Correlation between brain areas

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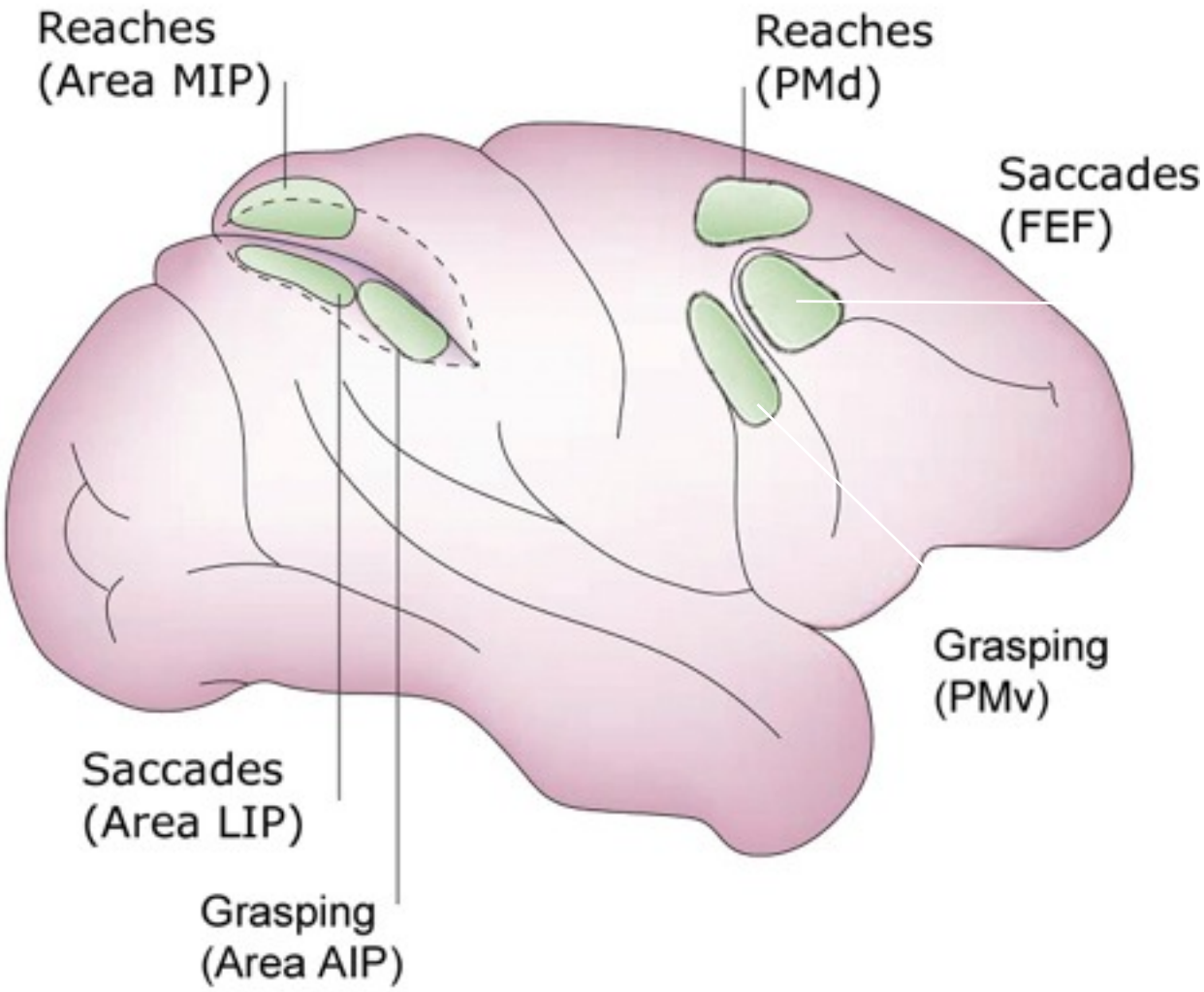
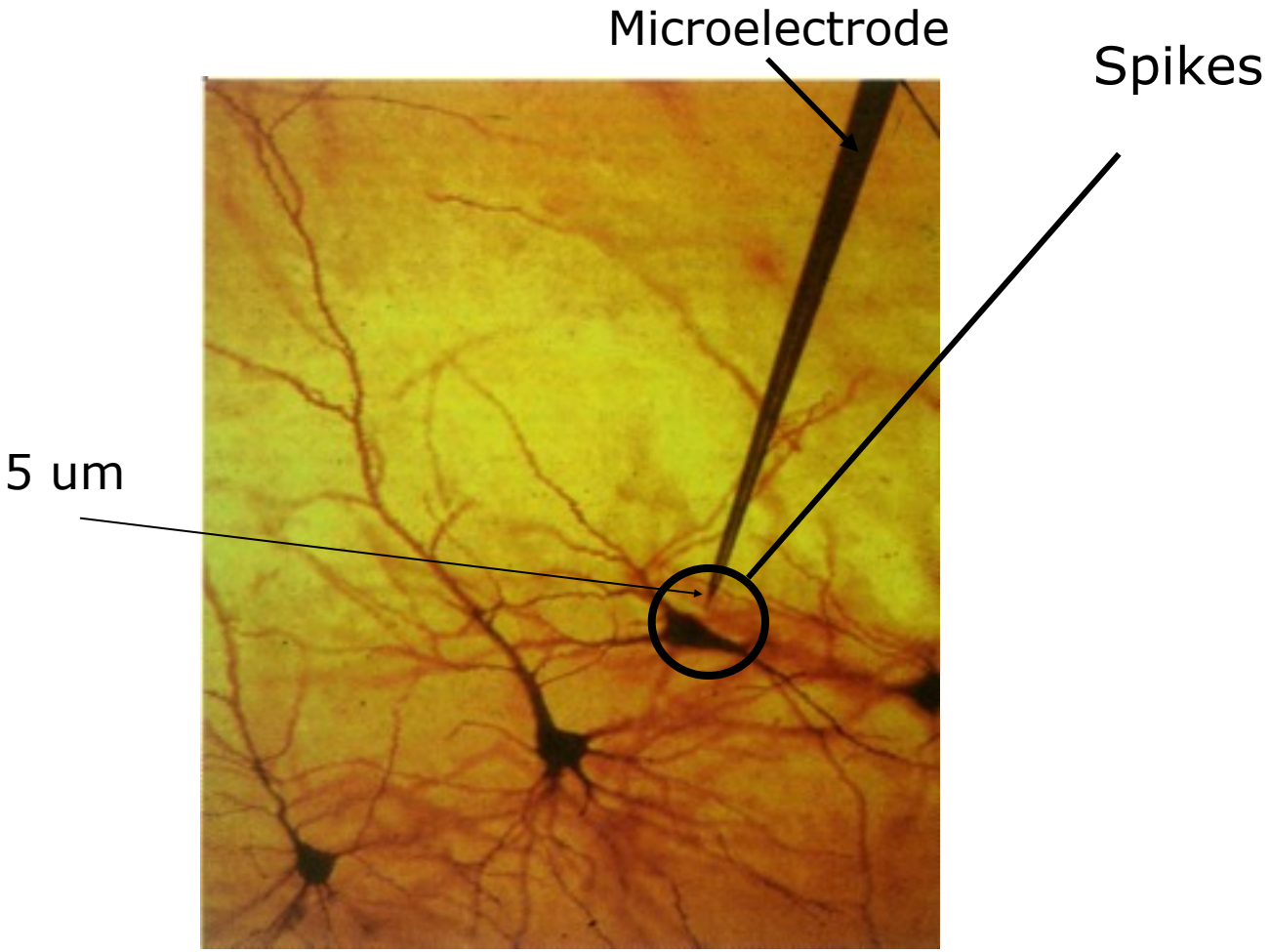
Neocortex is a mosaic of interconnected brain areas



