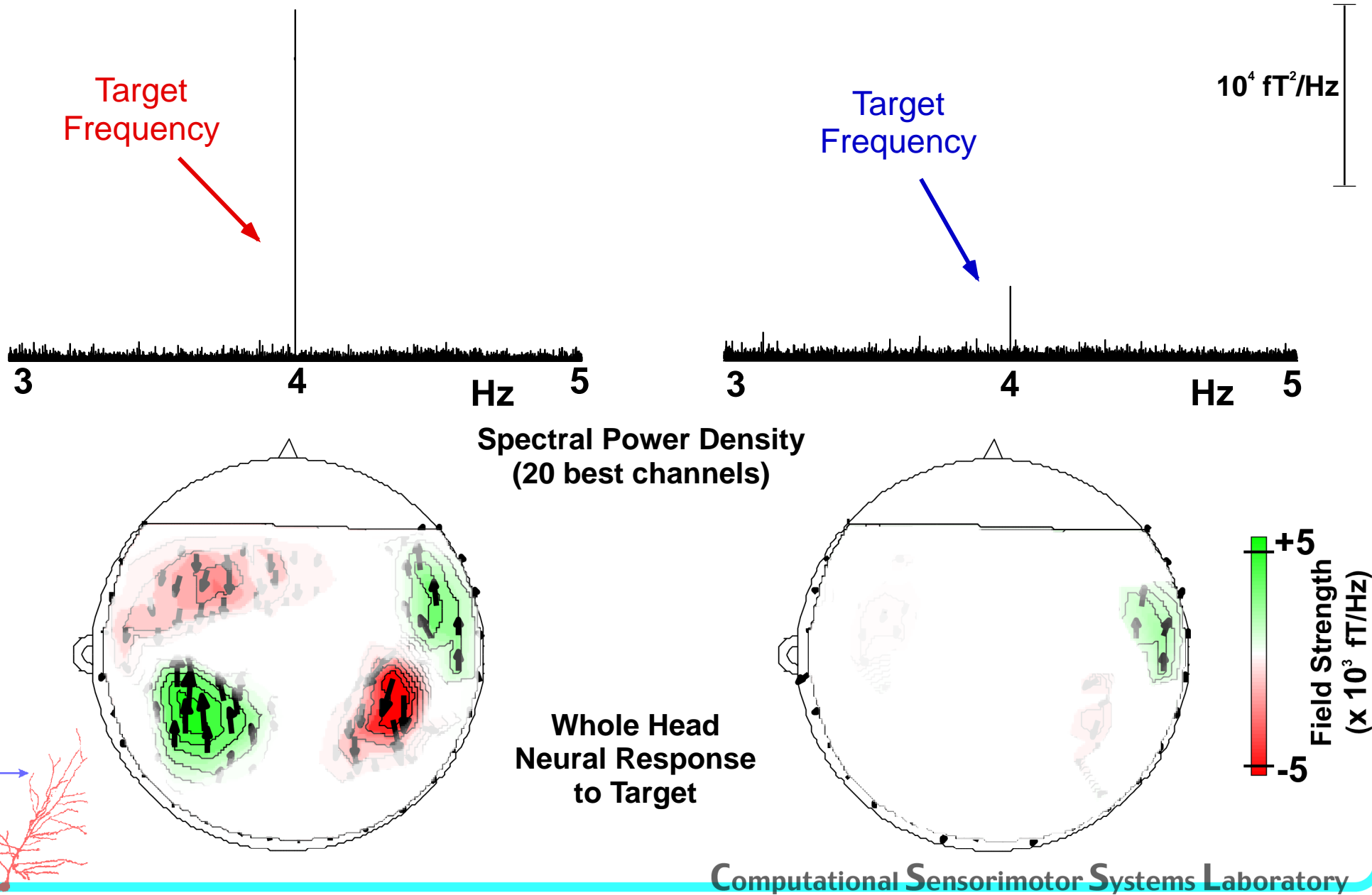
## Behavioral Performance for Masker Task



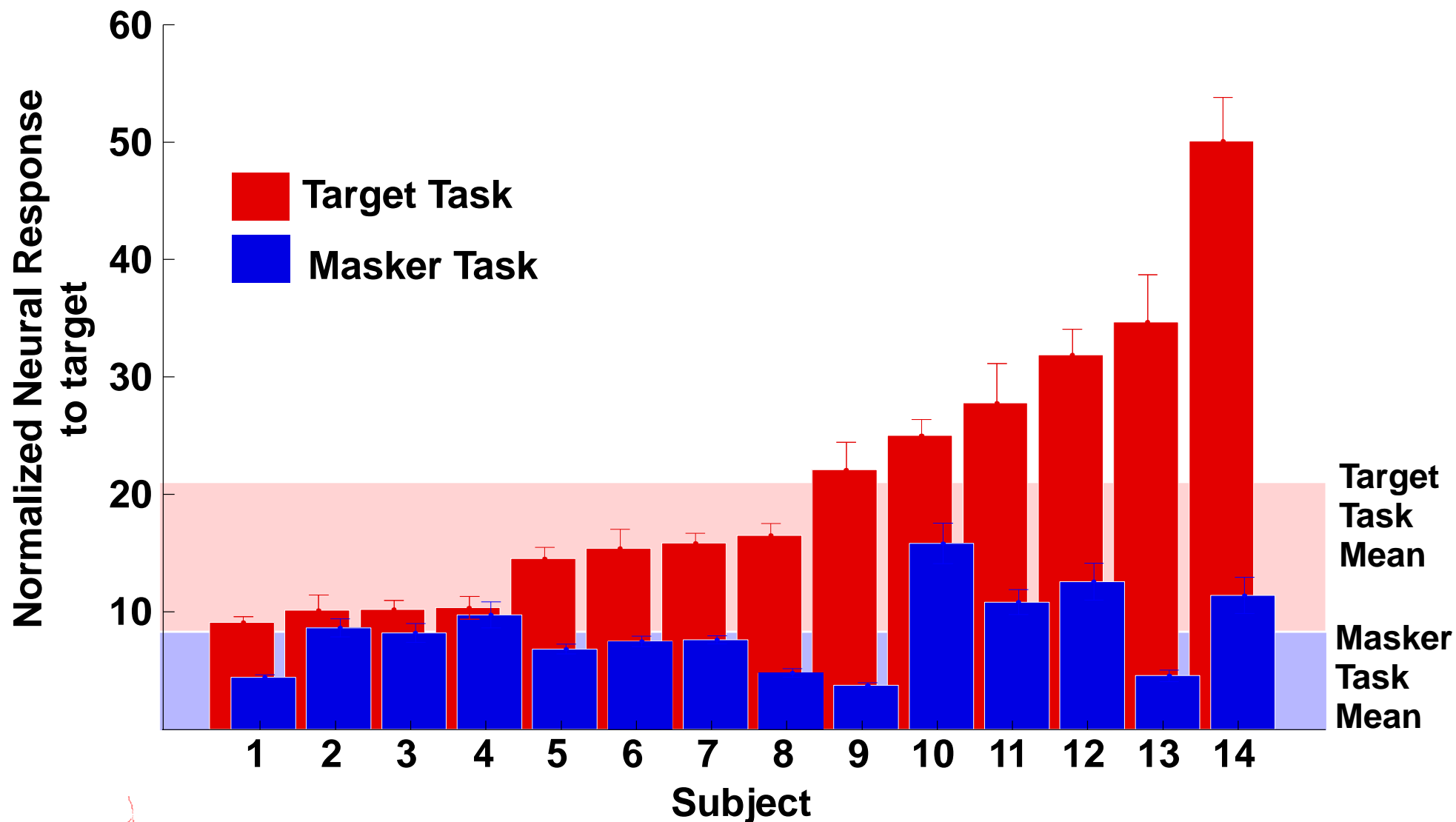
# Neural Response to Target

Neural Response to Target  
**Target Task**

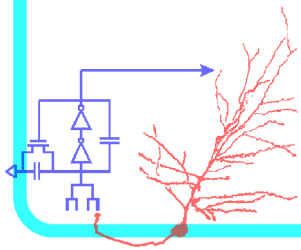
Neural Response to Target  
**Masker Task**



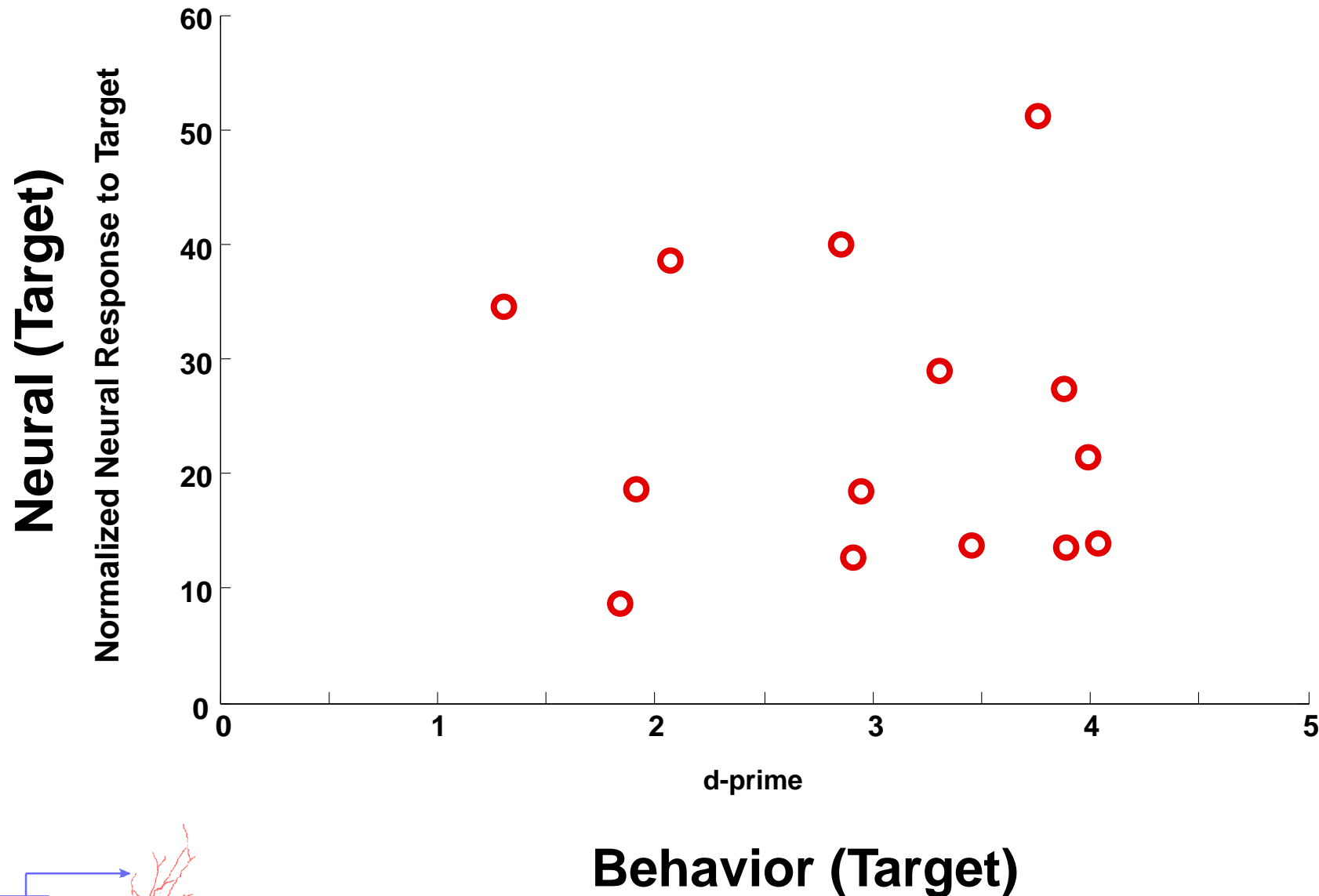
# Neural Response to Target by Subject



Mean Neural Source Location:  
 $14 \pm 5$  mm anterior to M100 Location  
Consistent with Heschl's Gyrus