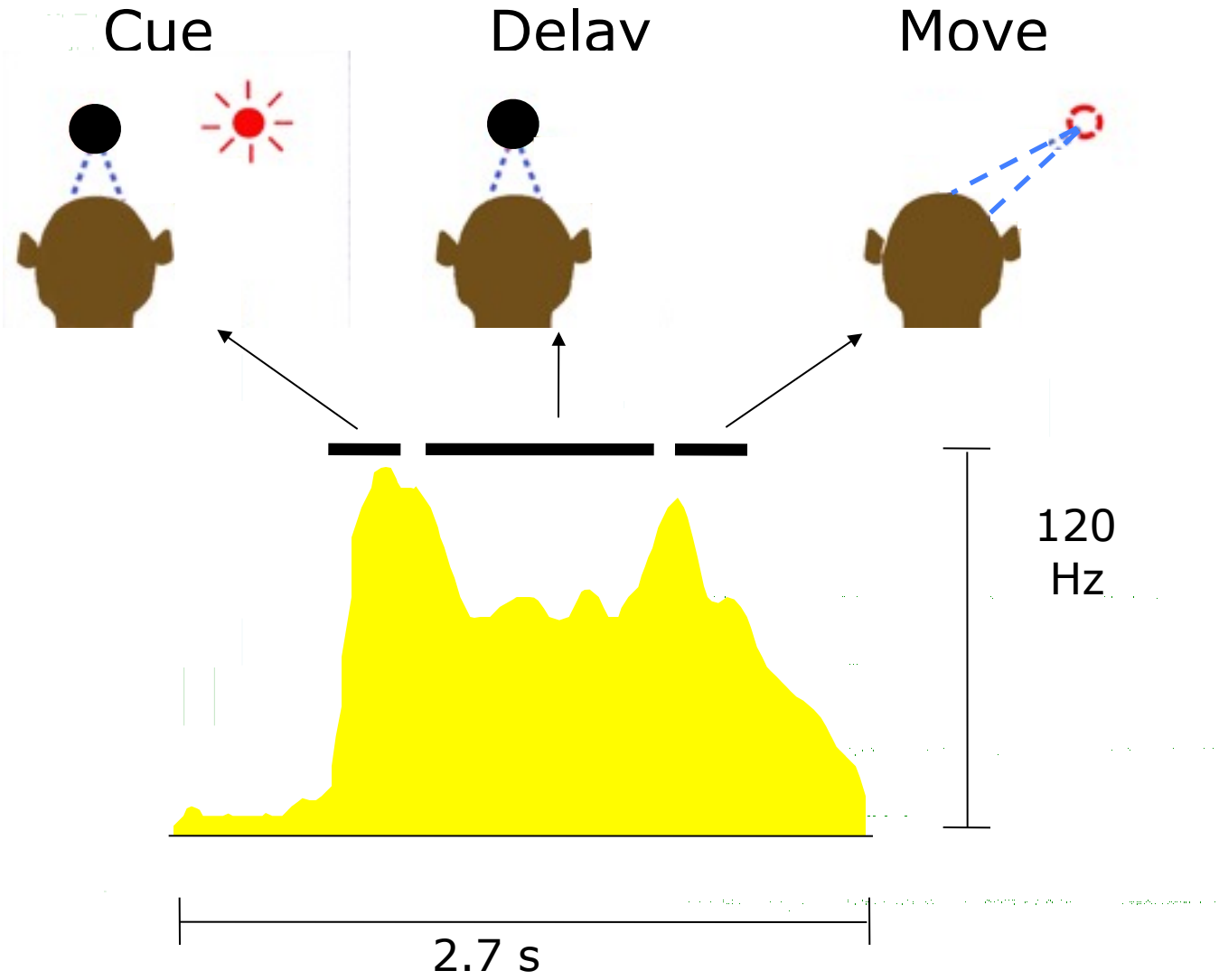
Electrical signals in the brain

- Single/multiple cell ~ 1-100 cells



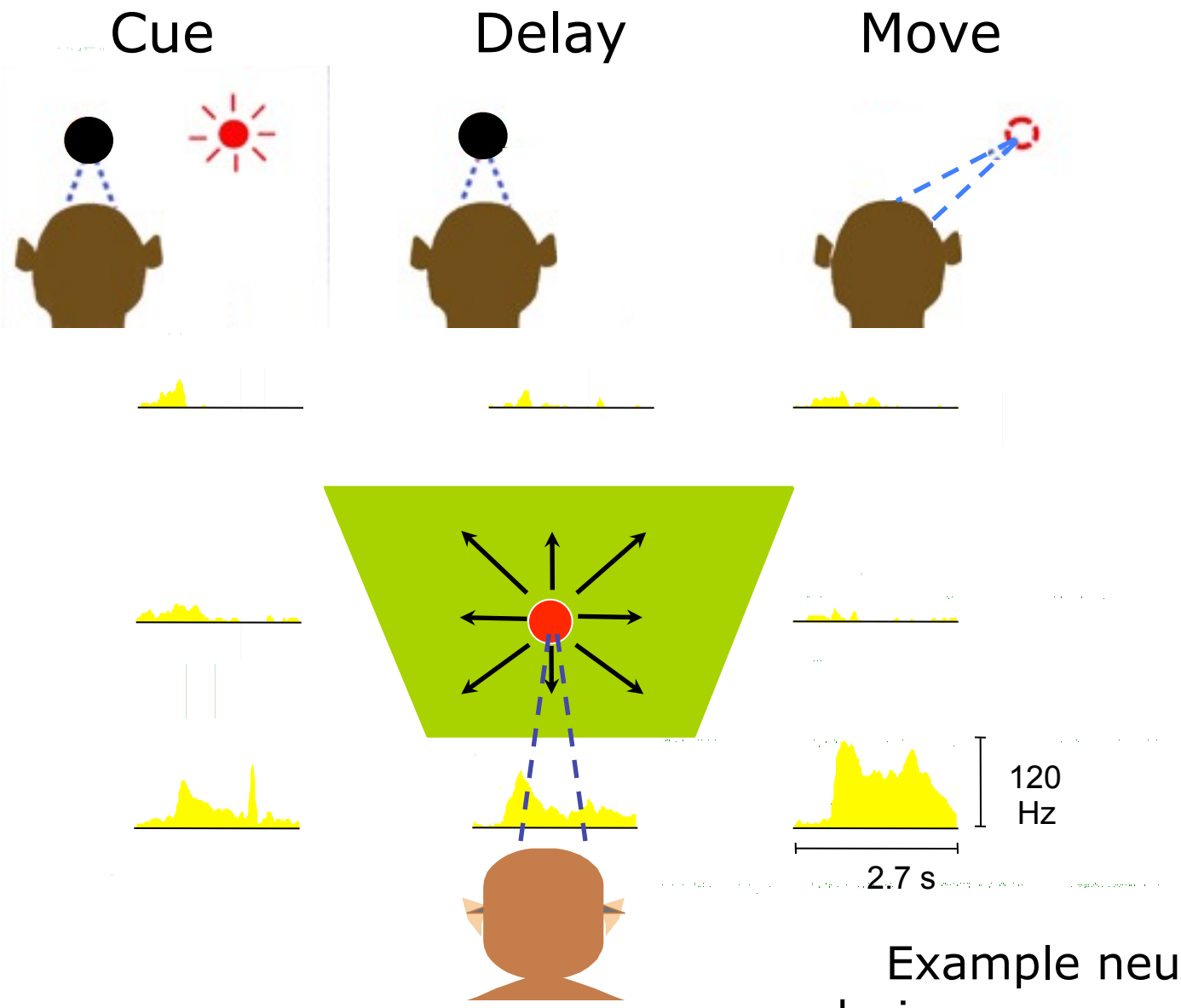
Eye movement task

Eye movement task



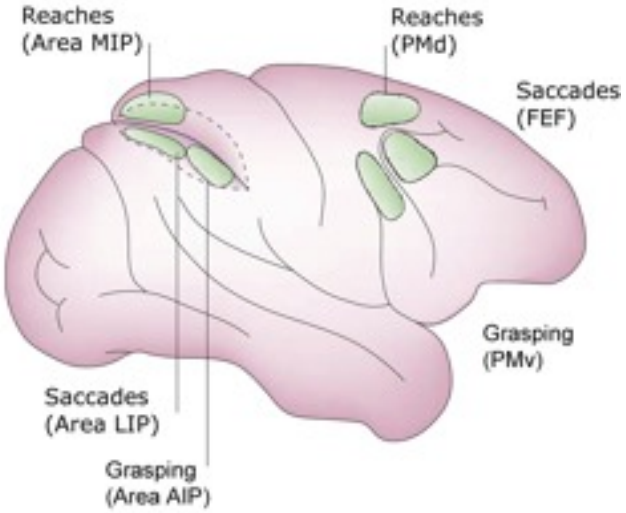
Example neuron
during eye movement

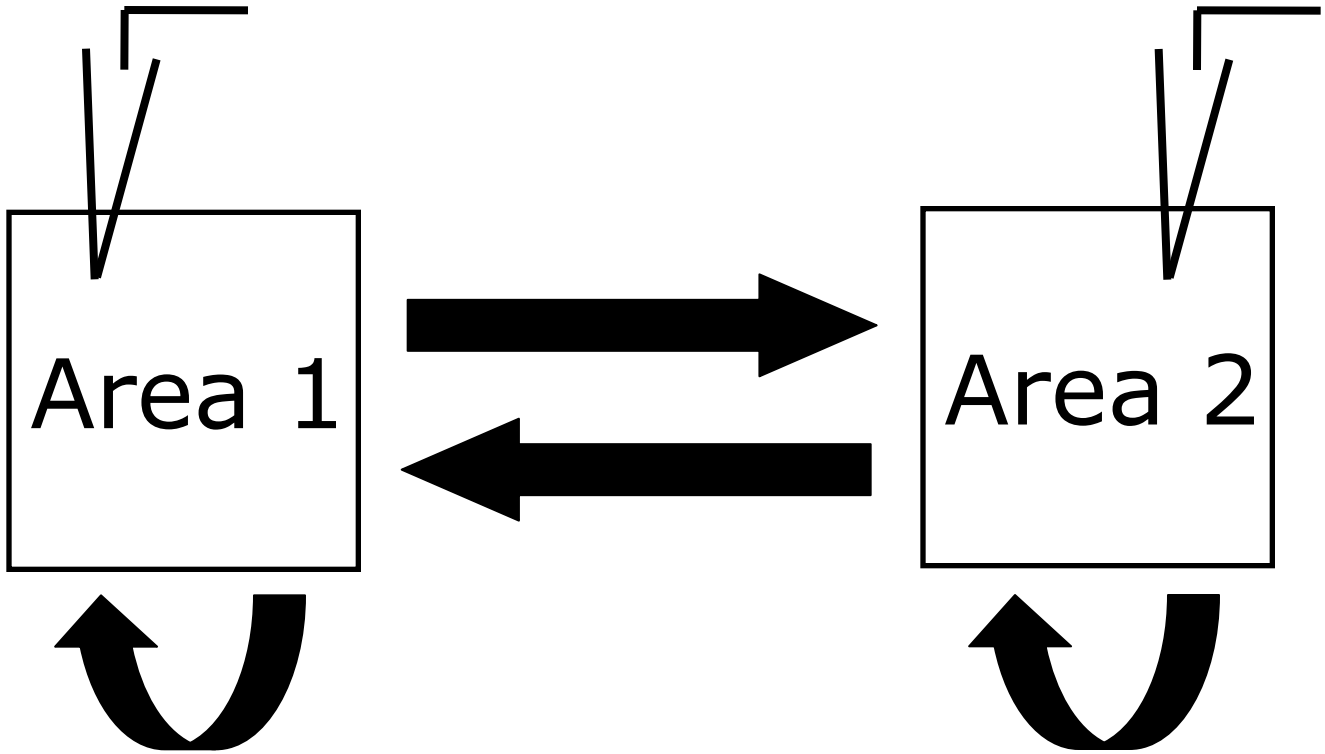
Activity is spatially tuned for movements



Example neuron
during eye movement

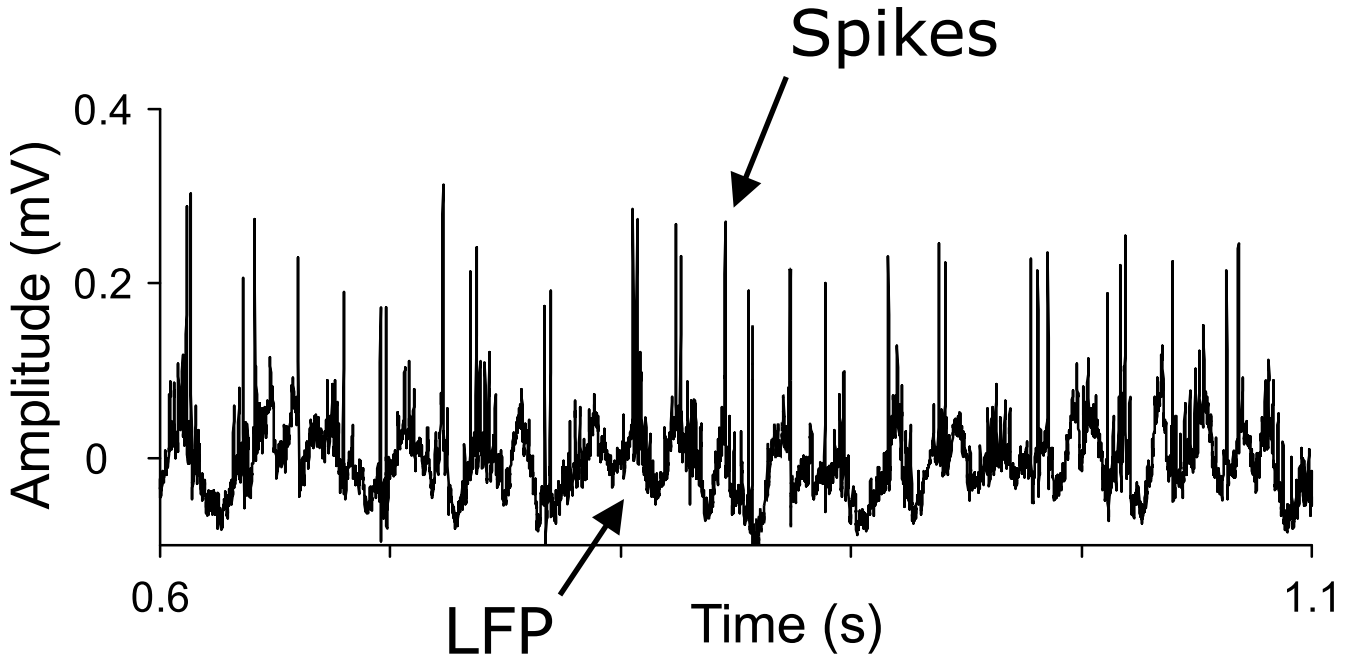
How do brain systems coordinate their activity?





Spiking and LFP activity

- Extracellular potential

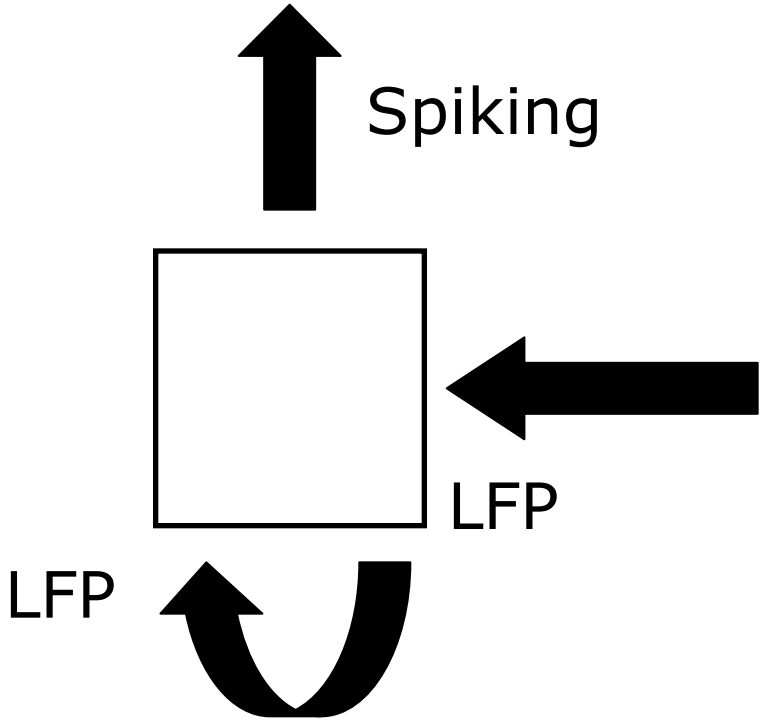


- Current summation determines the amplitude of LFP
  - Spatial and temporal

- Current summation determines the amplitude of LFP (Mitzdorf, 1985)
- Spatial correlations
  - Laminar organization of cells
  - Pyramidal cells apical dendrites
- Temporal correlations
  - Synchronous activity
  - Sensitivity to different time scales

LFP reflects inputs and local processing
Recorded spiking reflects outputs

(Towe and Harding, 1970)
(Barto et al, 2003)



LFP reflects inputs and local processing
Recorded spiking reflects outputs

(Towe and Harding, 1970)
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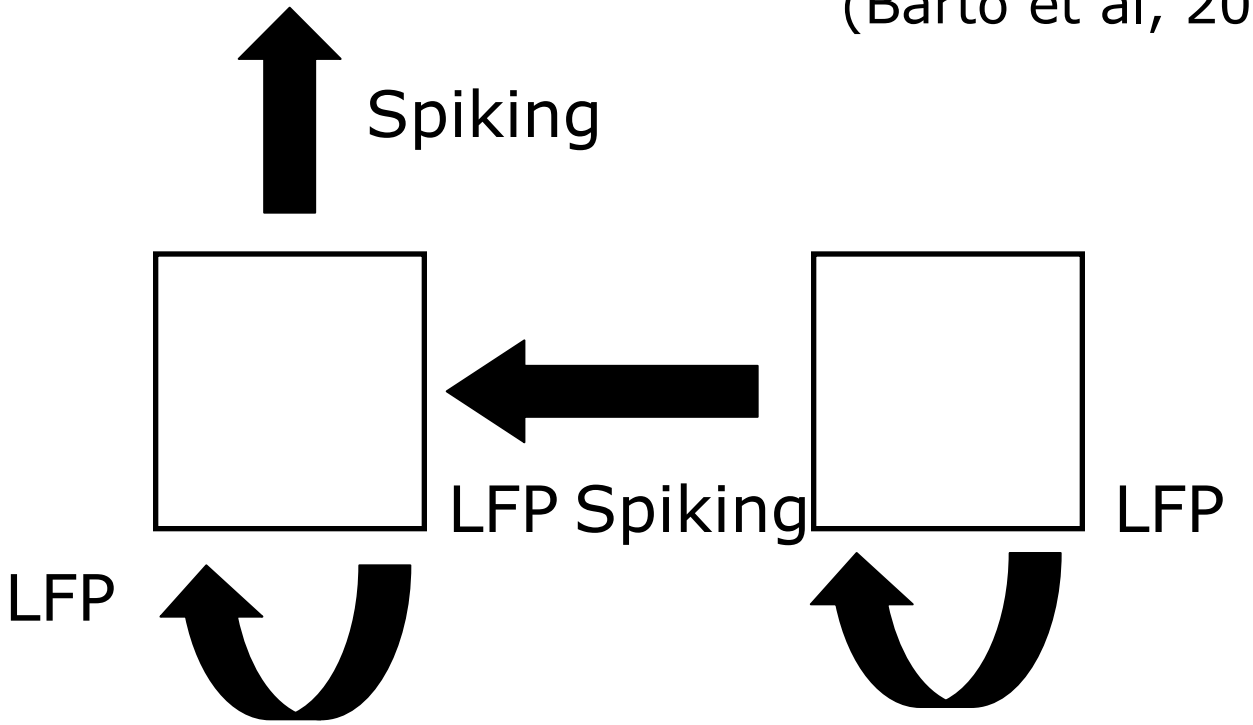


Study interactions between brain areas

How do we analyze spike trains and field potentials together?

v_t

LFP Voltage

Continuous process

t_n

Spike times

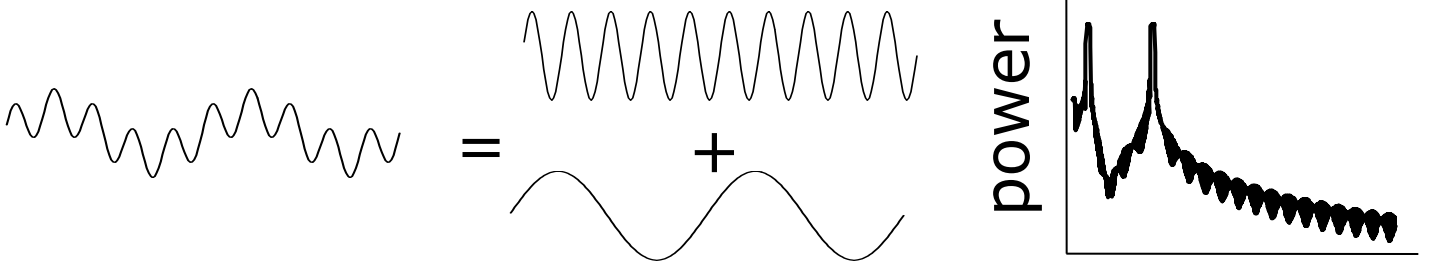
Point process

- Use spectral methods for a hybrid point-continuous process

Spectral intuition

v_t

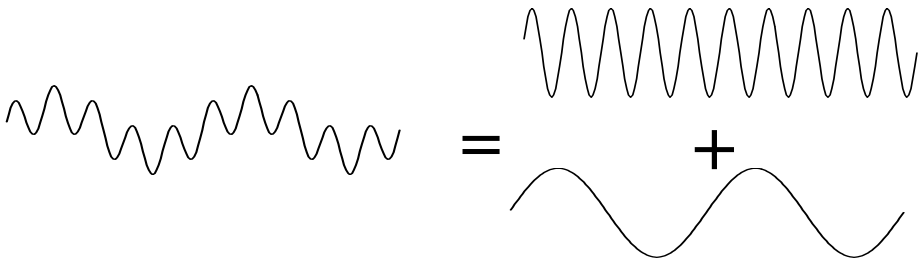
LFP Voltage



Spectral intuition

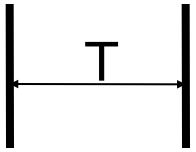
v_t

LFP Voltage



t_n

Spike times



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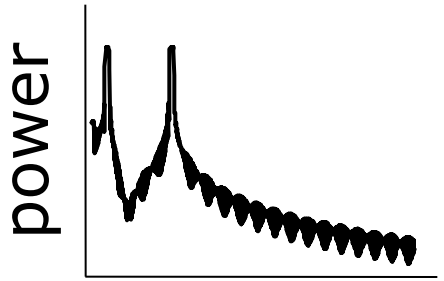
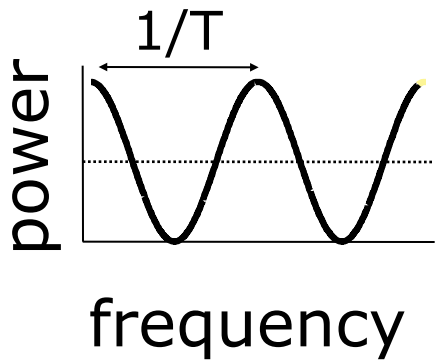
Spectrum



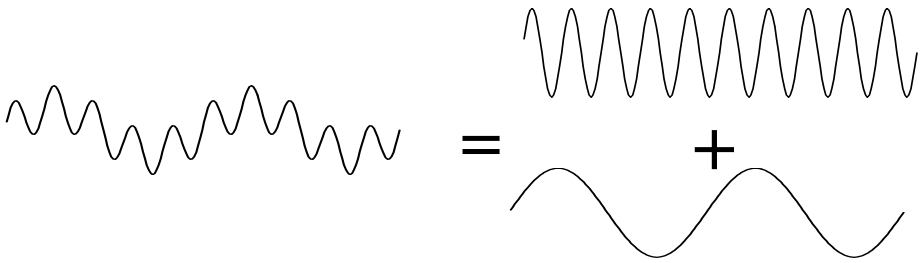


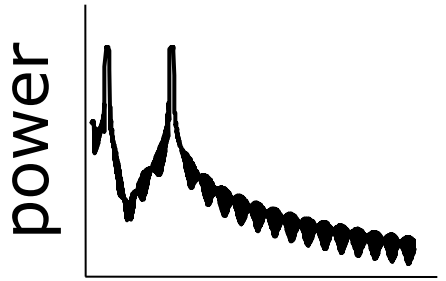
Spectral intuition

Spectrum

v_t

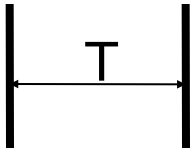
LFP Voltage





t_n

Spike times



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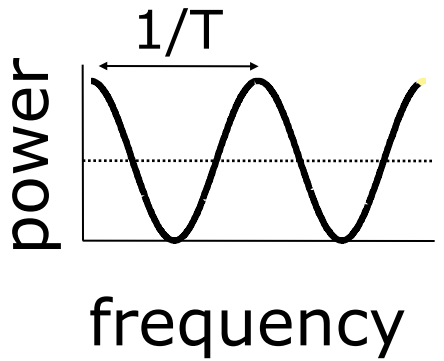