# Neural Response to Target vs. Behavior



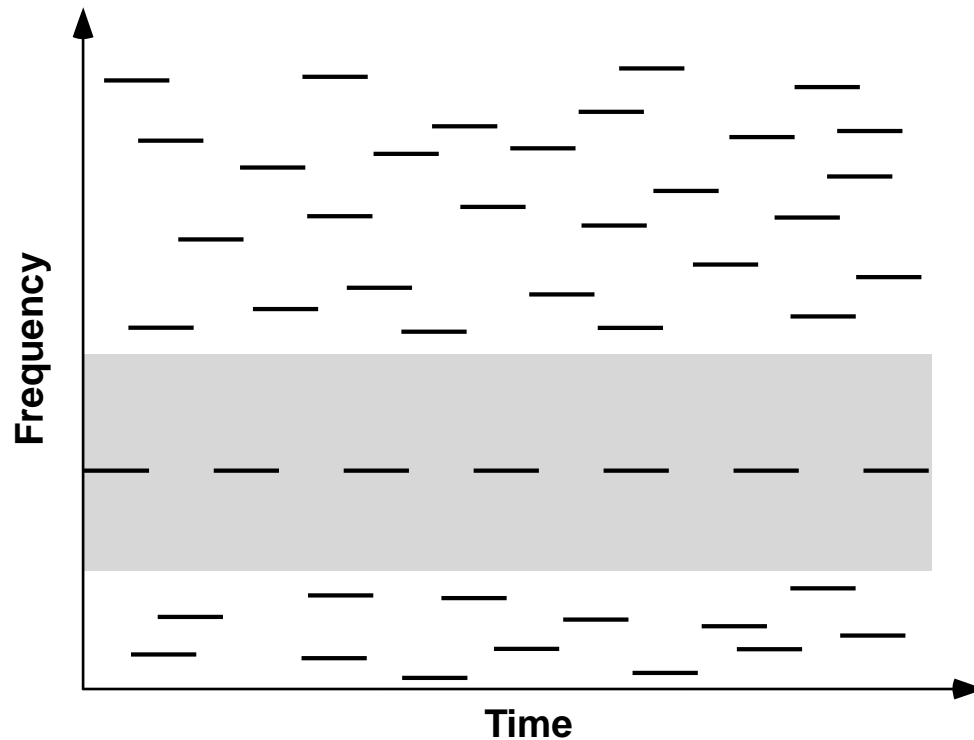
Target Task



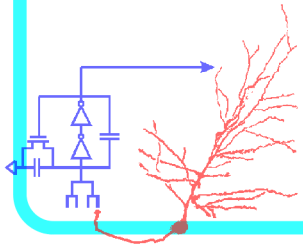
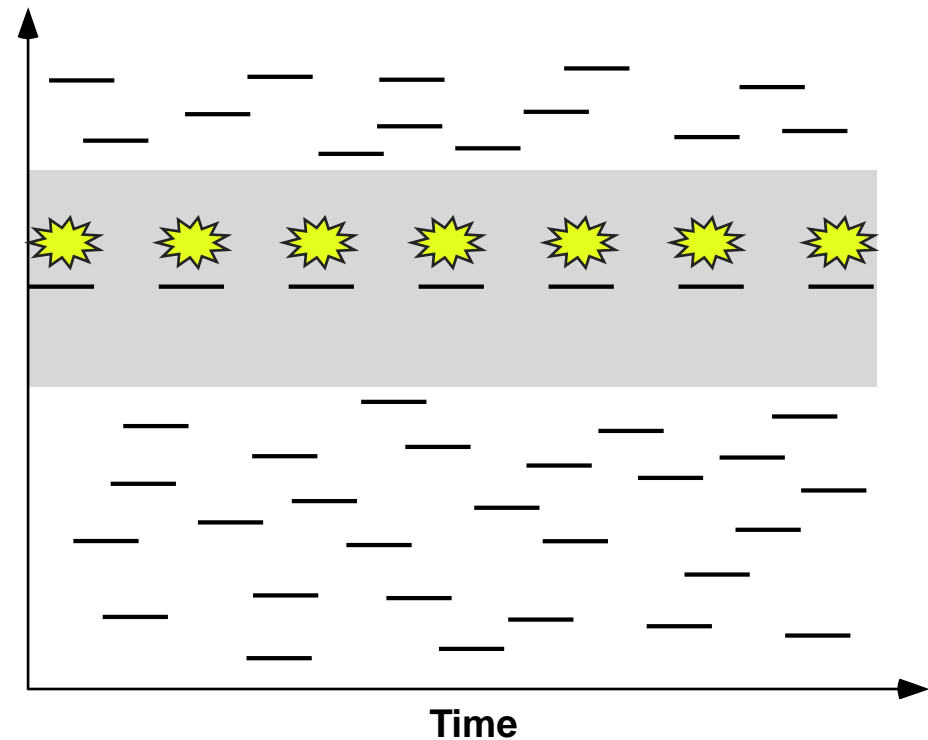
# *Effect of Target Frequency*

## *Auditory Pop-out*

**Low-frequency Target**



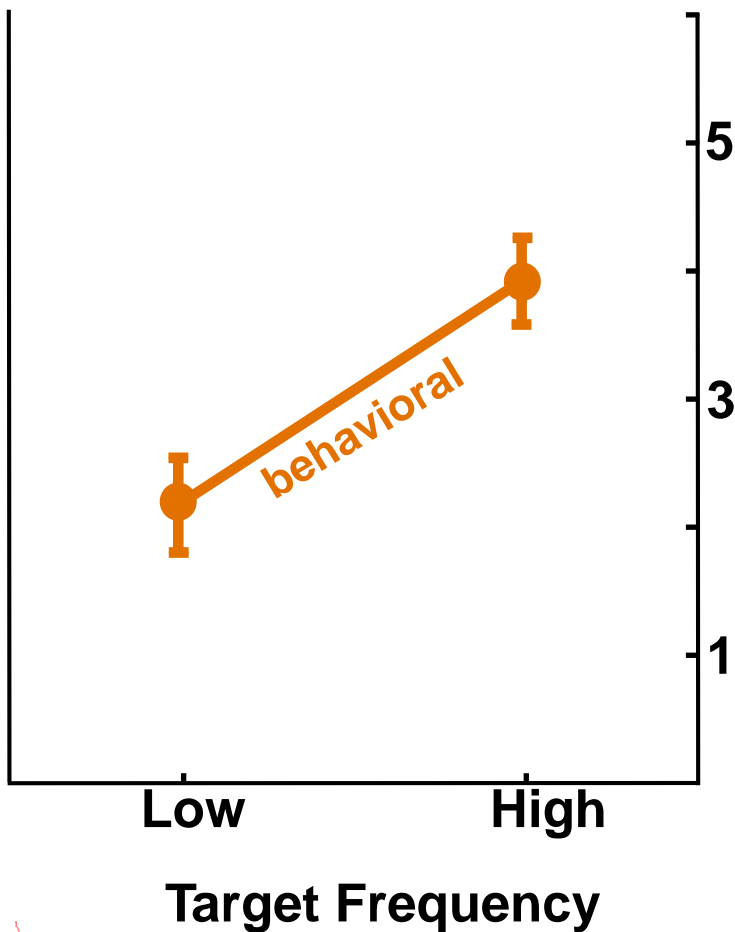
**High-frequency Target**



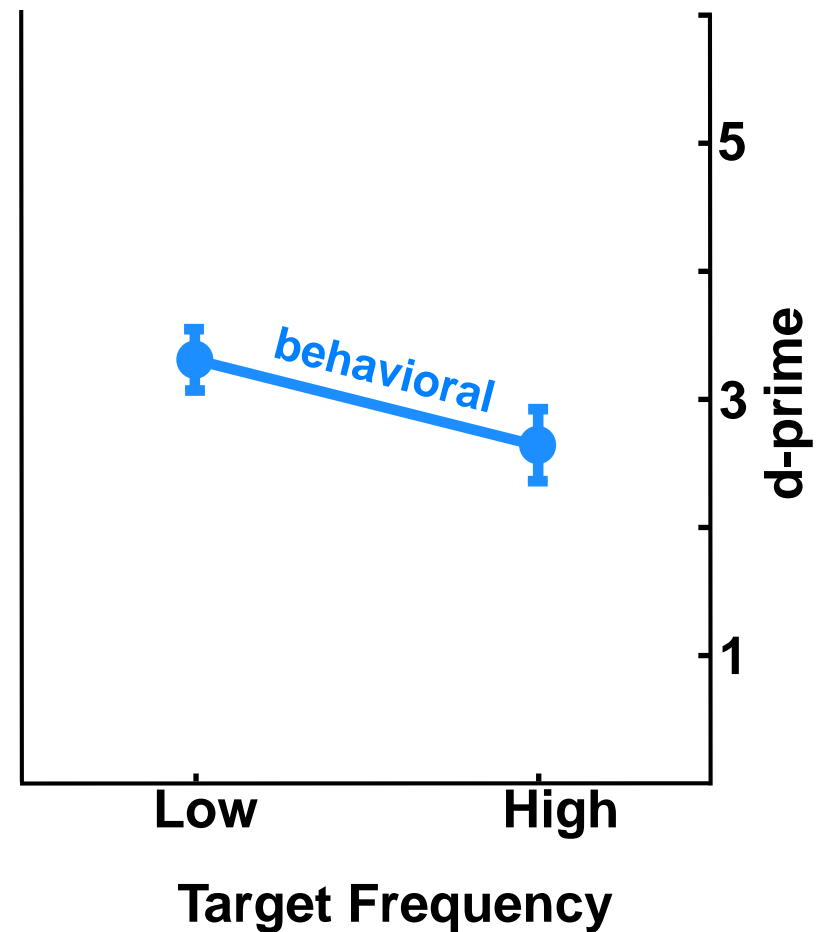
# Effect of Target Frequency

## Auditory Pop-out

**Target Task**

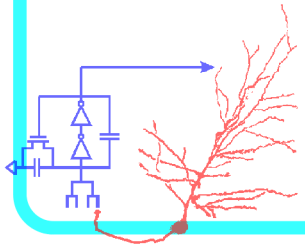


**Masker Task**



— Behavior from MEG (N=14)

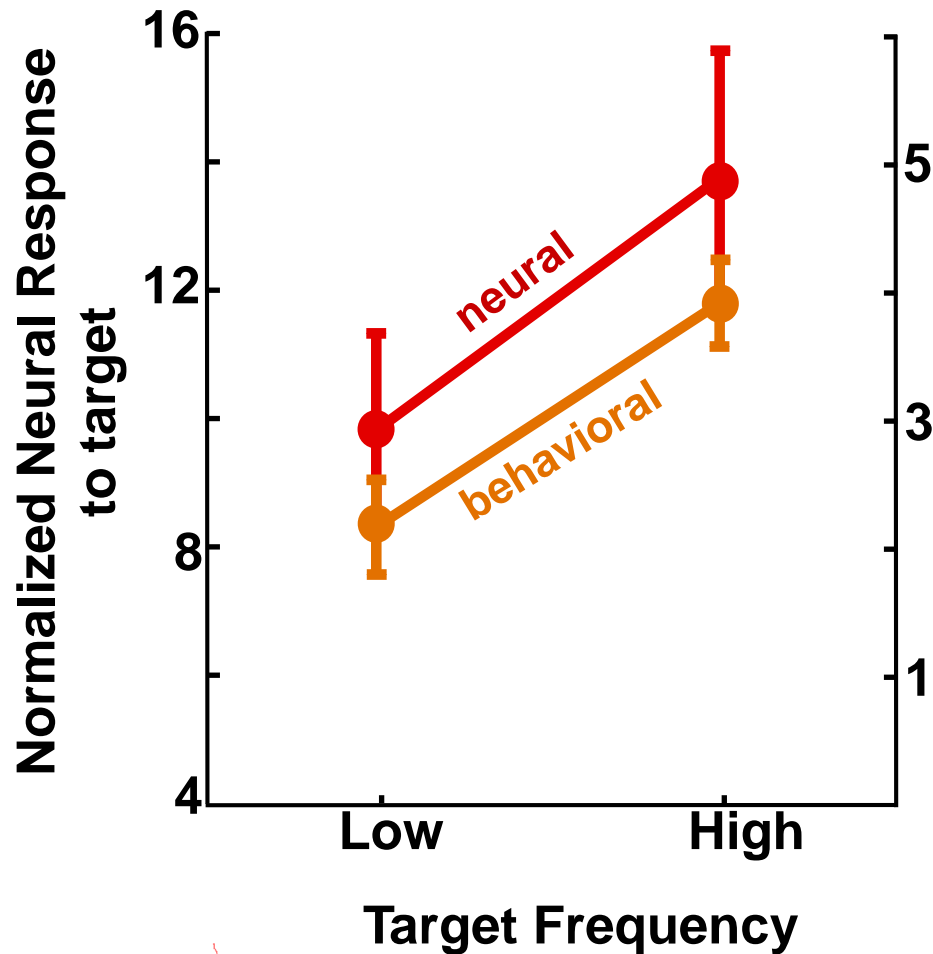
— Behavior from MEG (N=14)