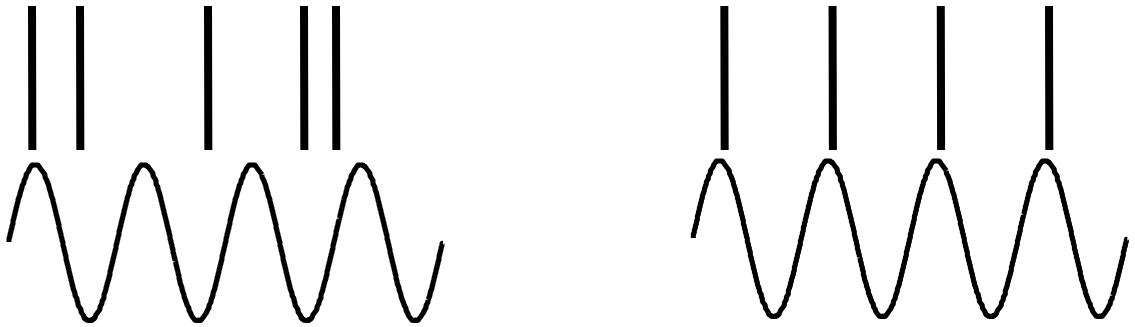
Coherency

Low

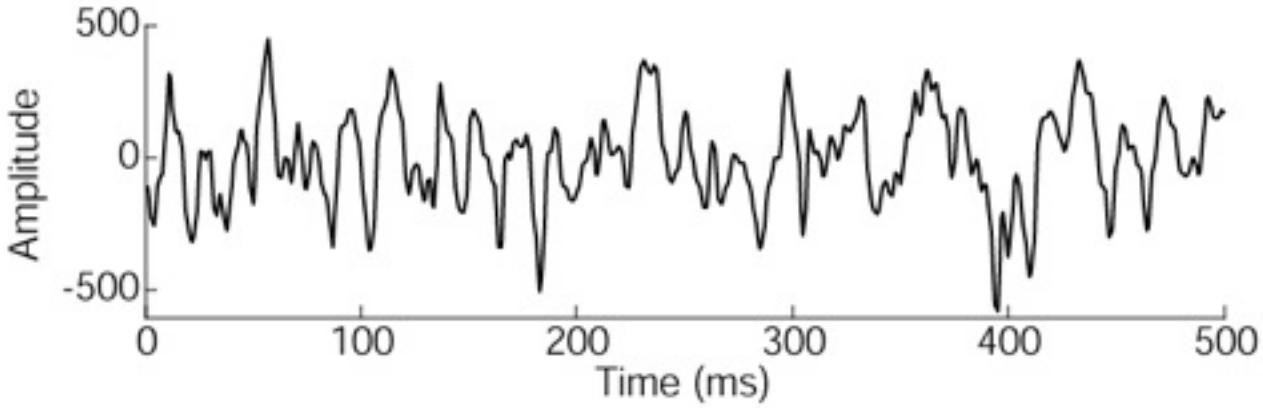
High $\phi = 0°$

Spikes

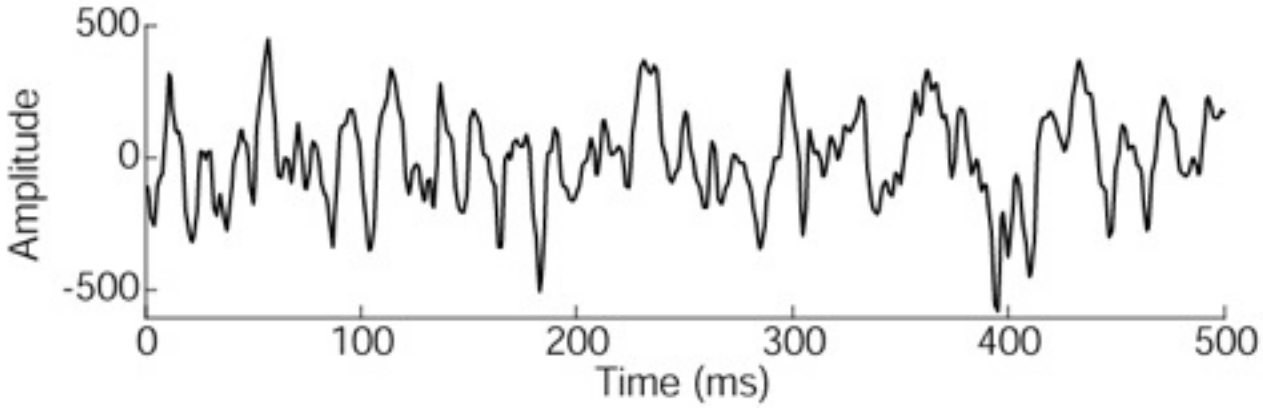
Field



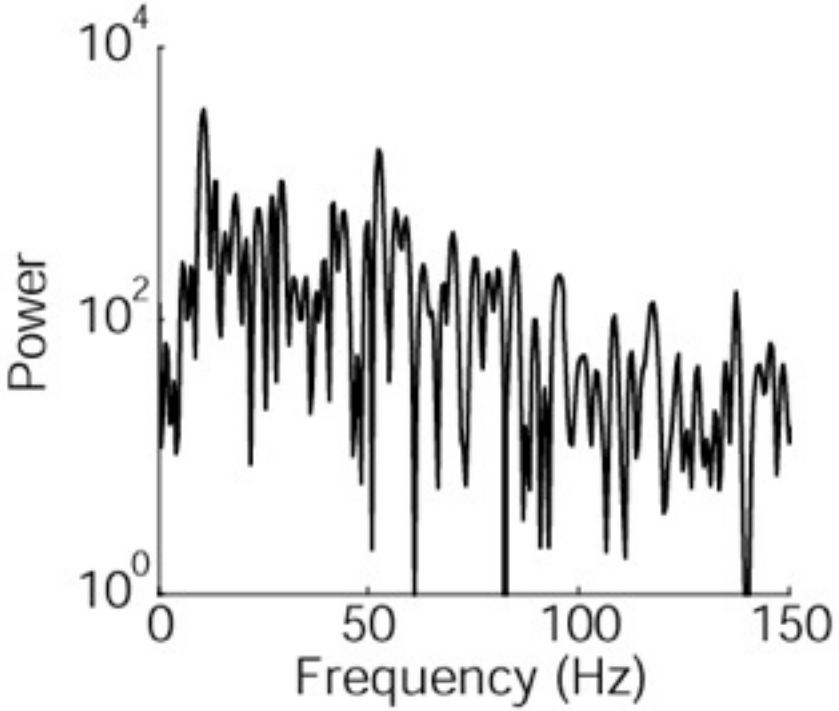
Example I: LFP spectrograms



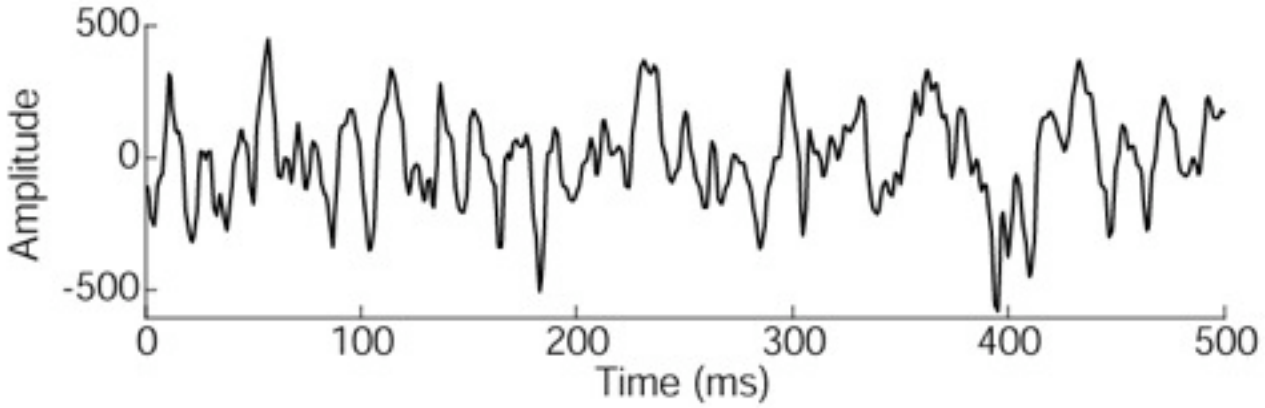
Example I: LFP spectrograms



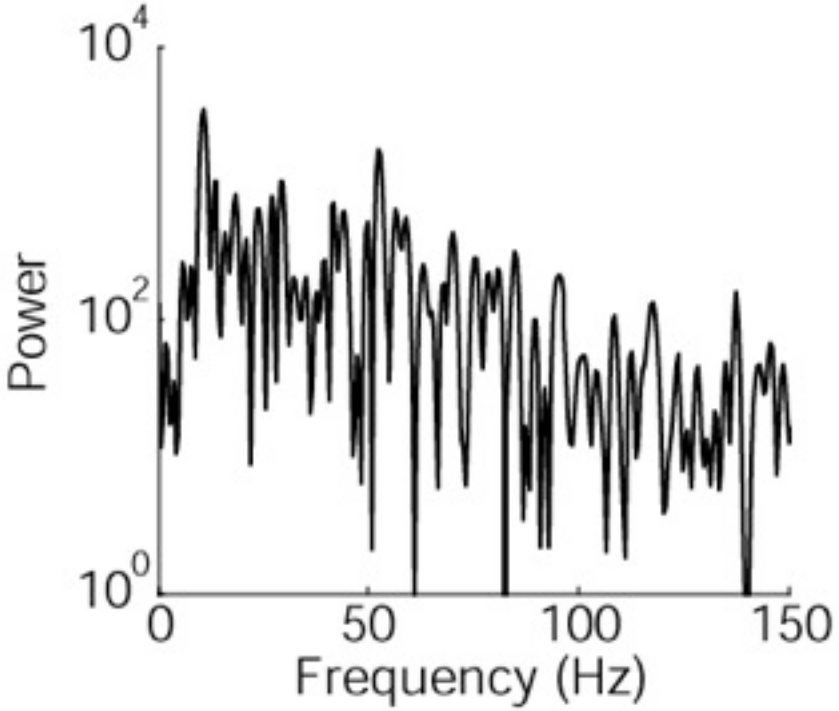
Periodogram – Single Trial



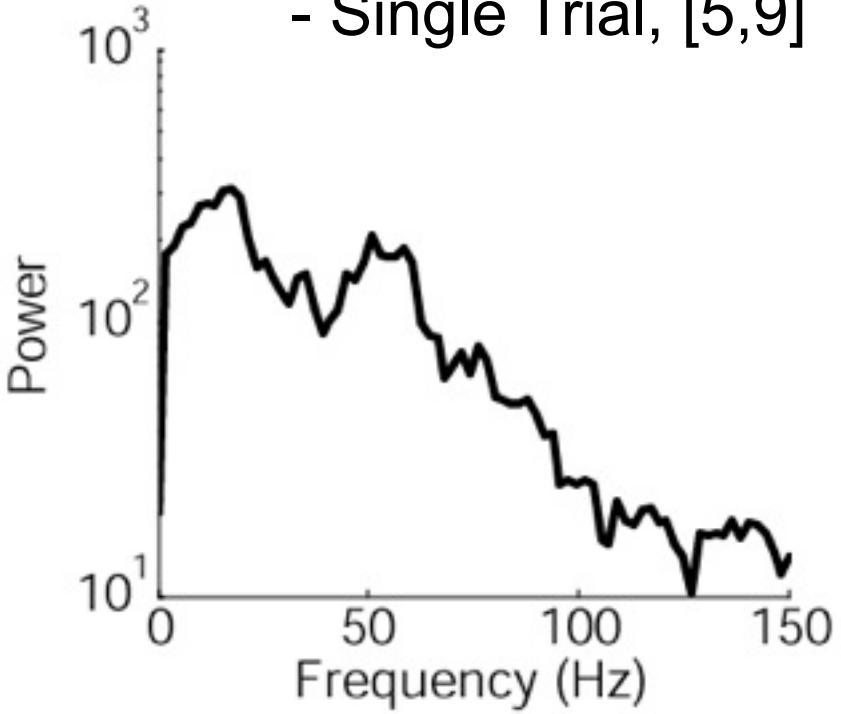
Example I: LFP spectrograms



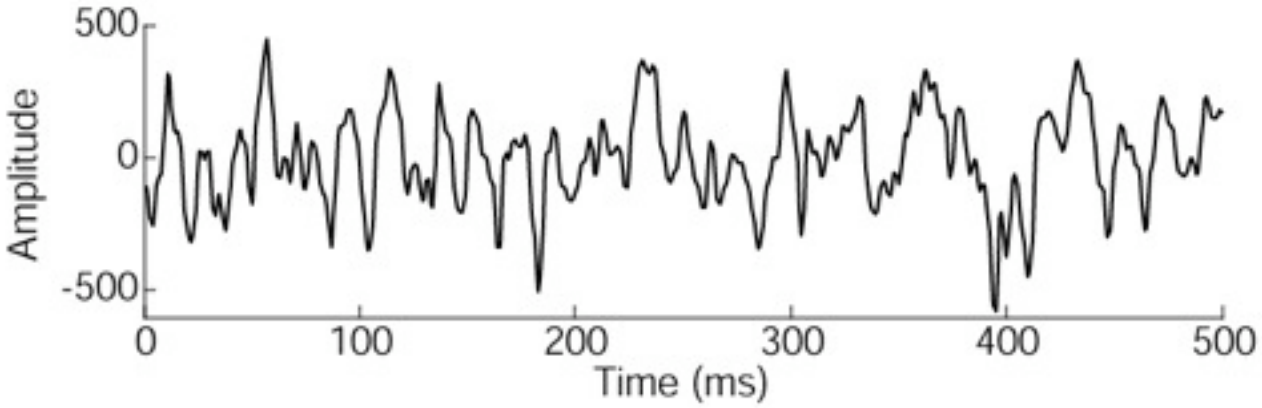
Periodogram – Single Trial



Multitaper estimate - Single Trial, [5,9]

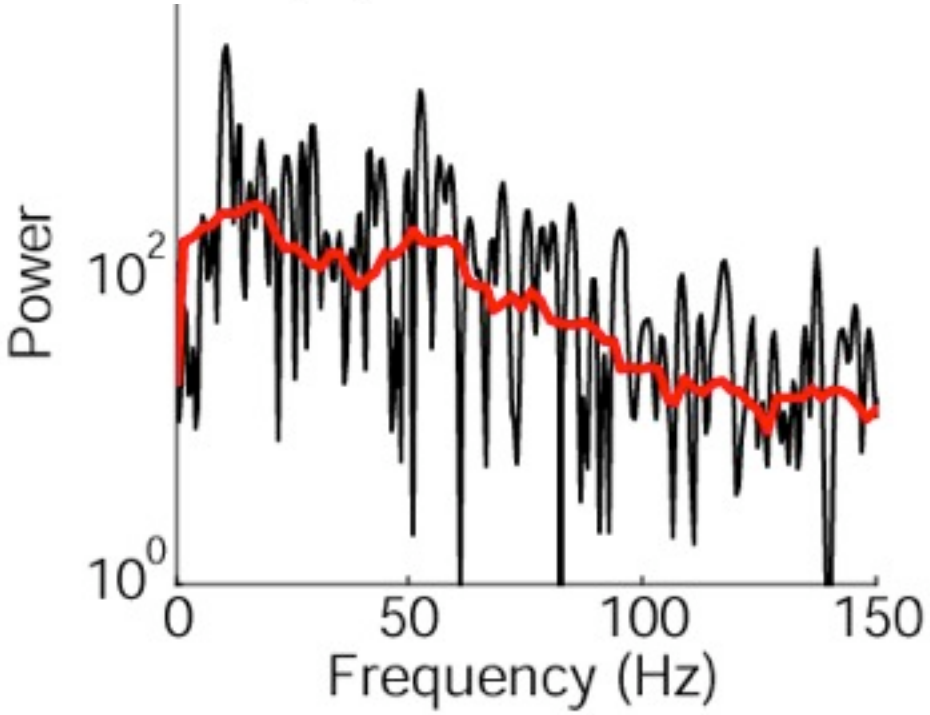


Example I: LFP spectrograms



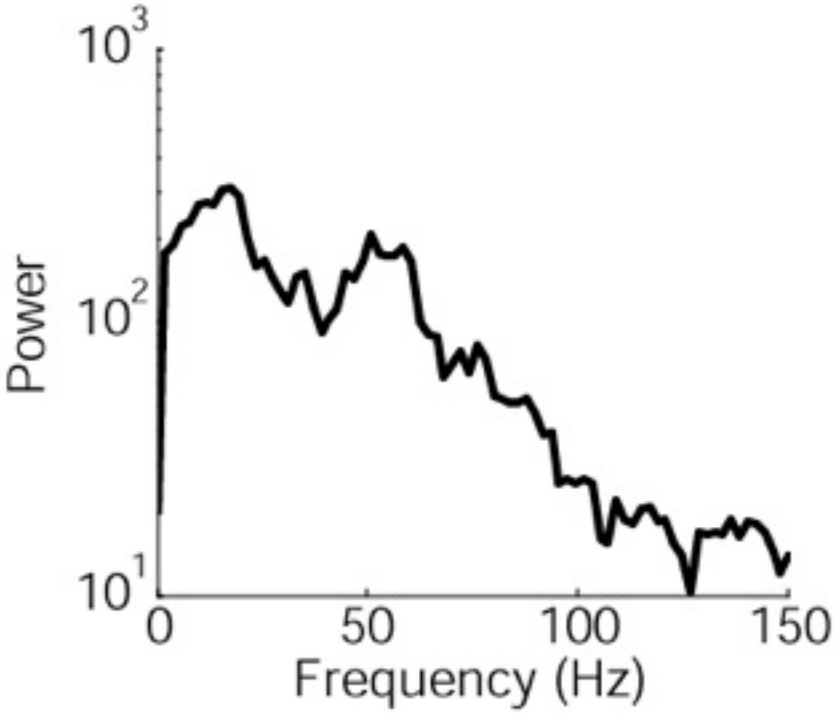
Periodogram
– Single Trial

Multitaper estimate
- Single Trial



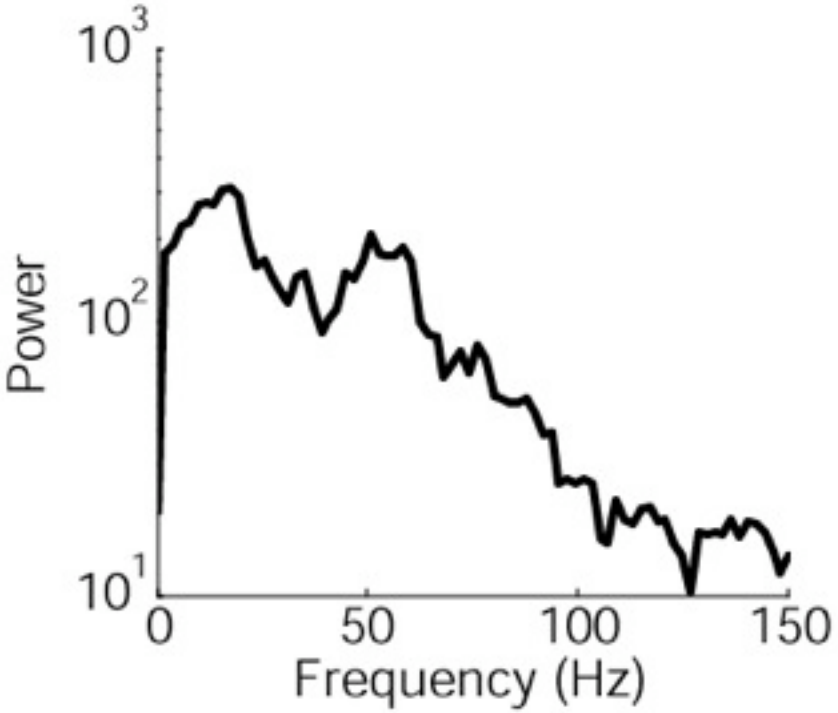
Example I: LFP spectrograms

Multitaper estimate
- Single Trial [5,9]

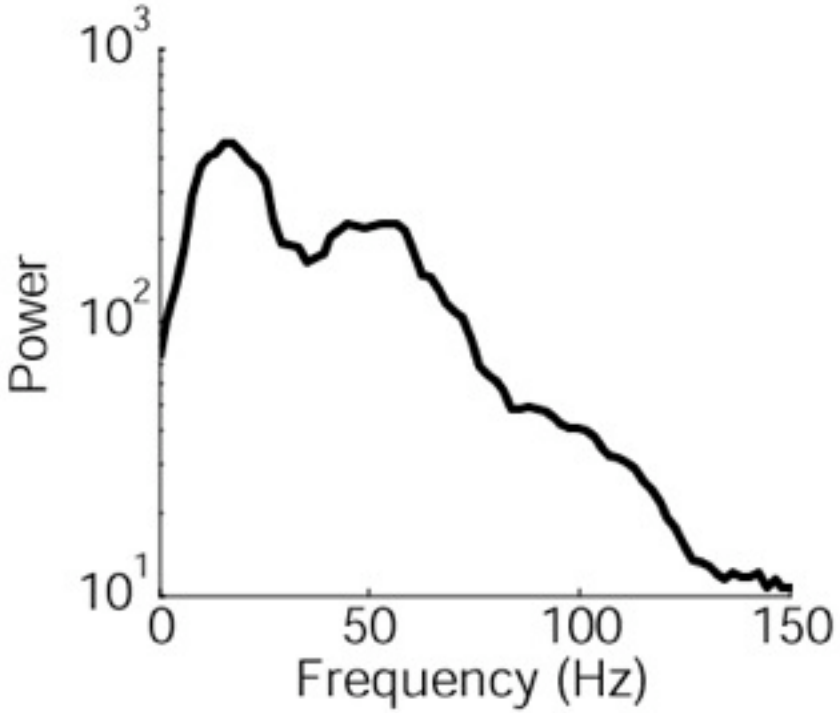


Example I: LFP spectrograms

Multitaper estimate
- Single Trial [5,9]



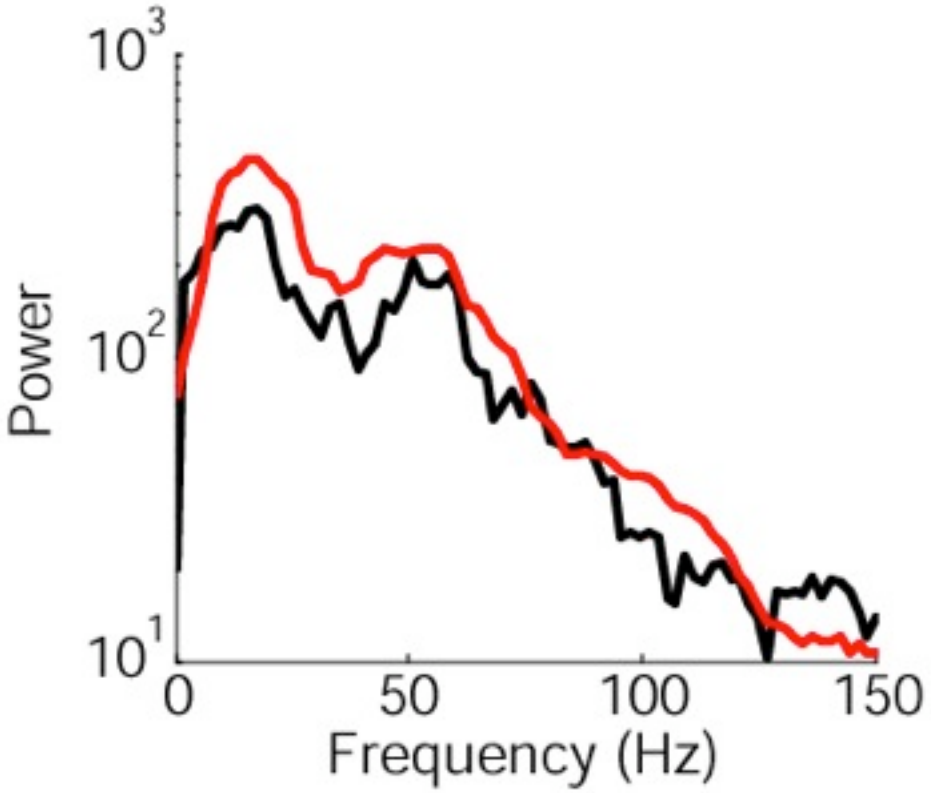
Multitaper estimate
- Nine Trials [5,9]