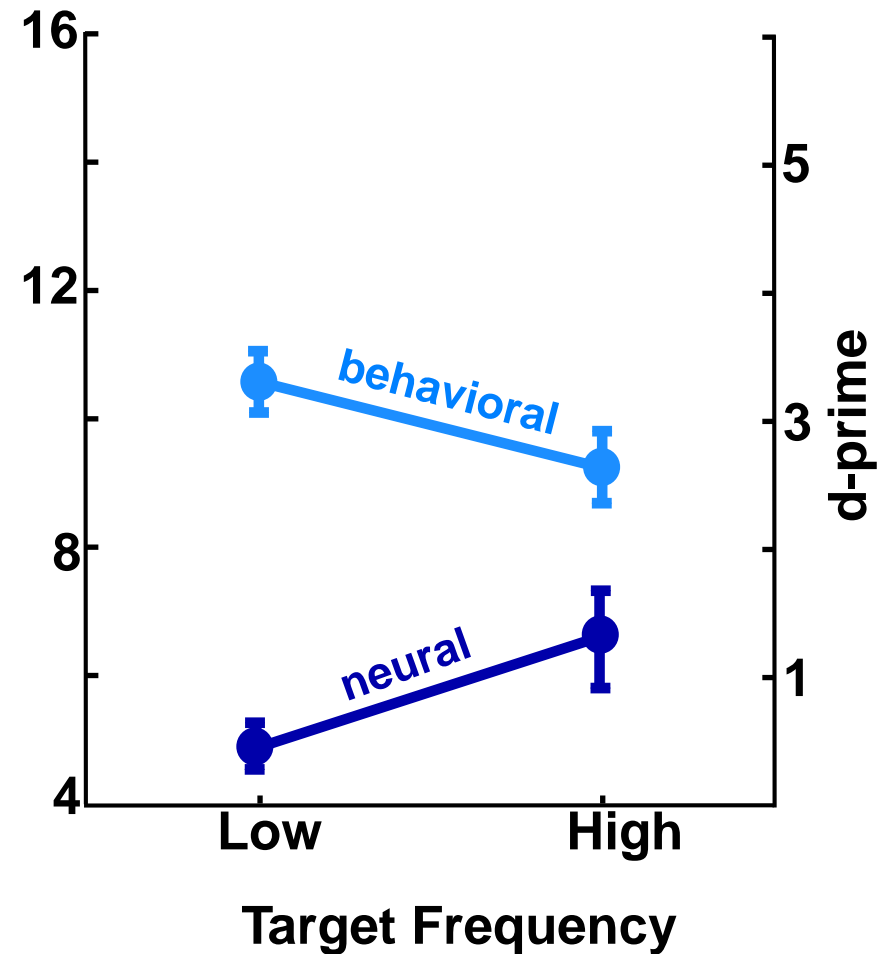
# Effect of Target Frequency

## Auditory Pop-out

### Target Task

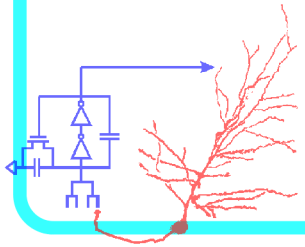


### Masker Task

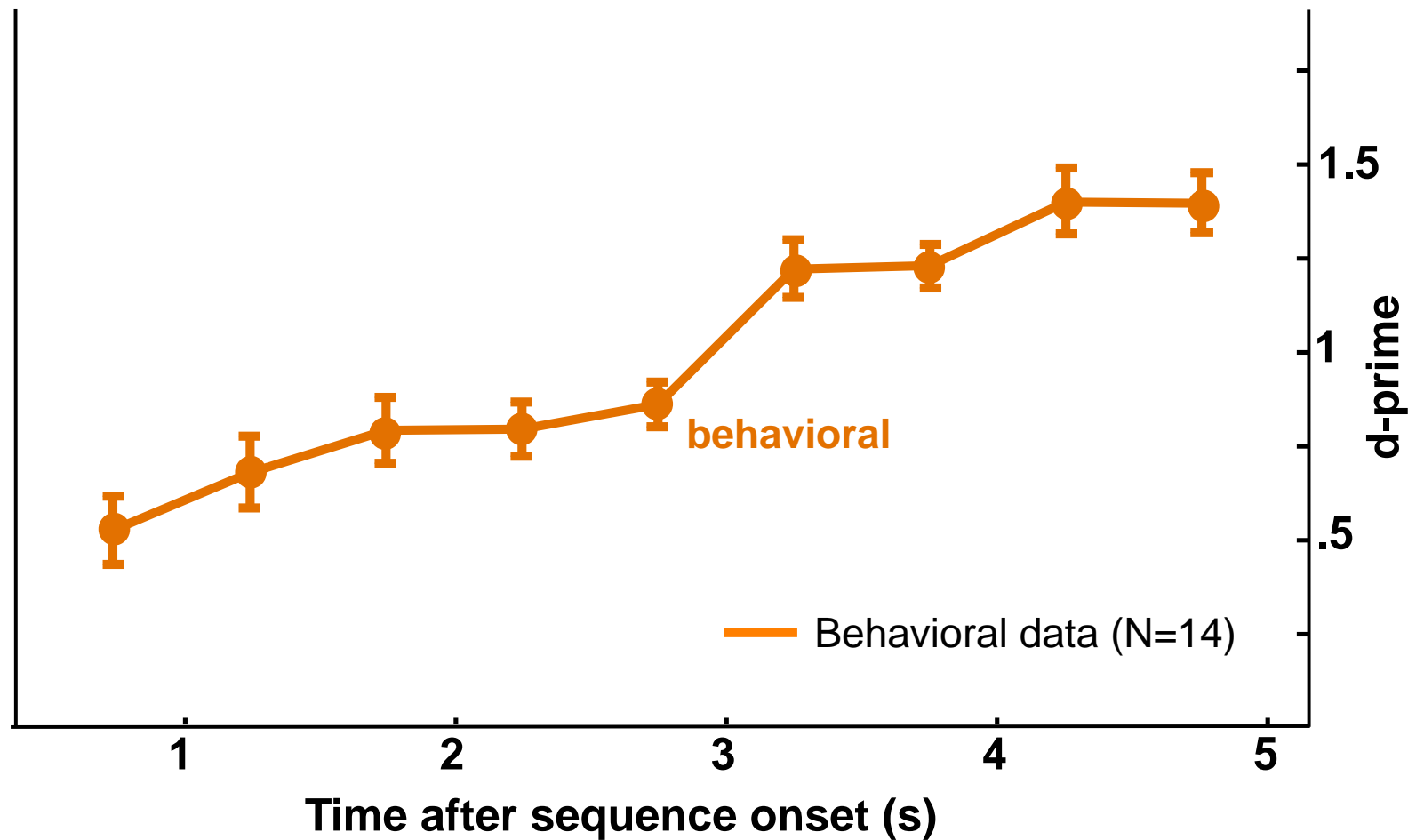


— Neural response (N=14)  
— Behavior from MEG (N=14)

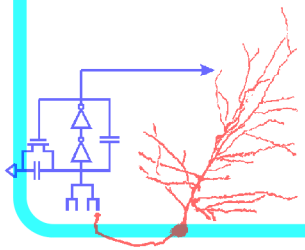
— Neural response (N=14)  
— Behavior from MEG (N=14)



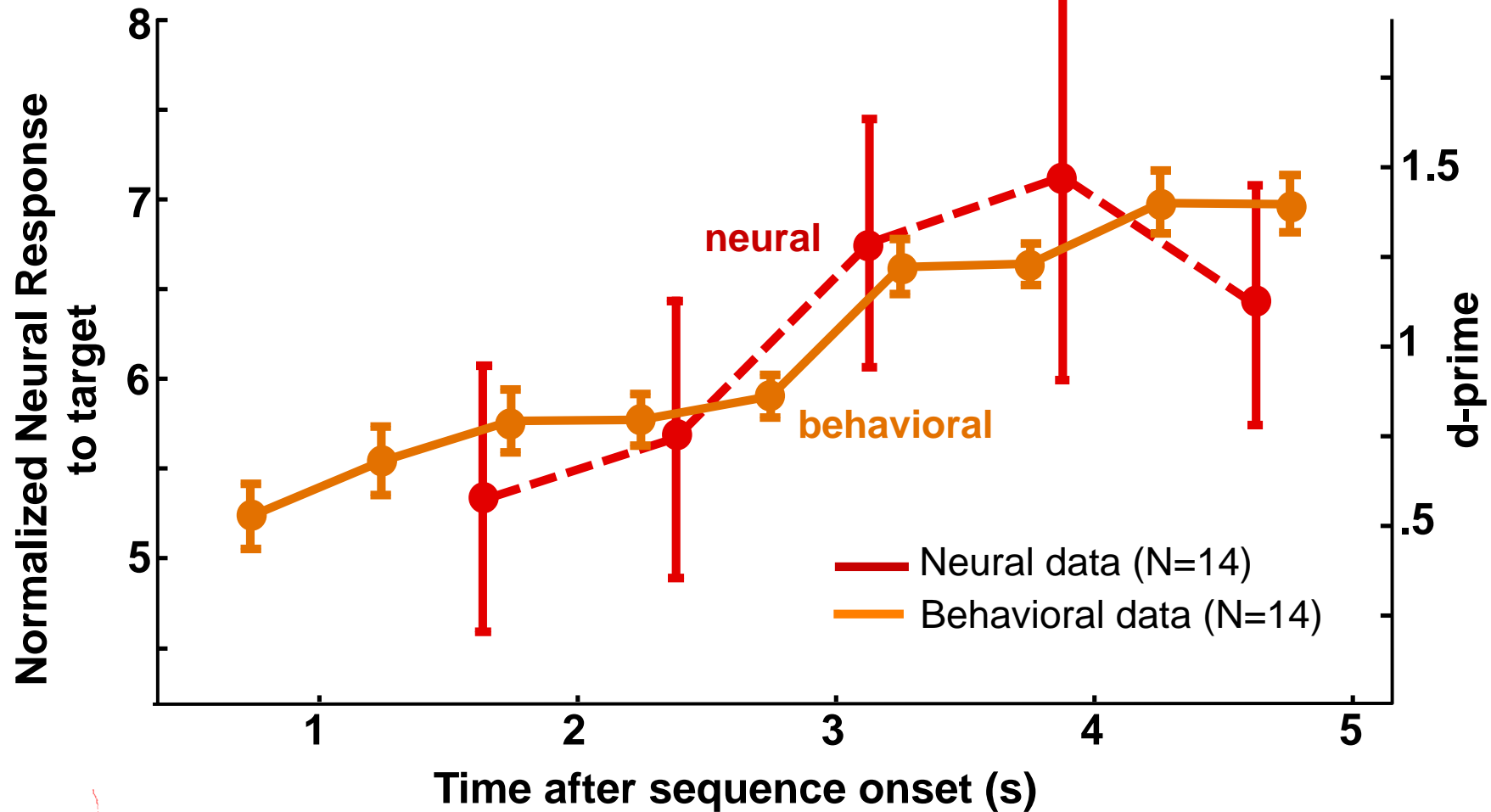
# *Behavioral & Neural Build-ups*



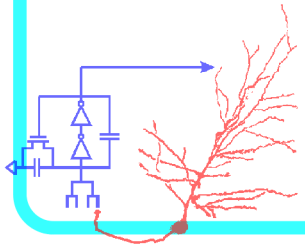
**Target Task**



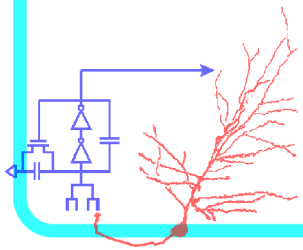
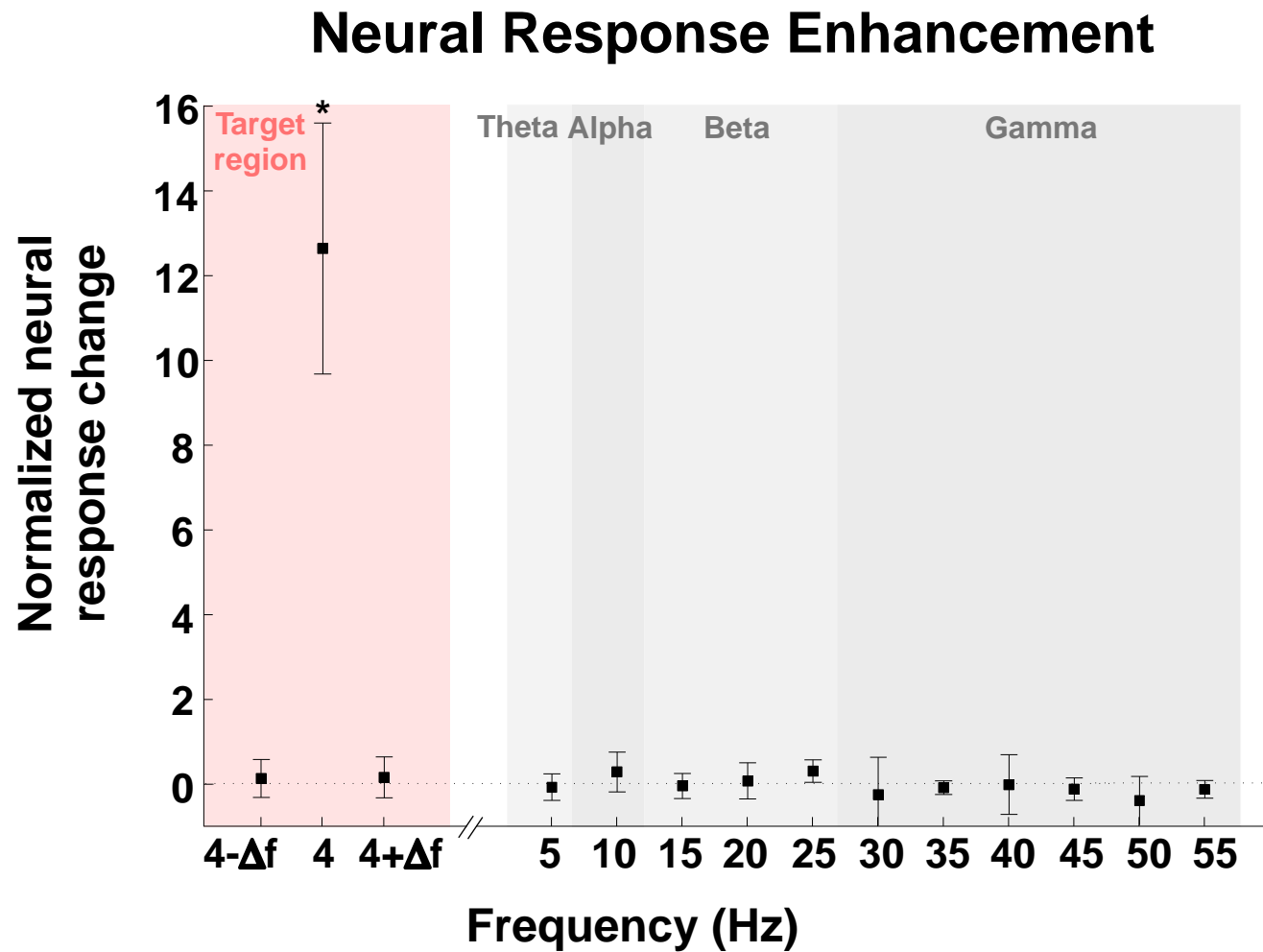
# Behavioral & Neural Build-ups



Target Task

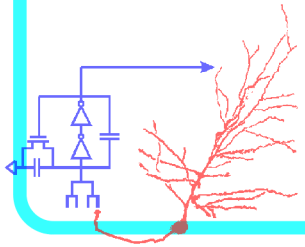
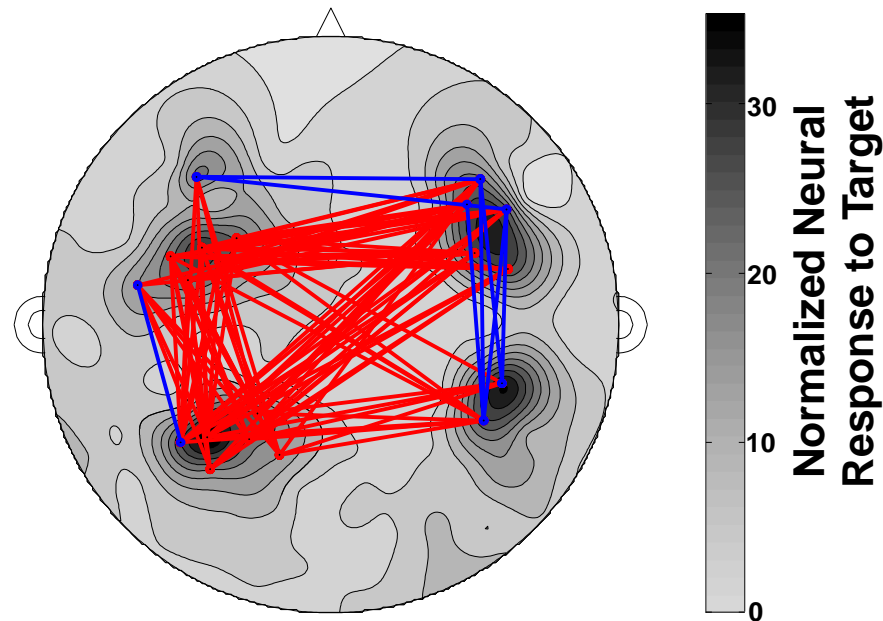


# Neural Enhancement by Frequency

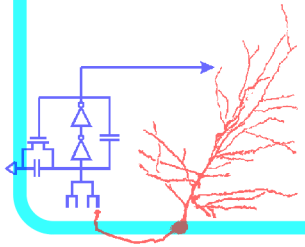
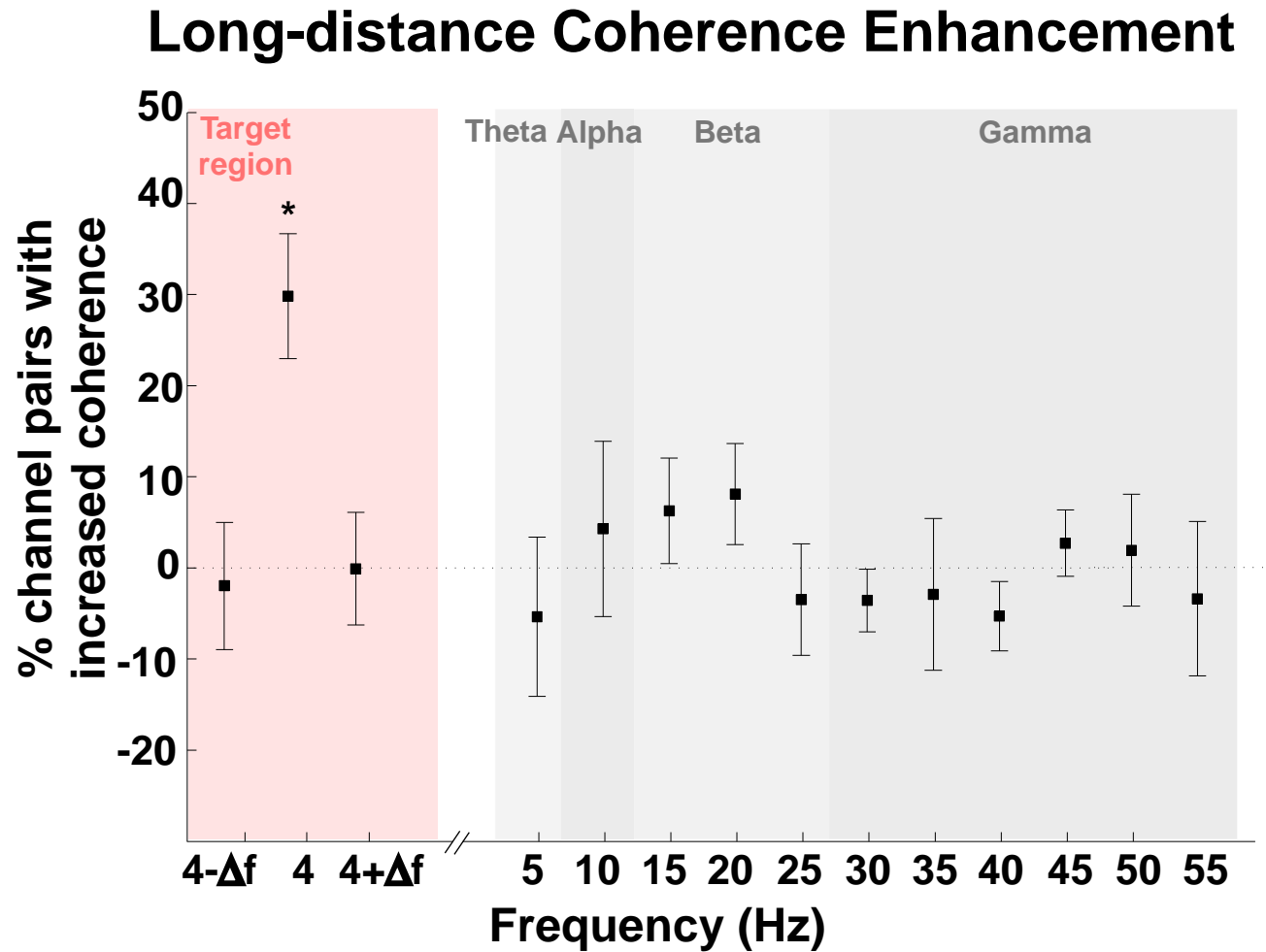


# Long Distance Phase Coherence

## Coherence at Target Rate of Single Subject

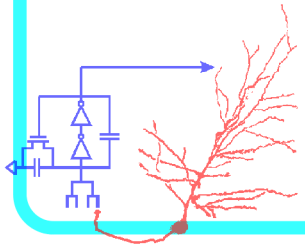
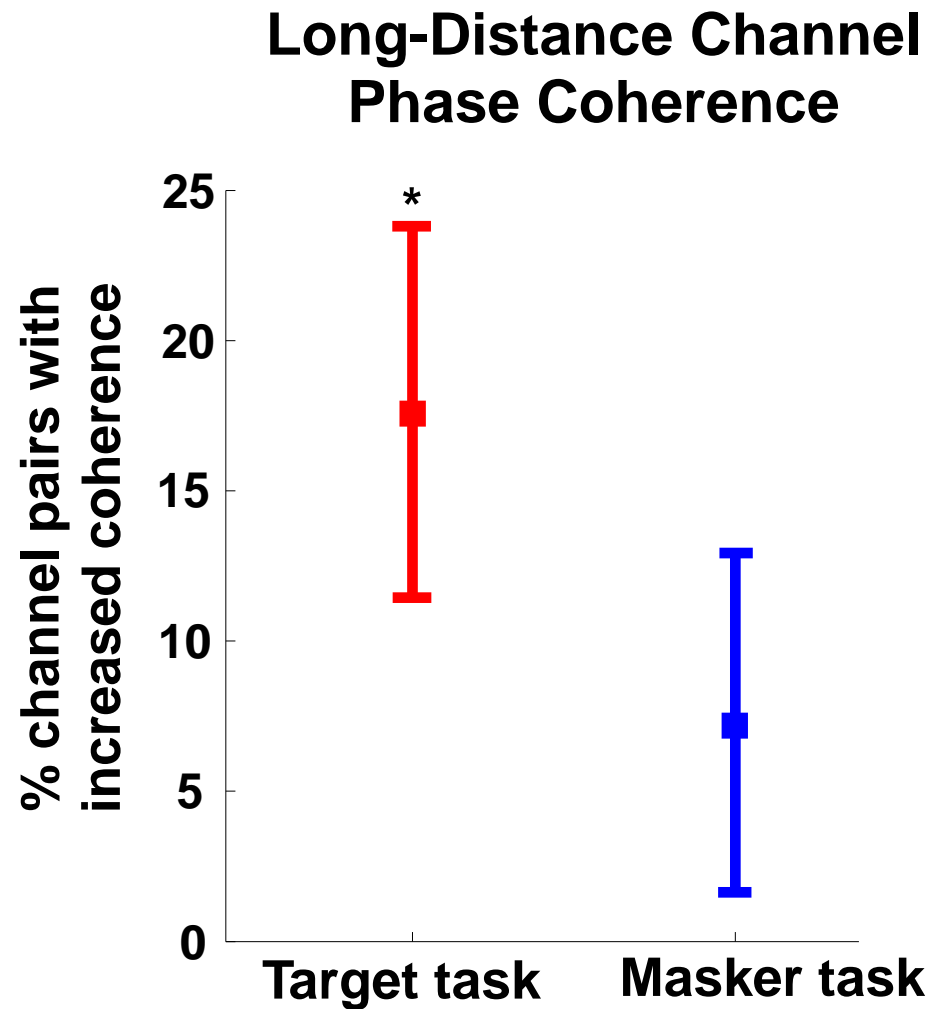


# Coherence Enhancement by Frequency

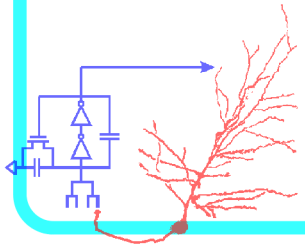
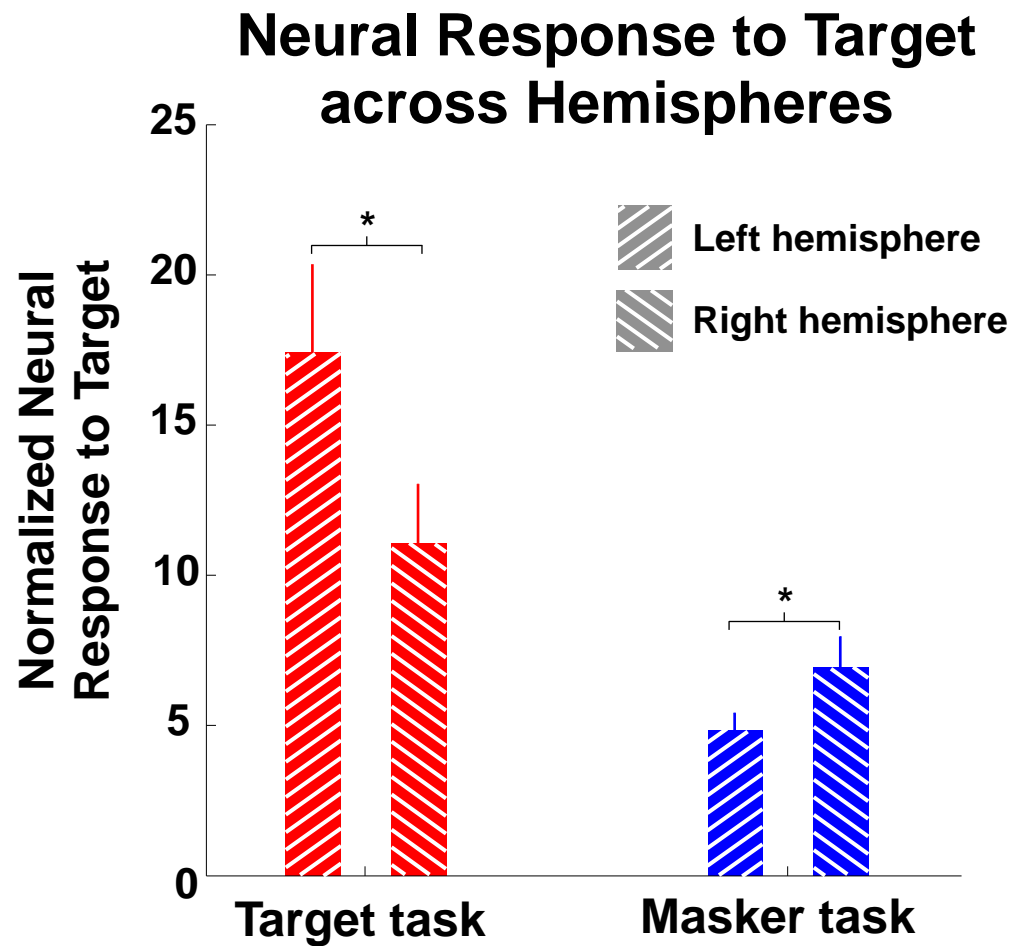




# Bottom-Up Coherence Enhancement

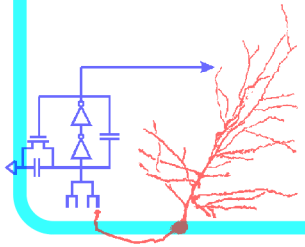
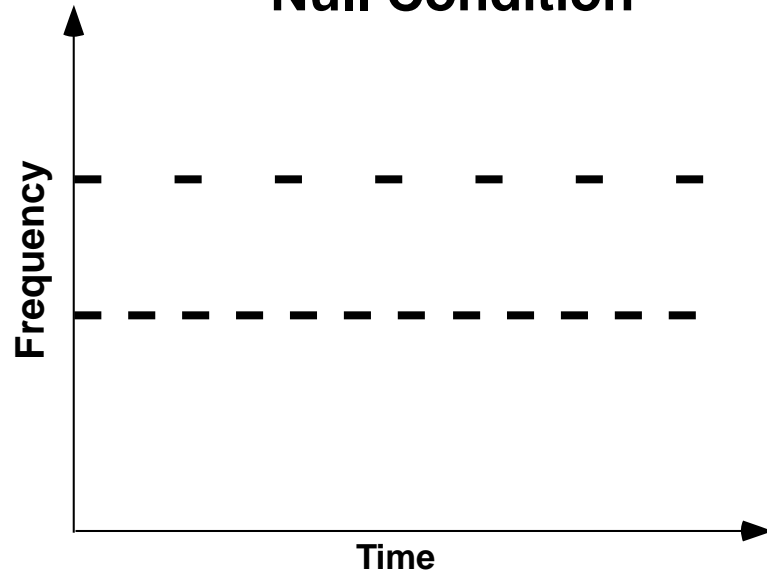