Example I: LFP spectrograms

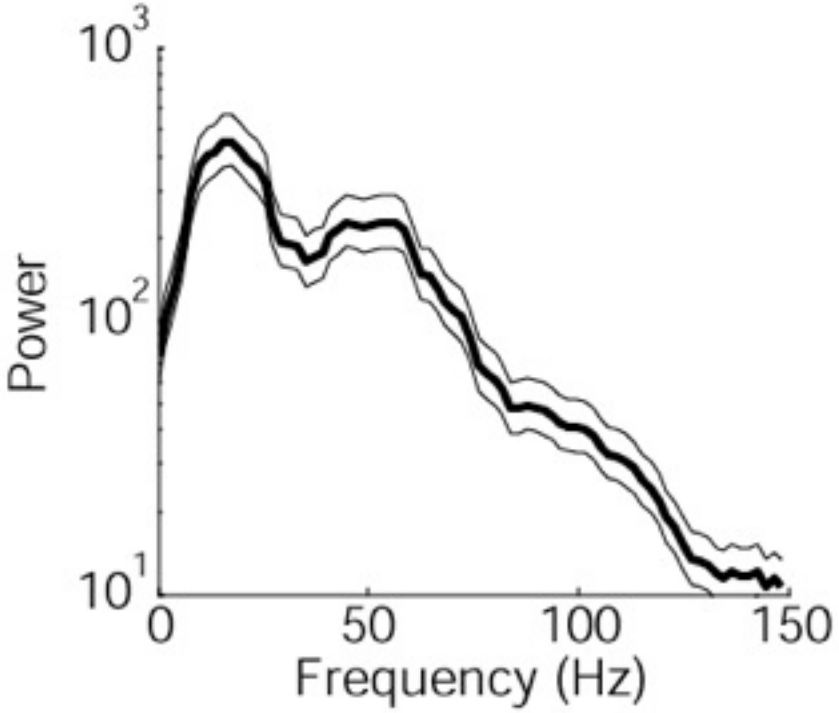
Multitaper estimate
- Single Trial

Multitaper estimate
- Nine Trials



Example I: LFP spectrograms

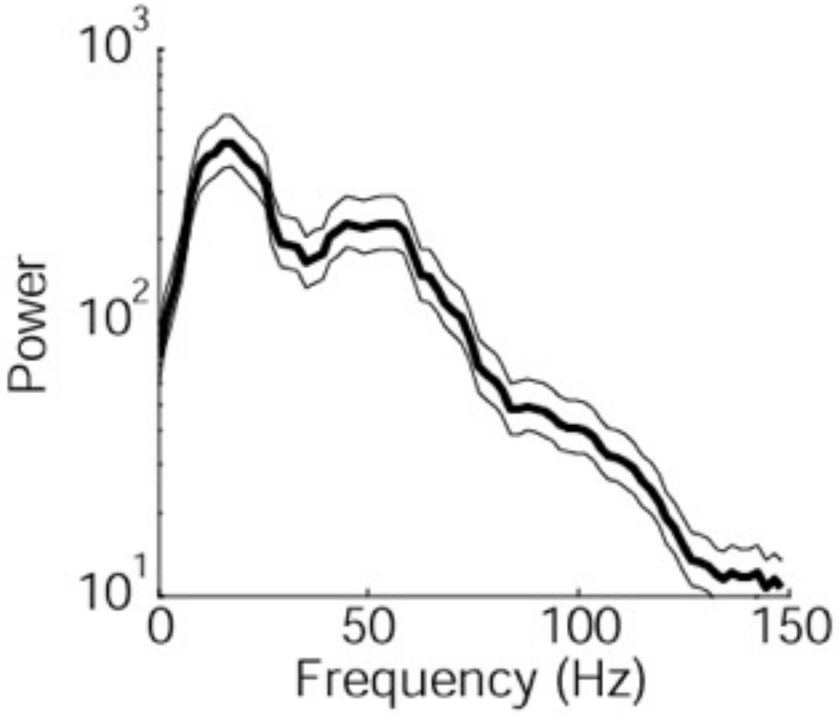
Multitaper estimate
- 95% Chi2



$$S \sim \chi^2_{2dof-1}$$

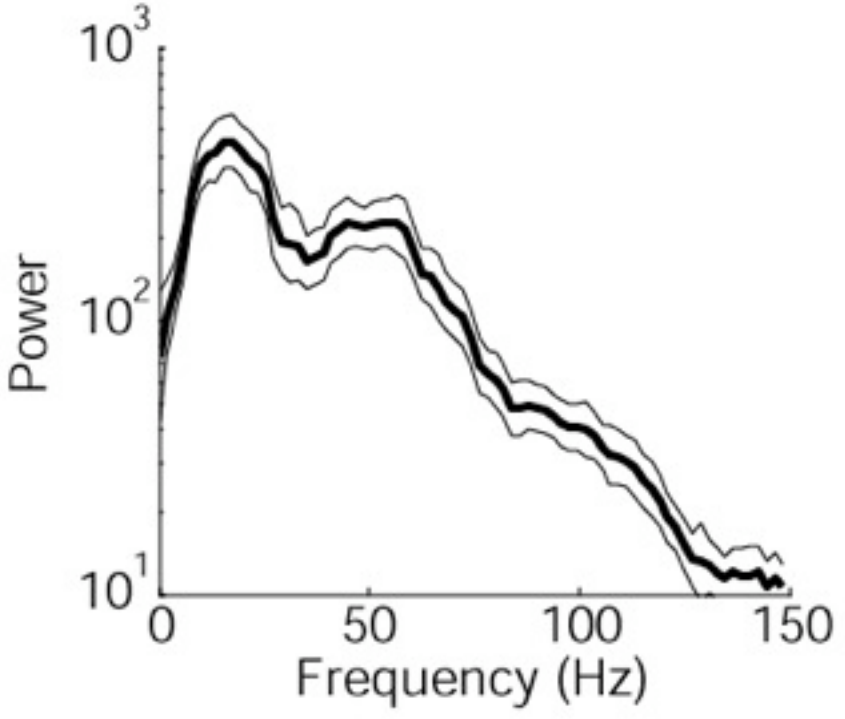
Example I: LFP spectrograms

Multitaper estimate
- 95% Chi2



$$S \sim \chi^2_{2dof-1}$$

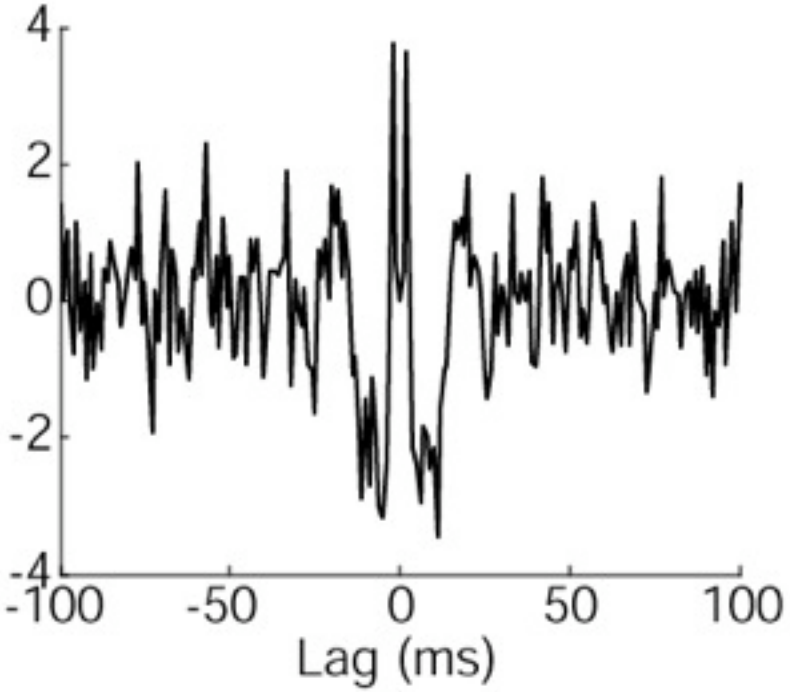
Multitaper estimate
- 95% Jackknife



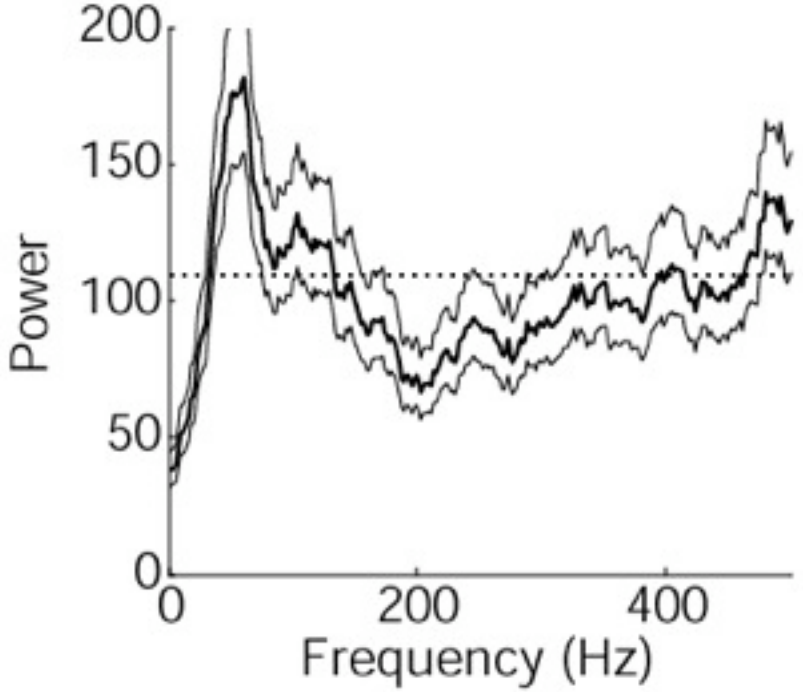
Leave-one-out

Example II: Spike rates, spectra and coherence

Auto-correlation fn

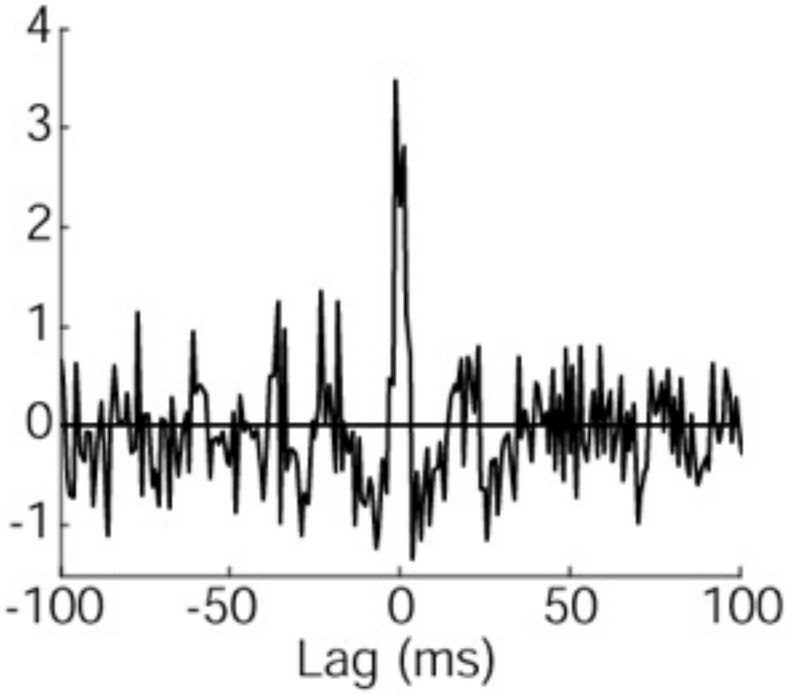


Multitaper spectrum
[8,15]