# Hemispheric Response Asymmetry



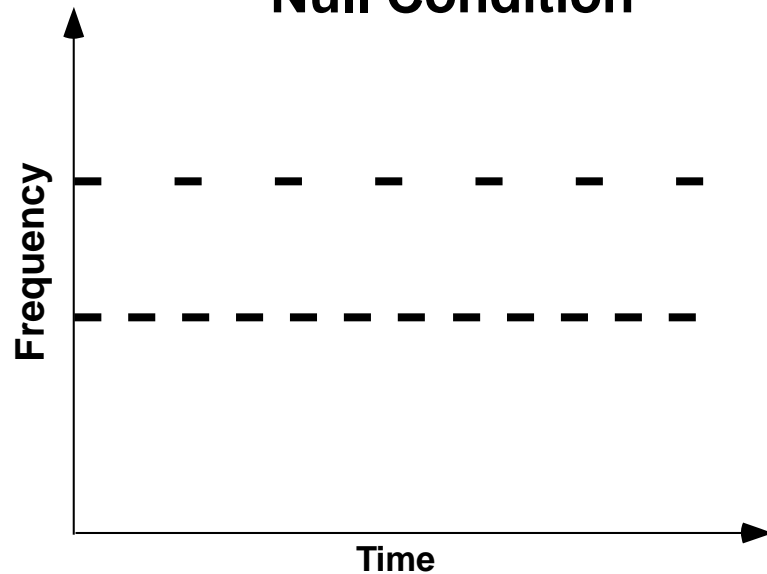
# *Follow-up Study (in progress)*

**Null Condition**

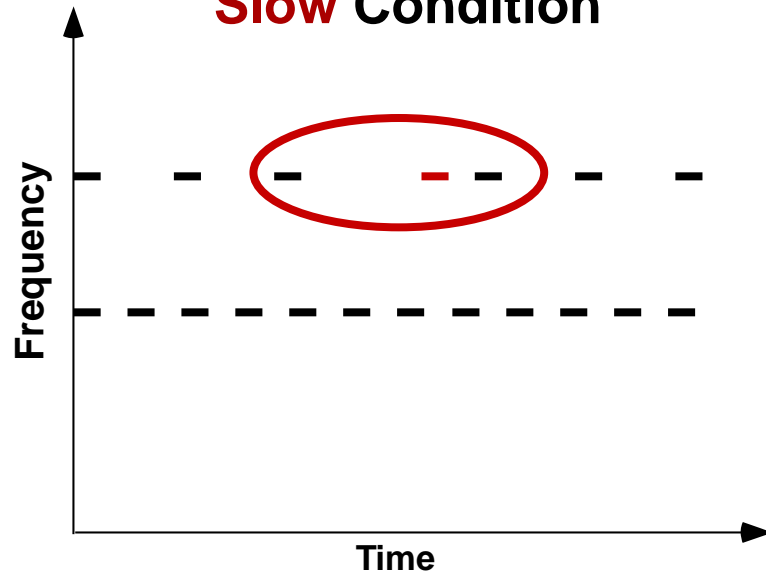


# Follow-up Study (in progress)

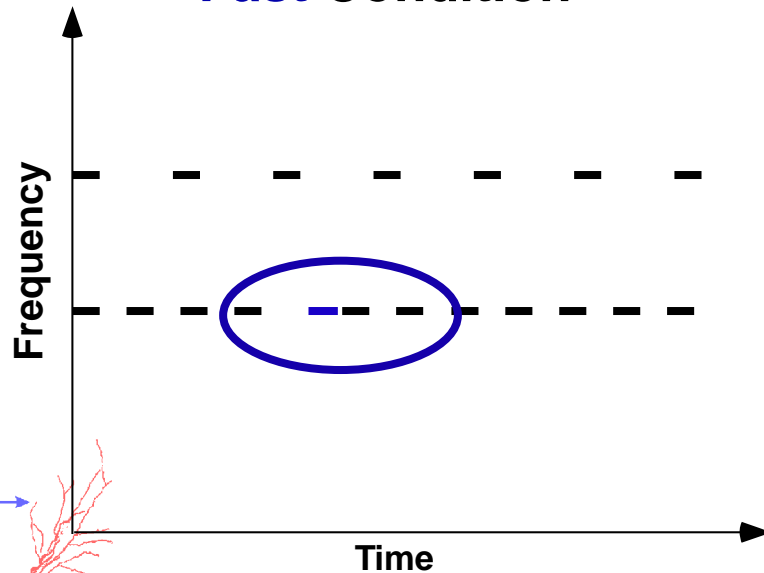
## Null Condition



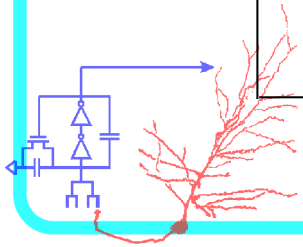
## Slow Condition



## Fast Condition

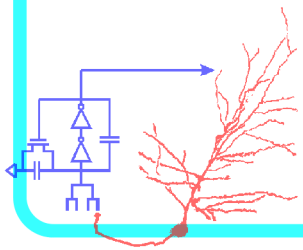


Target rates: 4Hz, 7 Hz  
Target rove: 250-500 Hz  
Duration: 5.25 s, 6.25 s, 7.25 s  
Frequency Separation:  $\pm 8$  st  
Tone dur: 75 ms  
Deviant Jitter: 40 ms, 70 ms



# Summary

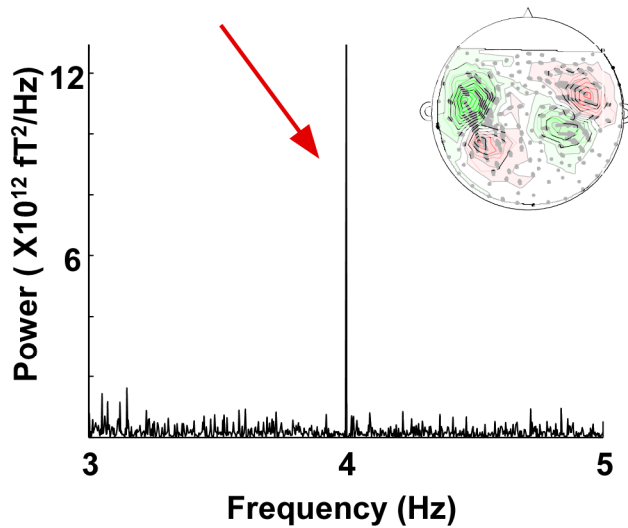
- Strong Neural Response to Target (despite Maskers)
  - + Acquired non-invasively, with high temporal resolution
- Attention strongly modulates Neural Response & Coherence
- Change in Behavior correlates with Change in Neural Response
  - + Bottom-Up (Auditory Pop-out)
    - Neural Response correlates *within subjects* with Target Task Behavior
    - Target Pop-out interferes with Masker Task
    - Neural Response anti-correlates *within subjects* with Masker Task Behavior
  - + Top-Down: Buildup of Neural Response correlates *within subjects* with Behavioral Buildup



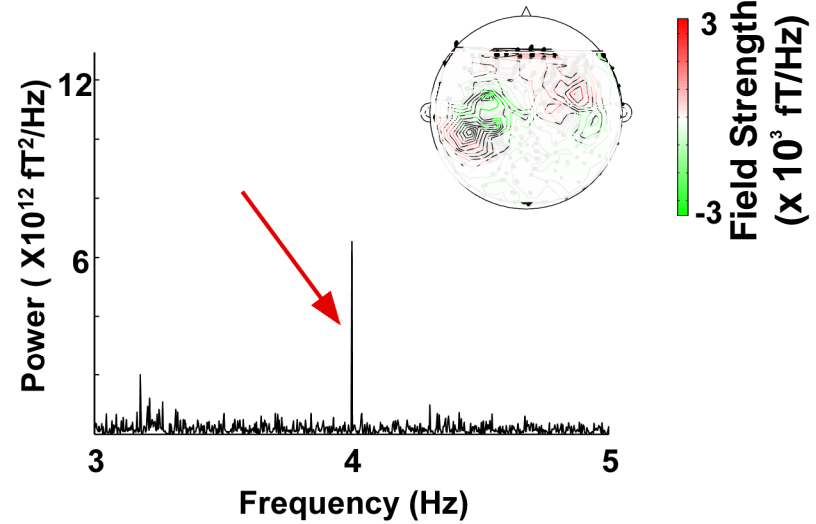
*Thank You*

# Attention Modulates Competing Streams

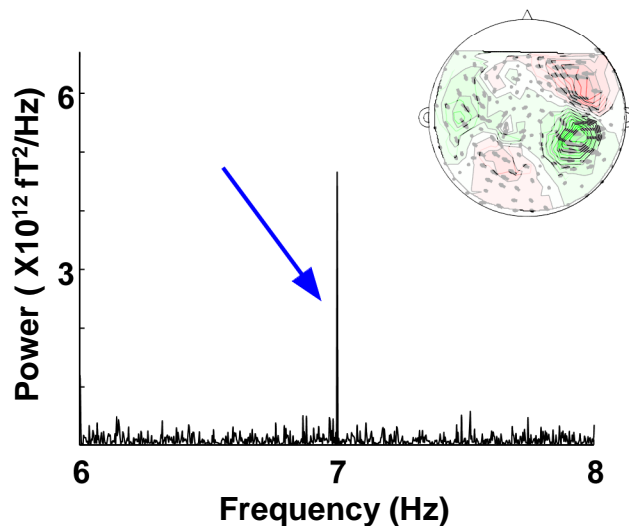
Tracking 4 Hz task



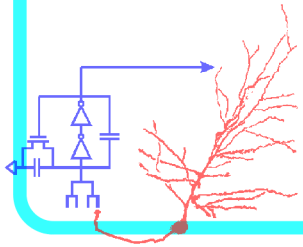
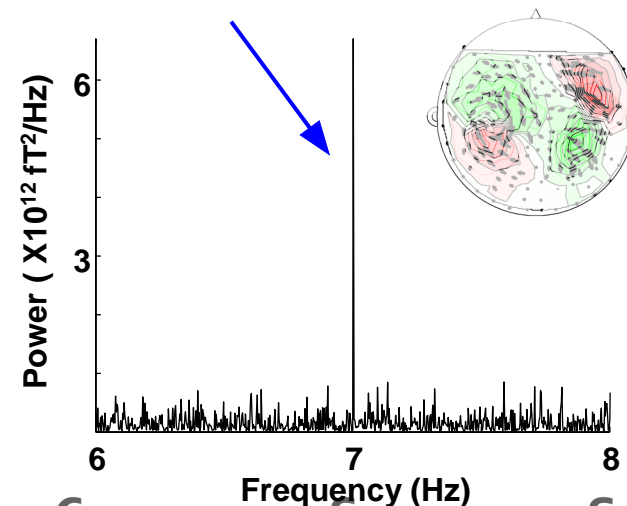
Tracking 7 Hz task



Tracking 4 Hz task

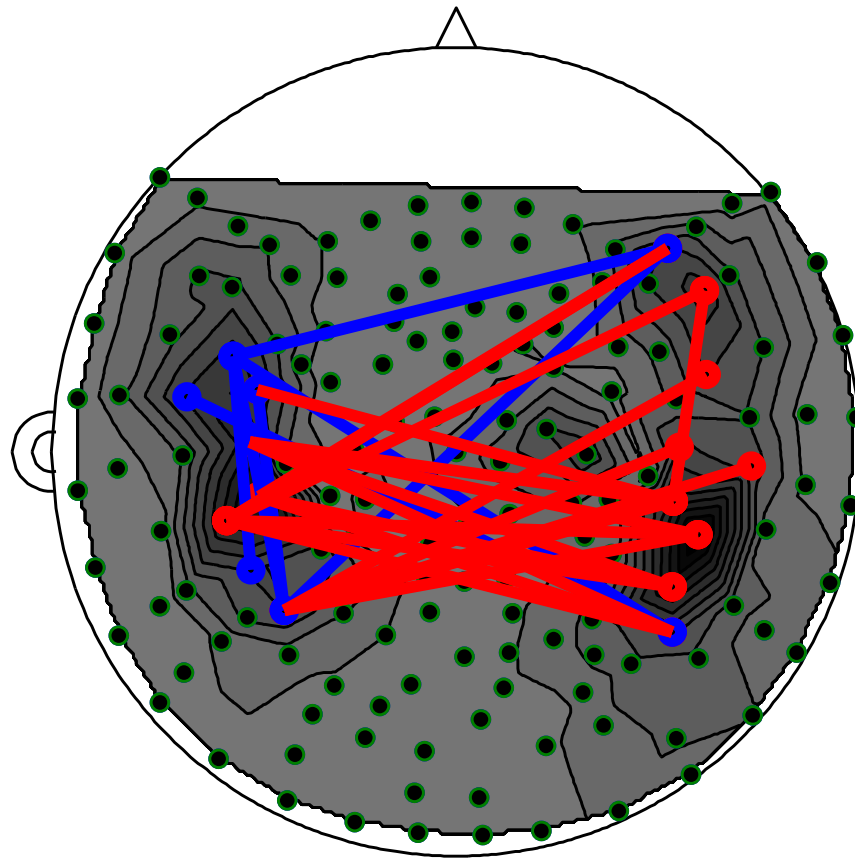


Tracking 7 Hz task

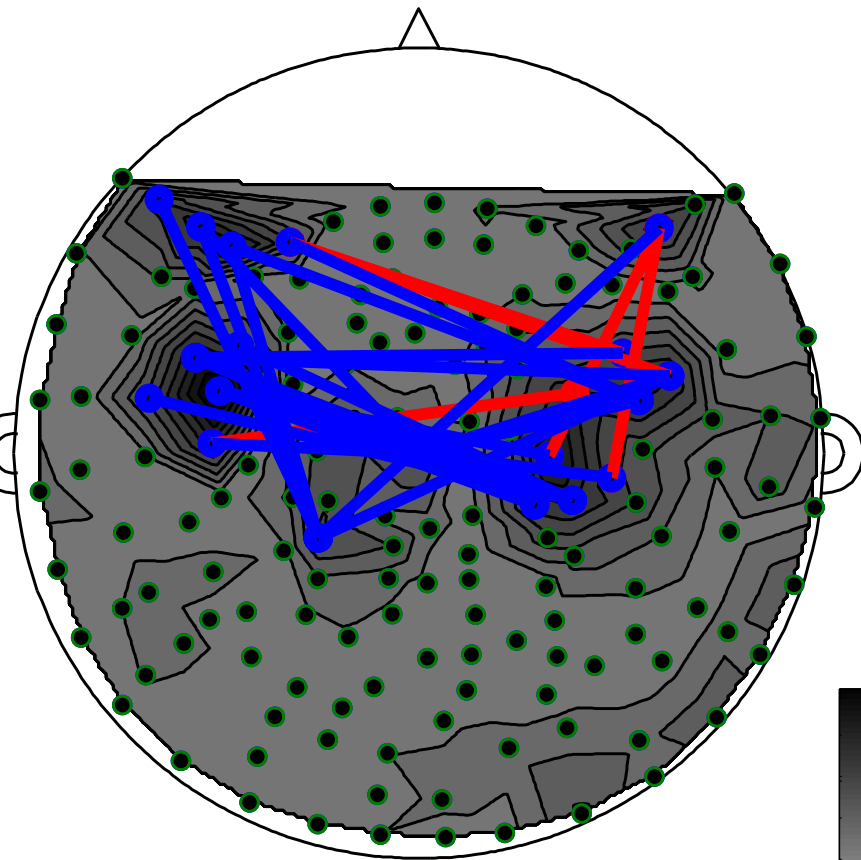


# Attention Modulates Phase Coherence

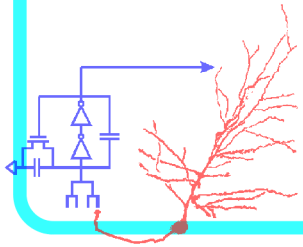
Coherence at 4 Hz  
of Single Subject



Coherence at 7 Hz  
of Single Subject



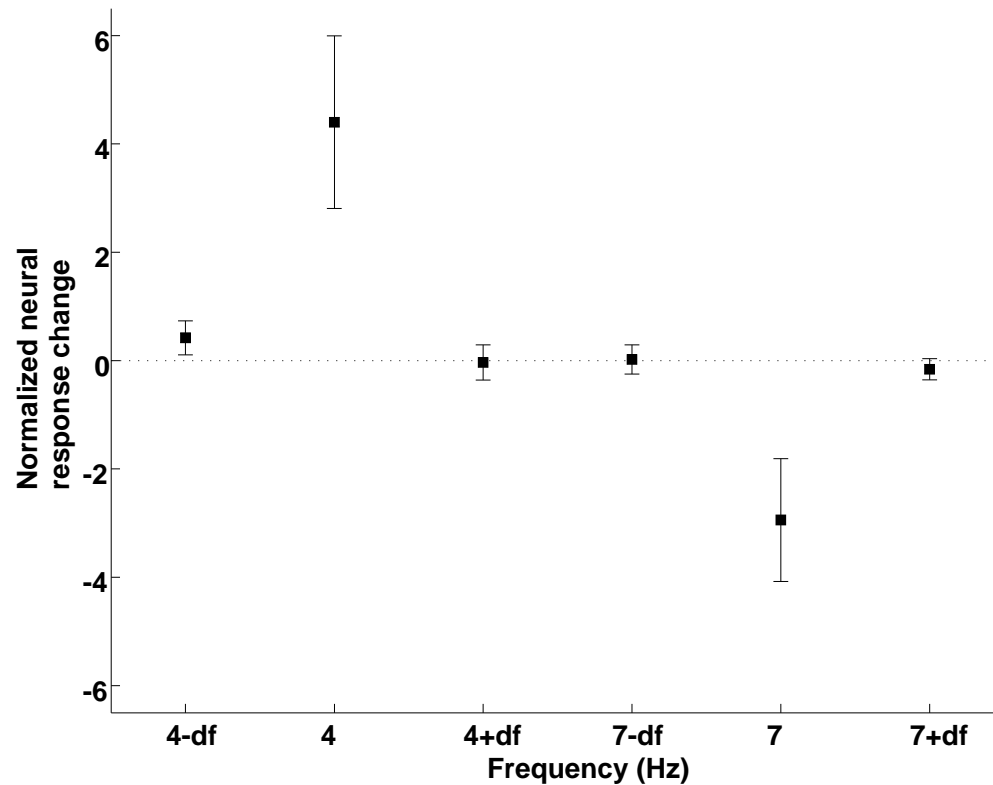
40  
0  
Normalized Neural  
Response to Target



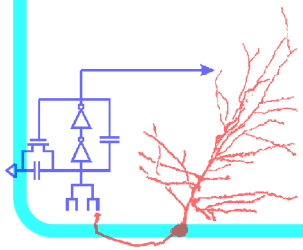
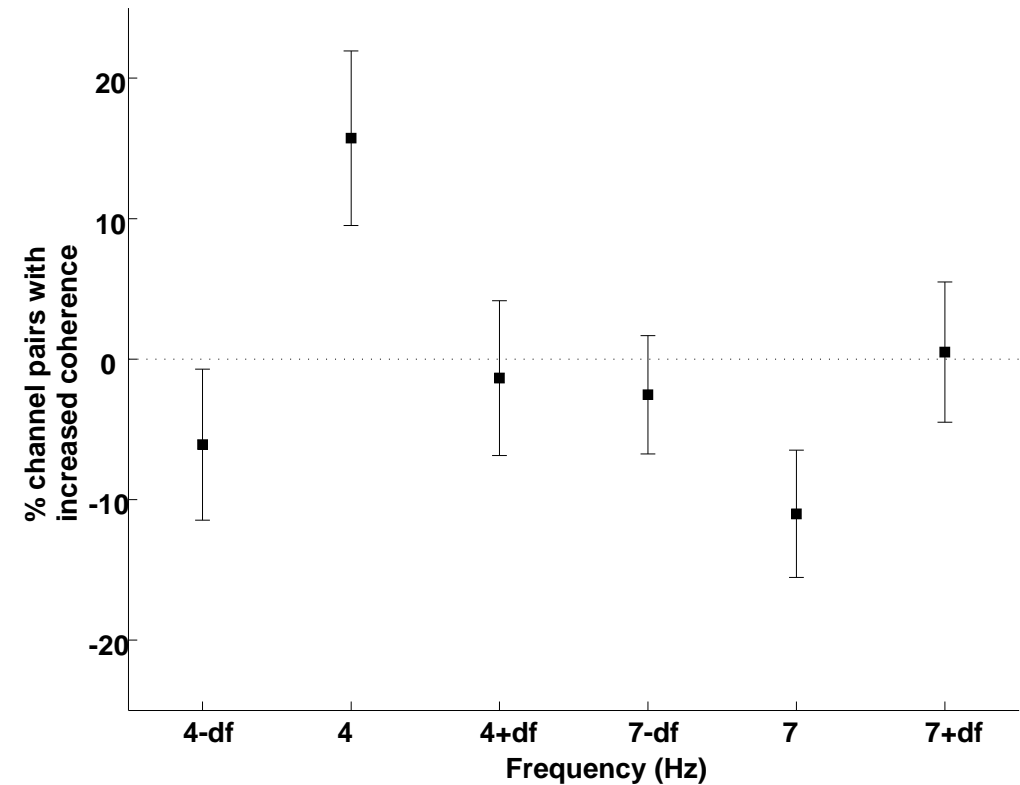


# *Behavioral & Neural Build-ups*

## Neural Response Enhancement

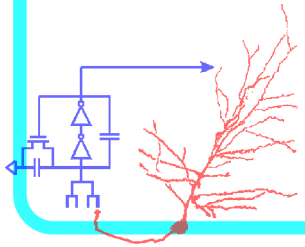
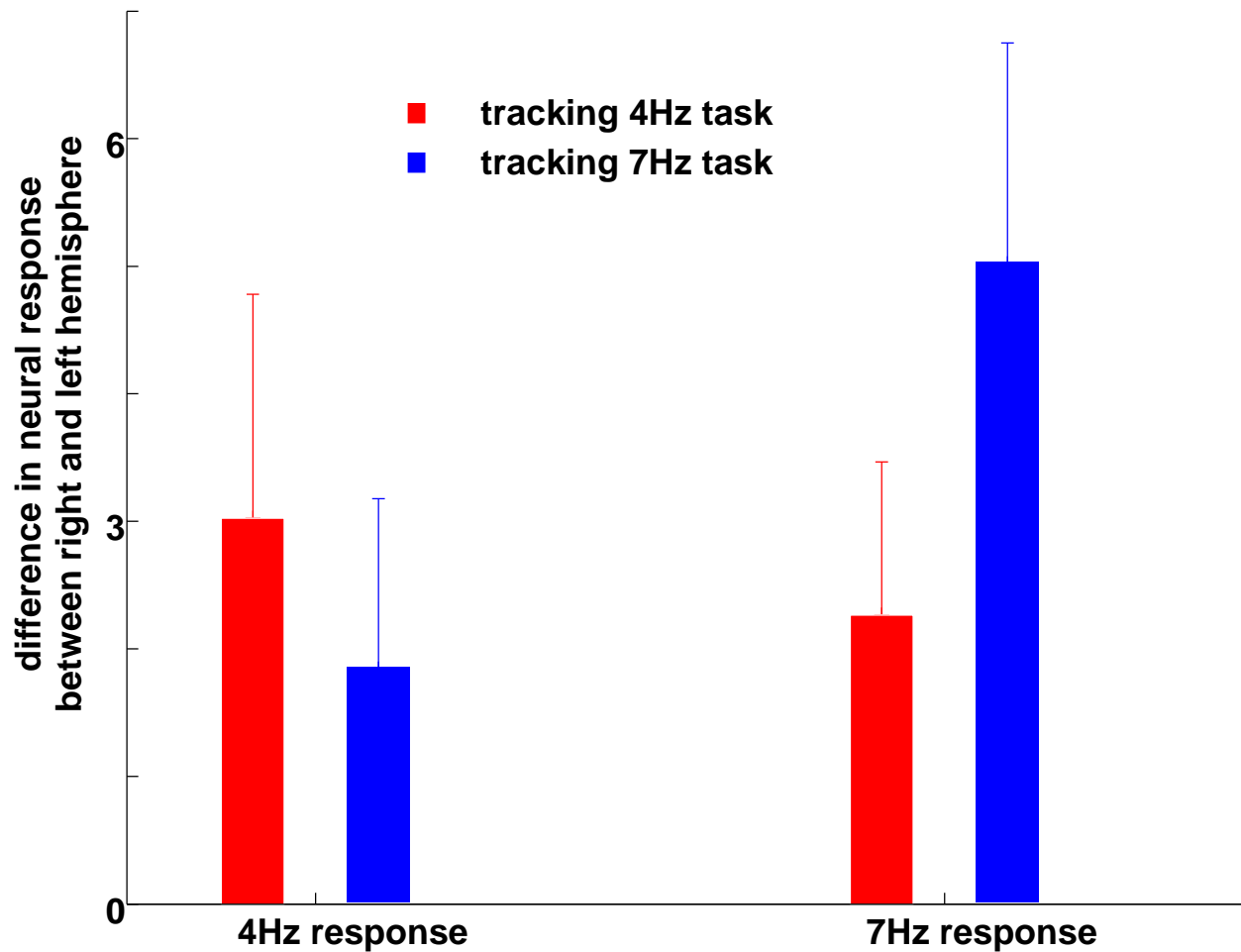