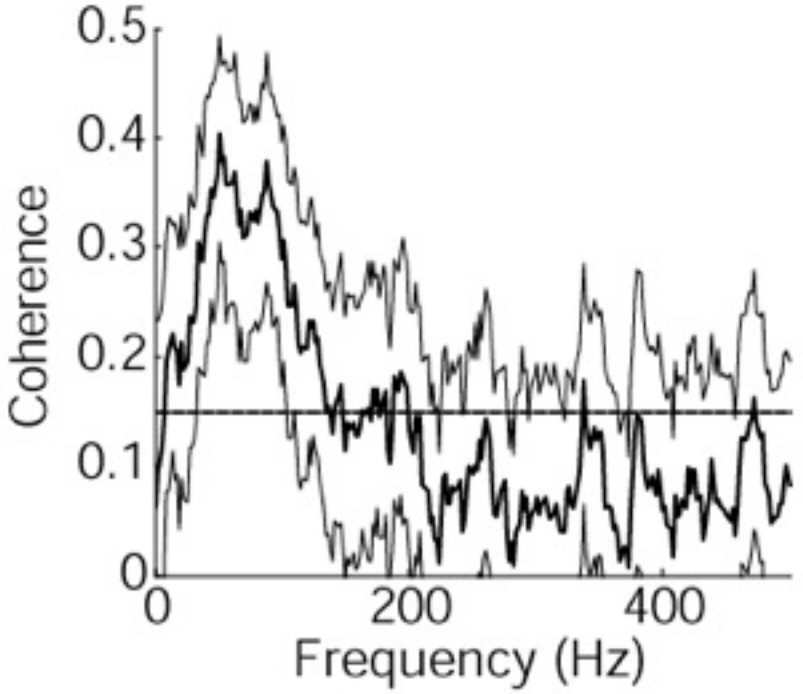


Example II: Spike rates, spectra and coherence

Cross-correlation fn

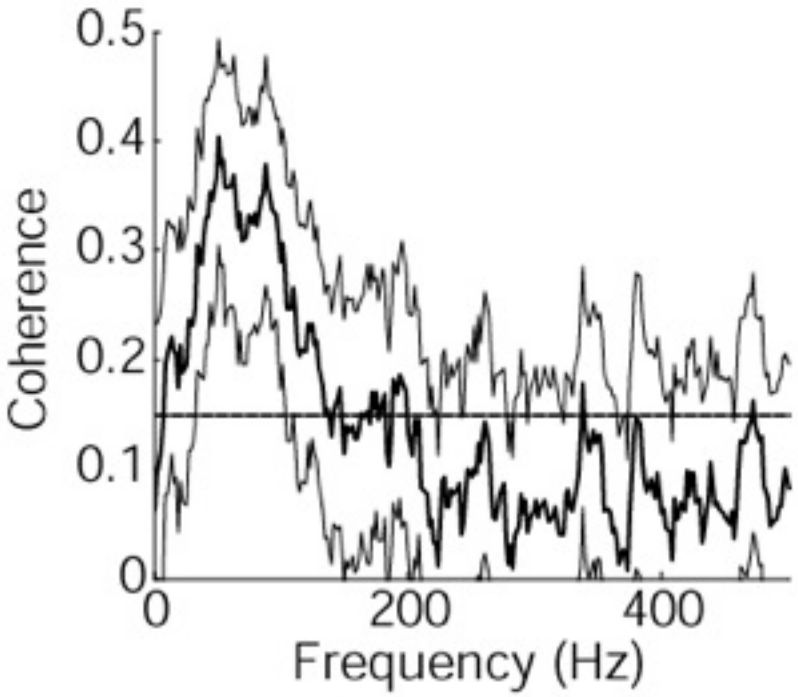


Multitaper coherence
9 trials, [8,15]

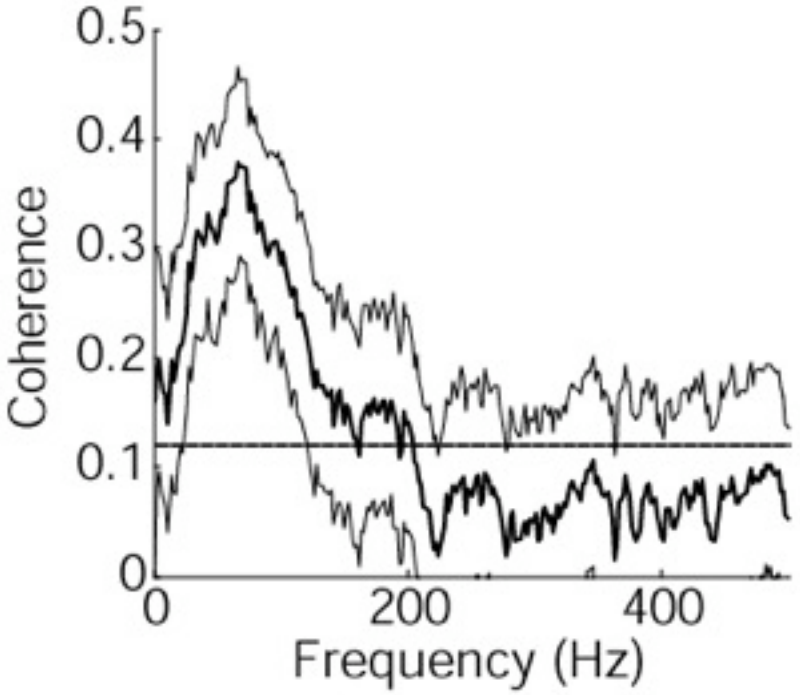


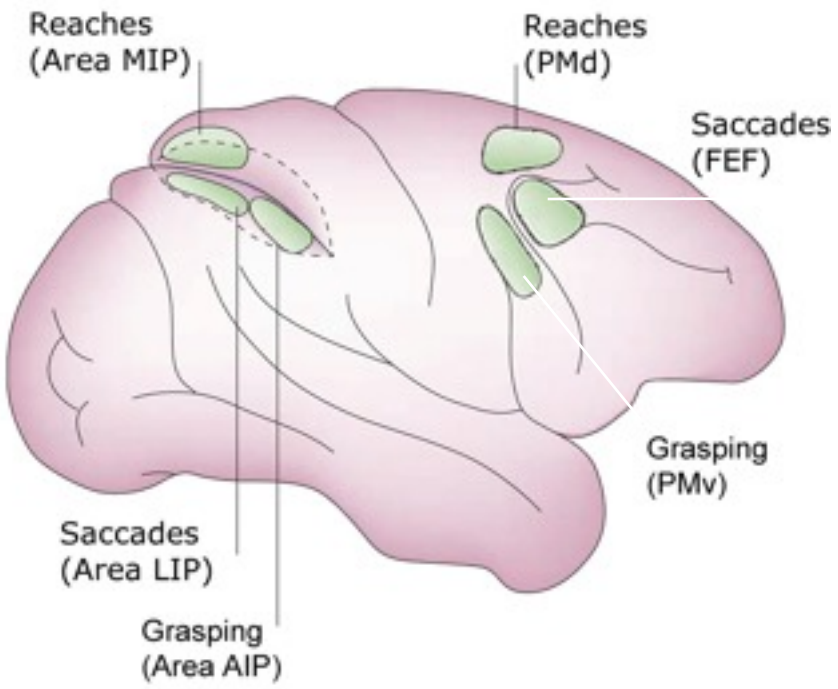
Example II: Spike rates, spectra and coherence

Multitaper coherence
9 trials, [8,15]

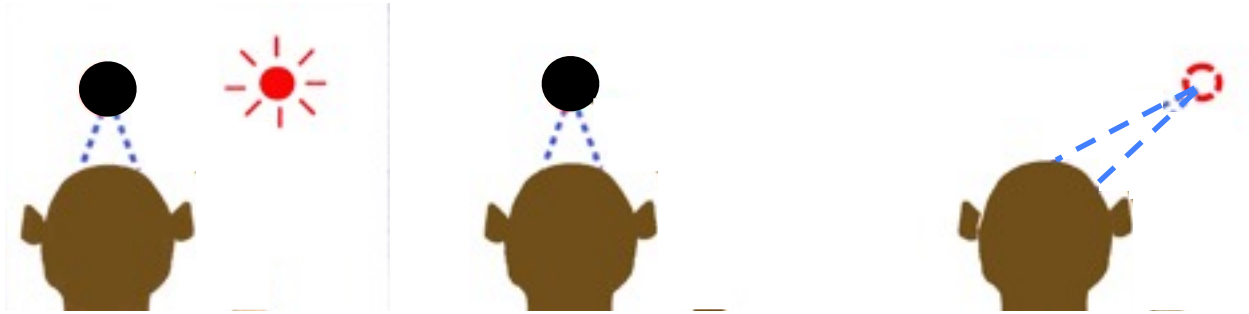


Multitaper coherence
9 trials, [12,23]