## Long-distance Coherence Enhancement

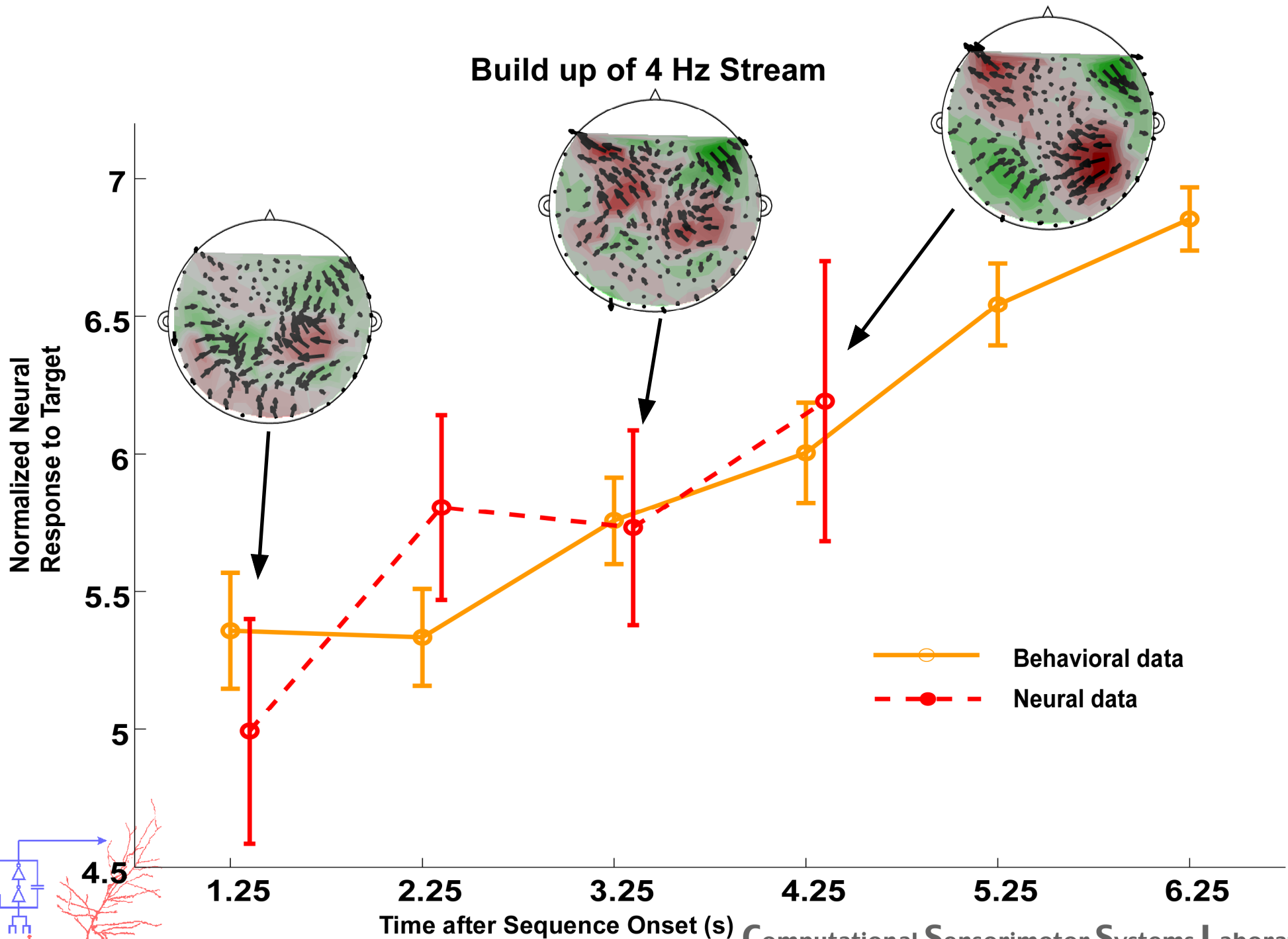


# Right Hemispheric Advantage

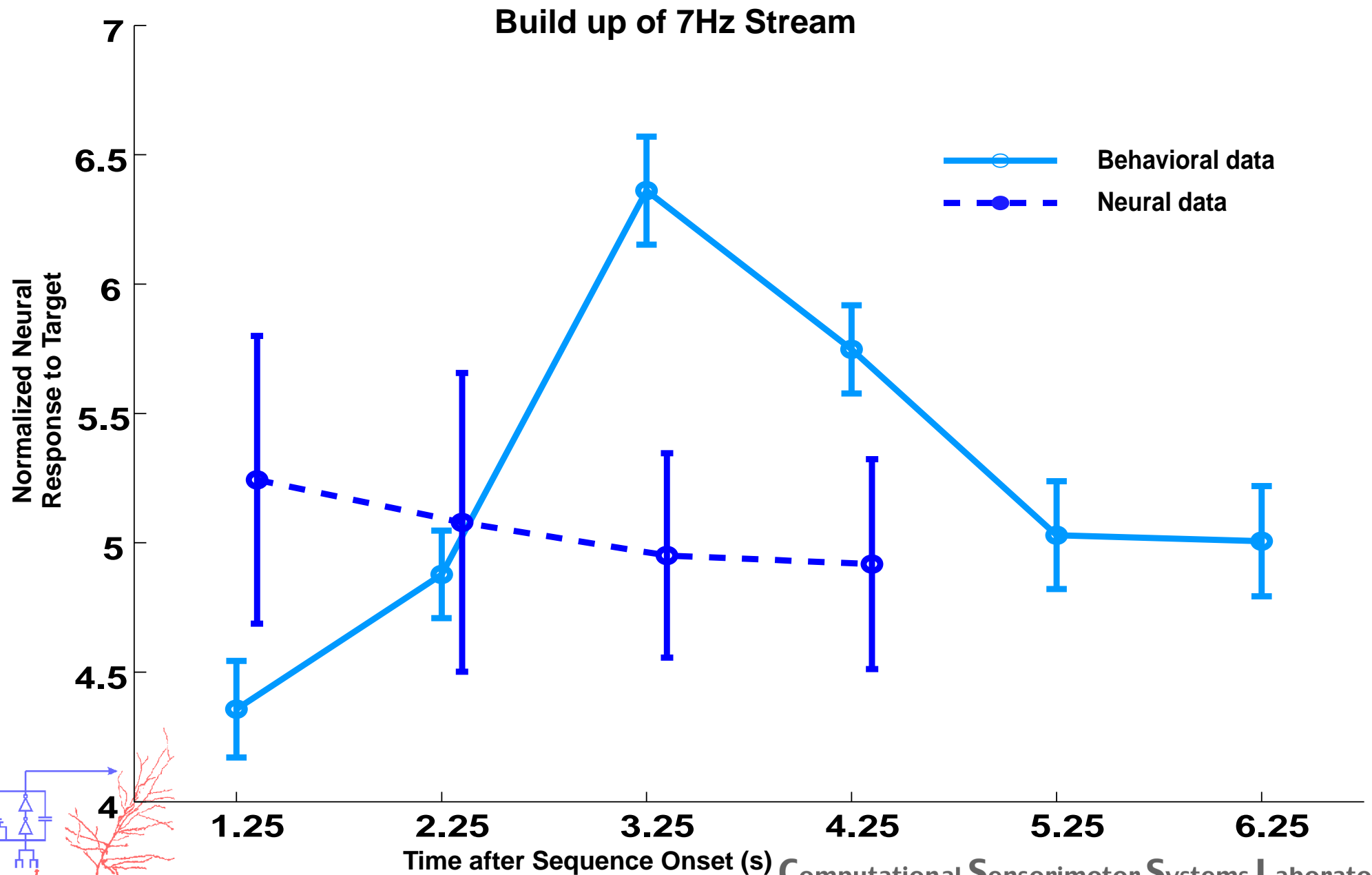
## Neural Response to Target across Hemispheres



# Behavioral & Neural Build-ups

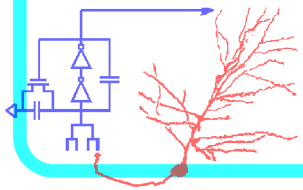
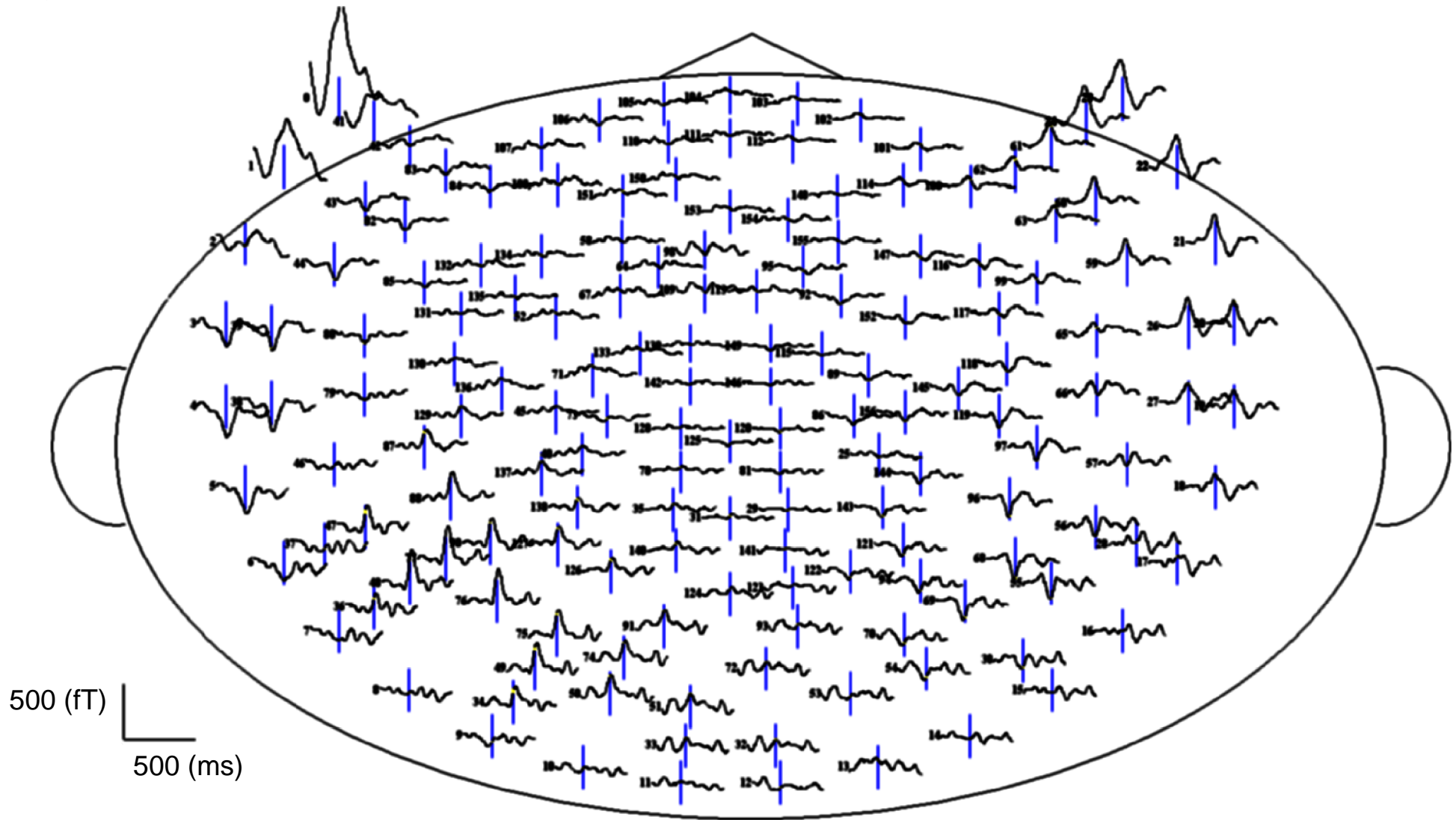


# *Behavioral & Neural Build-ups*



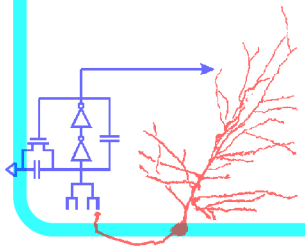
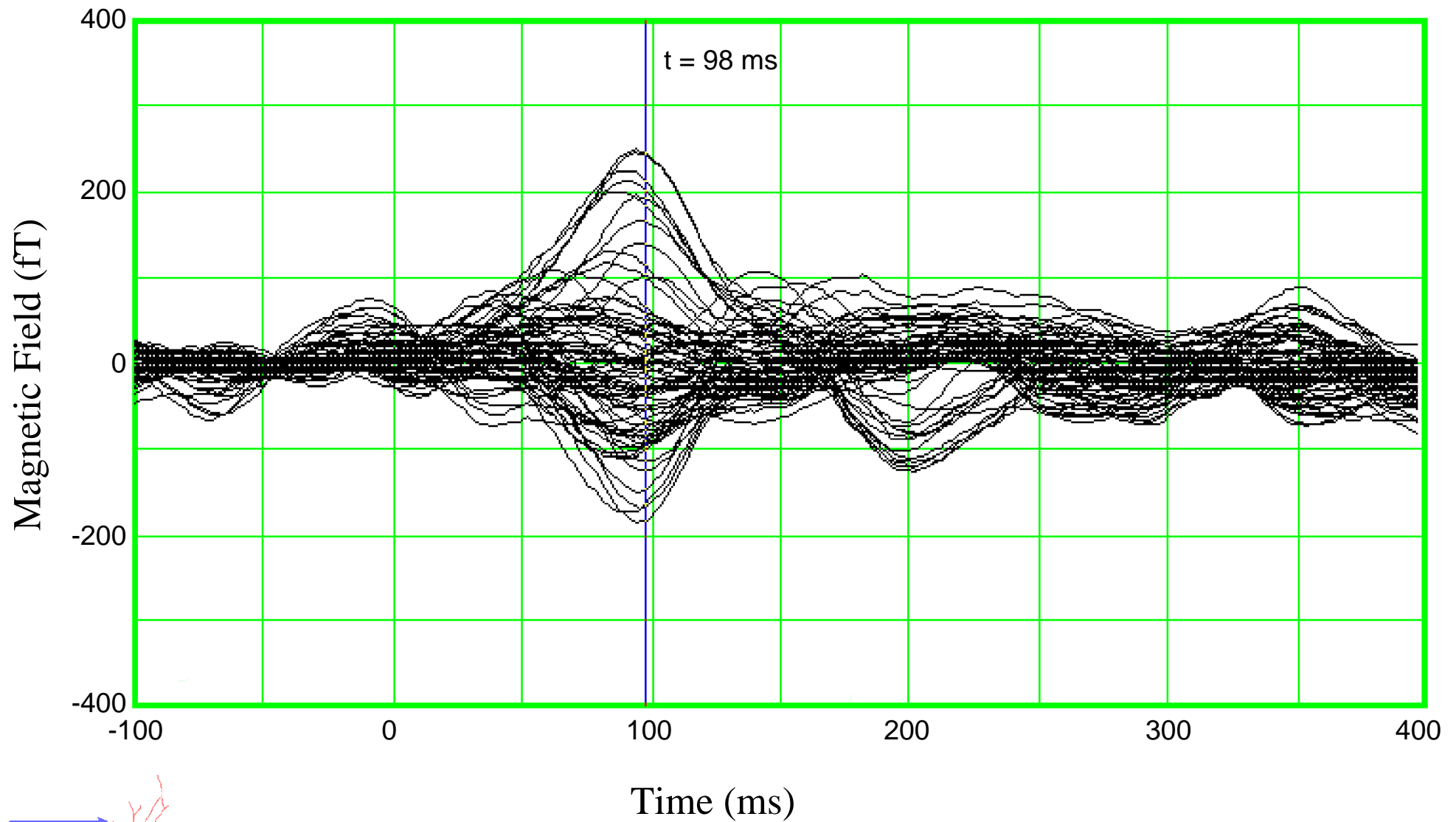
# MEG Response

## *Spatial Map of Time Series*

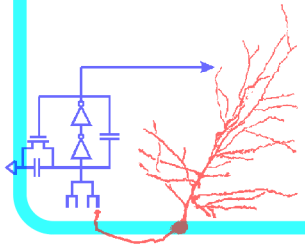
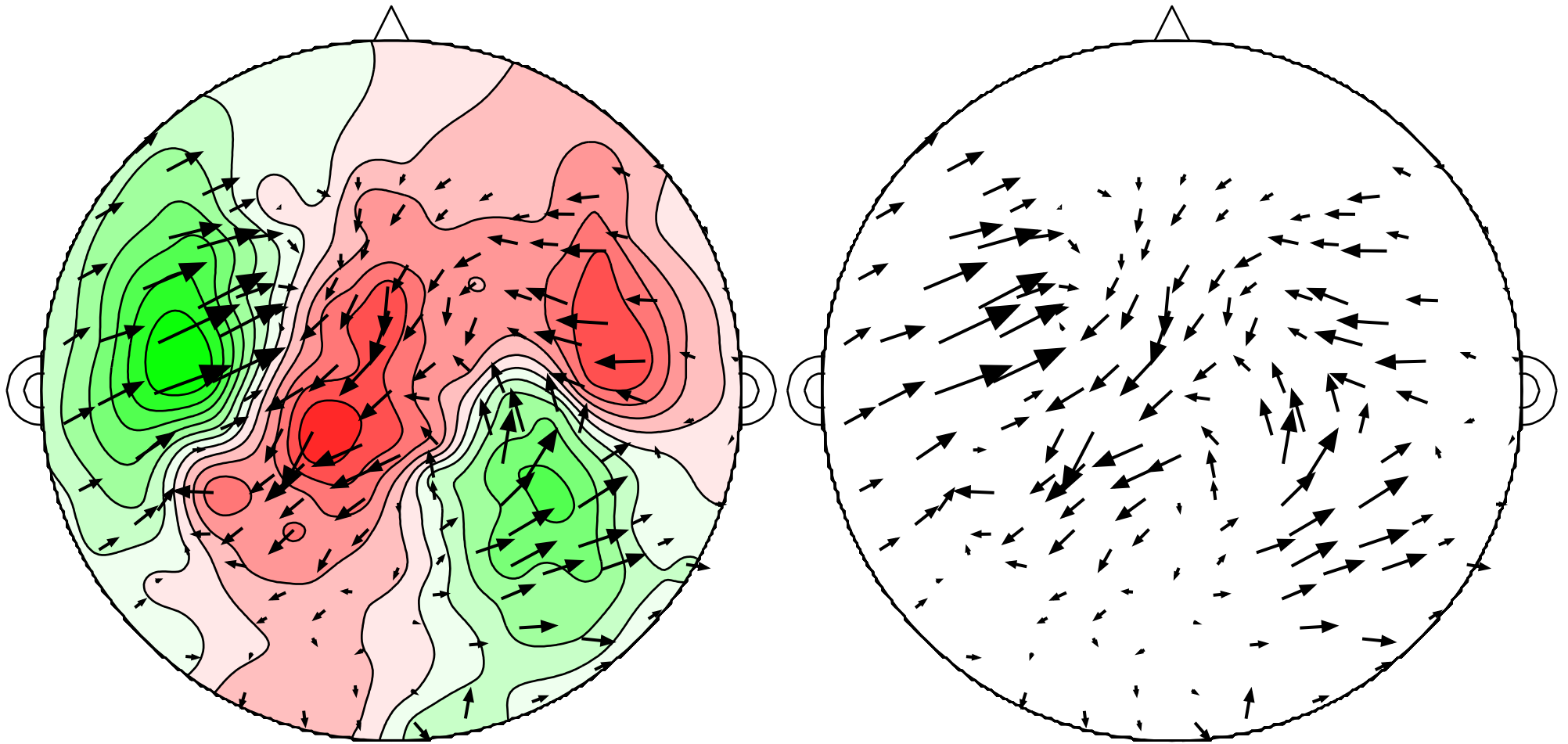


# *MEG Response*

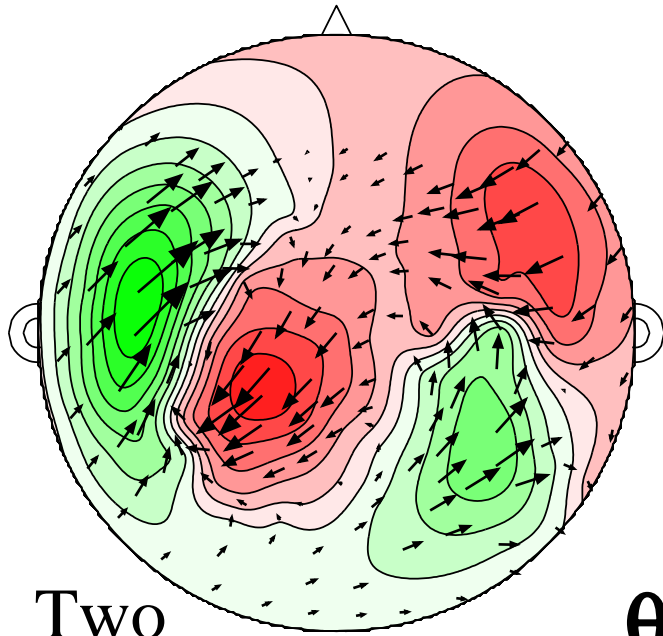
## *Butterfly Plot*



# Complex Magnetic Field



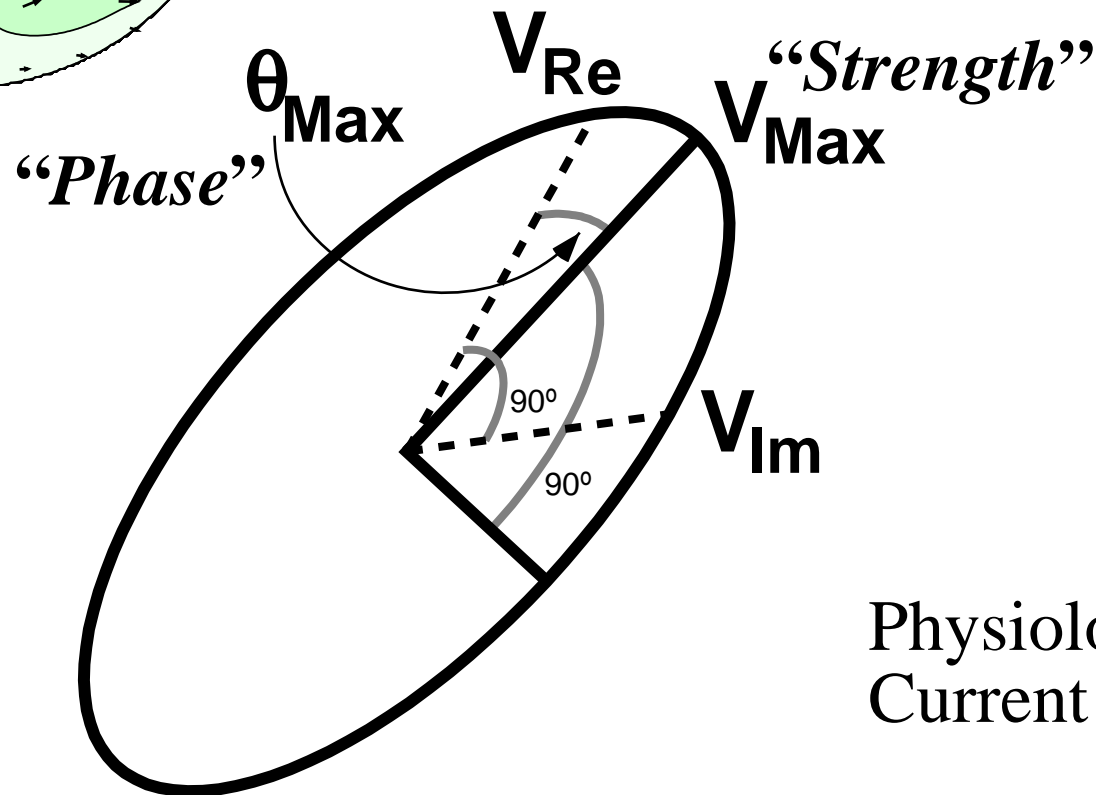
# Complex Equivalent-Current Dipoles



Two  
Dipole  
Fit

$$\vec{V} = \vec{V}_{\text{Re}} + i \vec{V}_{\text{Im}}$$

$$\vec{V}(\theta) = \vec{V}_{\text{Re}} \cos(\theta) + \vec{V}_{\text{Im}} \sin(\theta)$$



*“Sharpness”*

$$\eta = \frac{|\mathbf{V}_{\text{Min}}|}{|\mathbf{V}_{\text{Max}}|}$$

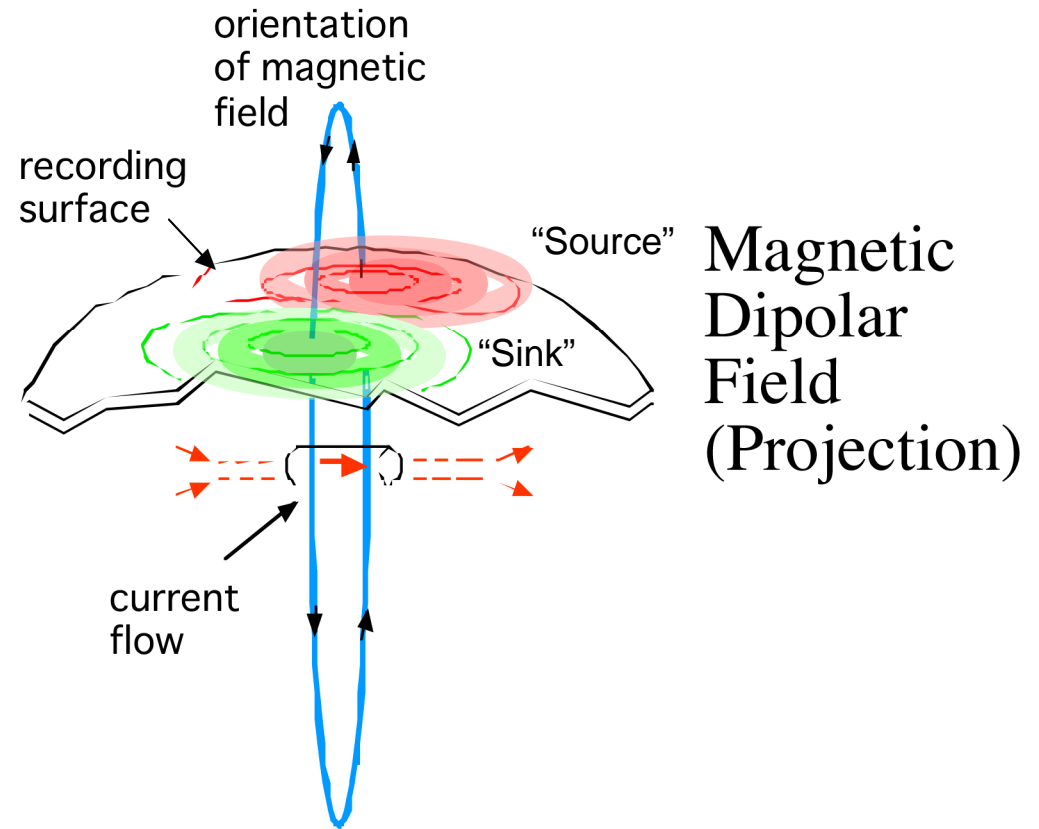
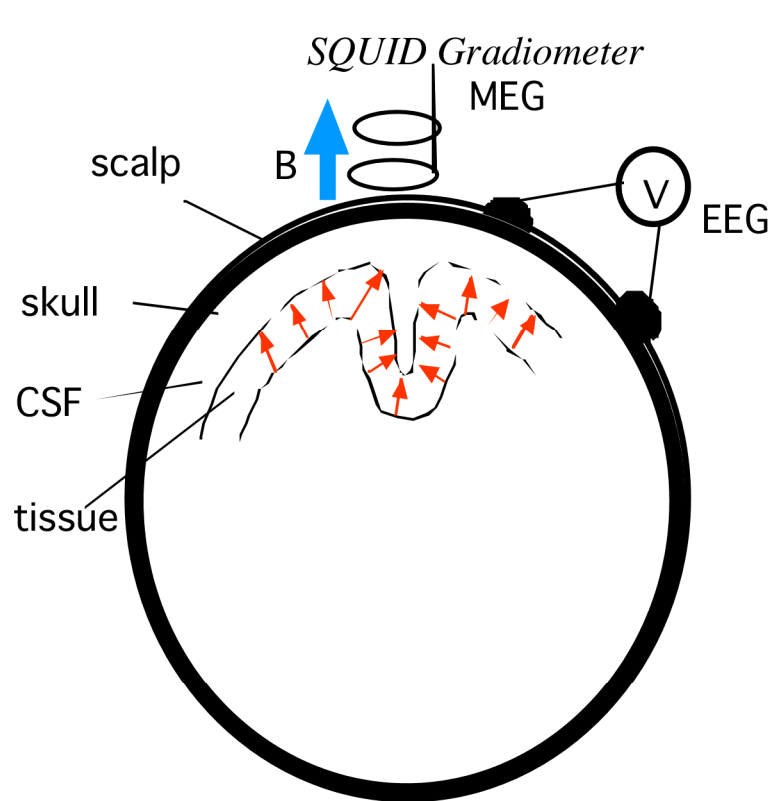
$$0 < \eta < 1$$

$\hat{\mathbf{V}}_{\text{Max}}, \hat{\mathbf{V}}_{\text{Min}}$   
*Orientations*

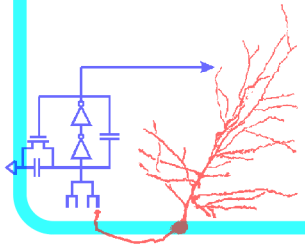
Physiologically Simple  
Current Sources:  $\eta = 0$



# MEG Measures Neural Currents



- Direct electrophysiological measurement
  - not hemodynamic
  - real-time
- No unique solution for distributed source



# MEG Response

## Flattened Isofield Contour Map