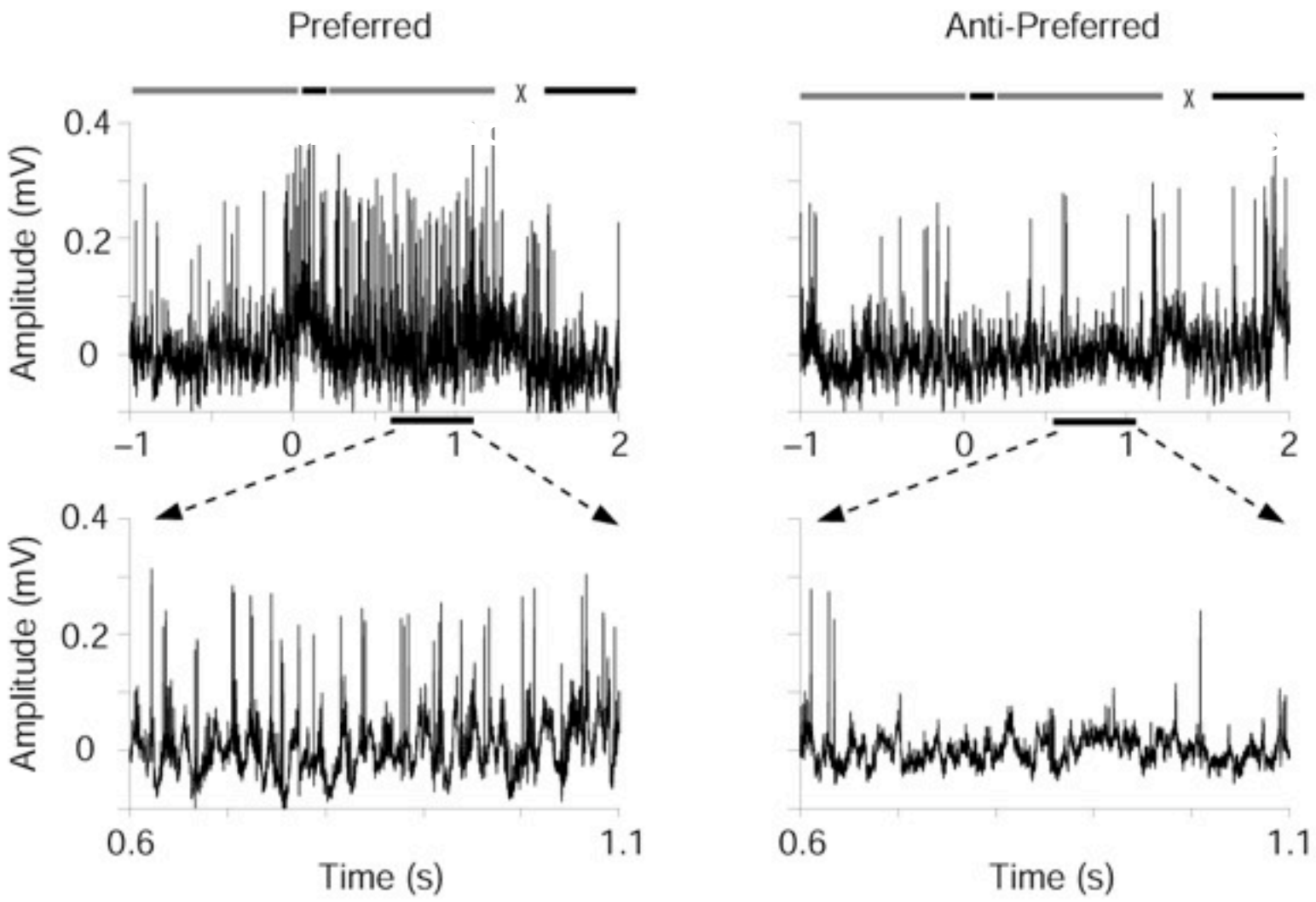




Cue Memory Saccade

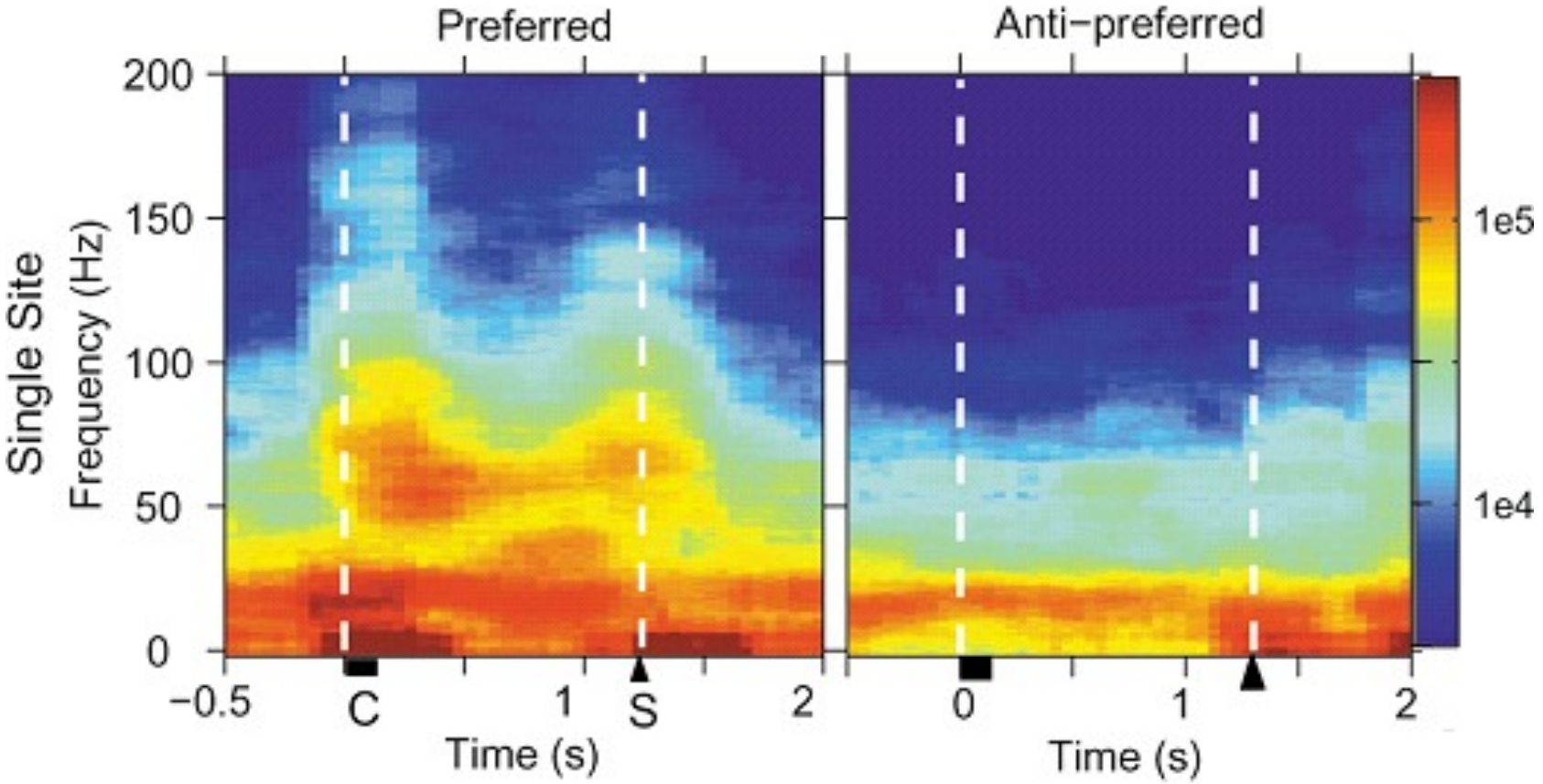


Does LFP reflect movement plans?
How is spiking related to LFP?



Pesaran et al. (2002)

In LIP, gamma band LFP activity shows spatial tuning



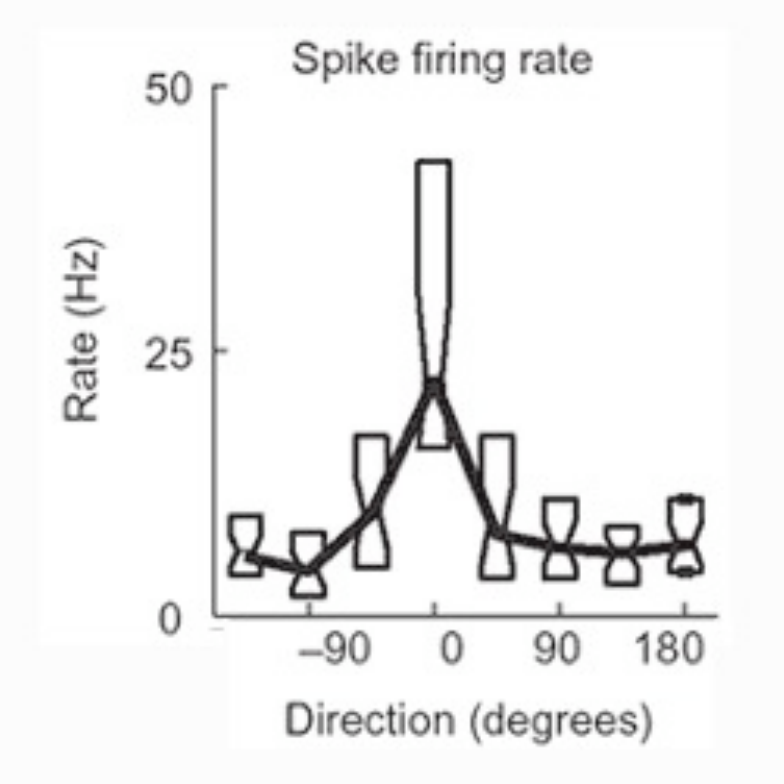
■ = Cue

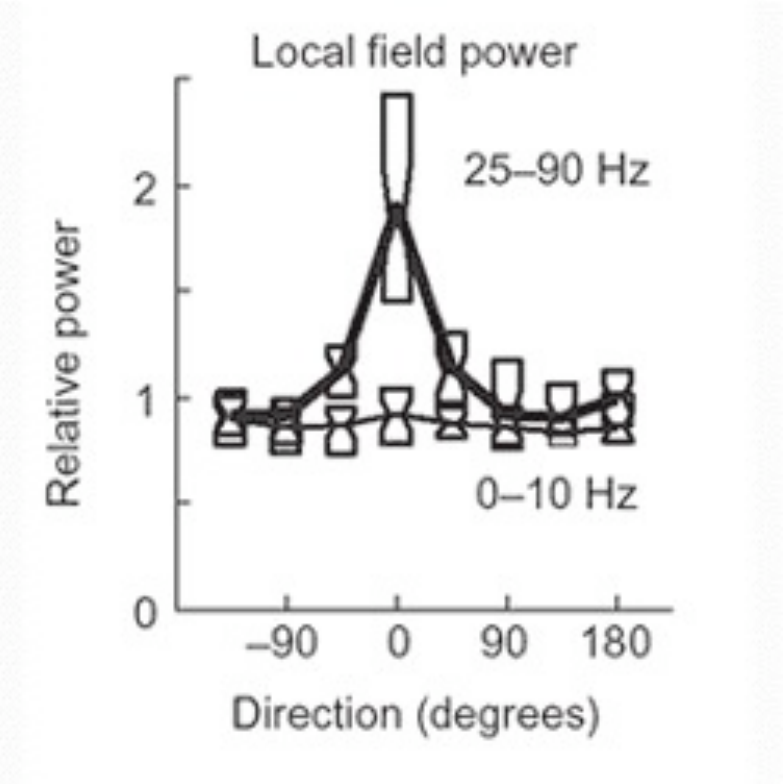
▲ = Saccade

Single electrode in Area LIP

Pesaran et al (2002)

Gamma band LFP tuning is similar to spike rate

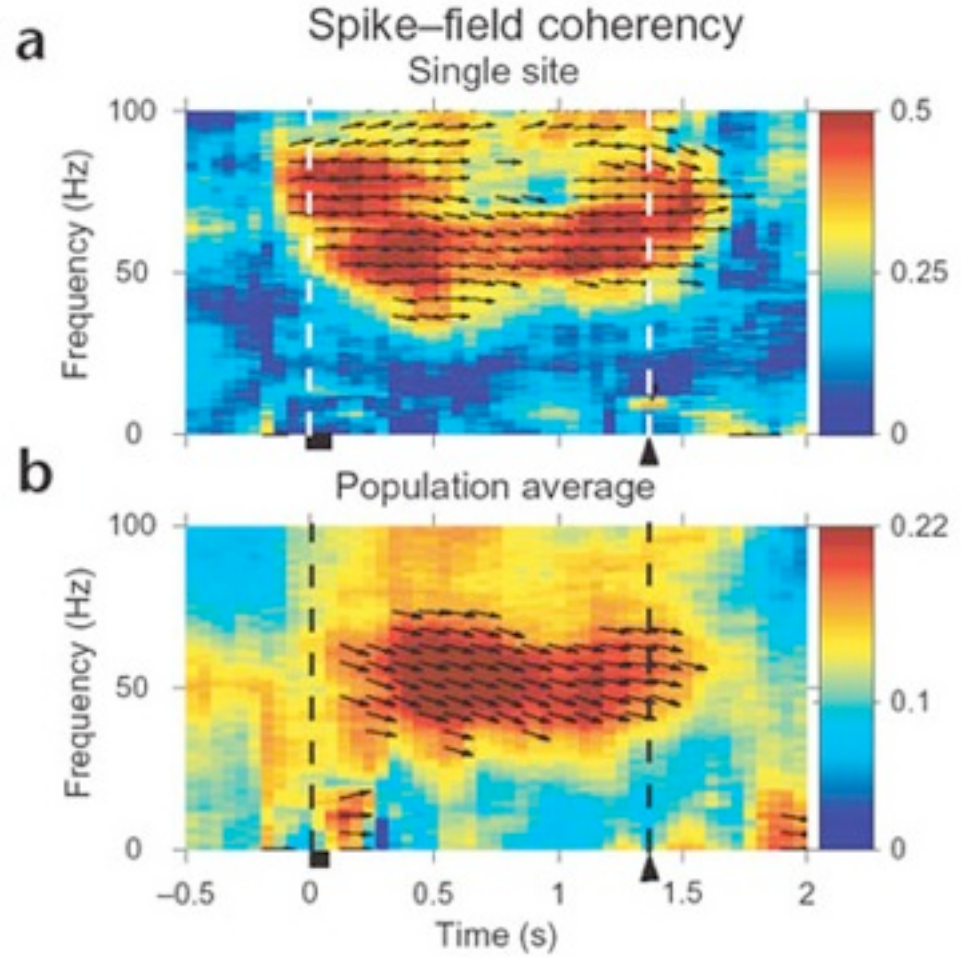




Single electrode in Area LIP

Pesaran et al (2002)

LIP contains significant spike-field correlations



■ = Cue

▲ = Saccade

Pesaran et al (2002)

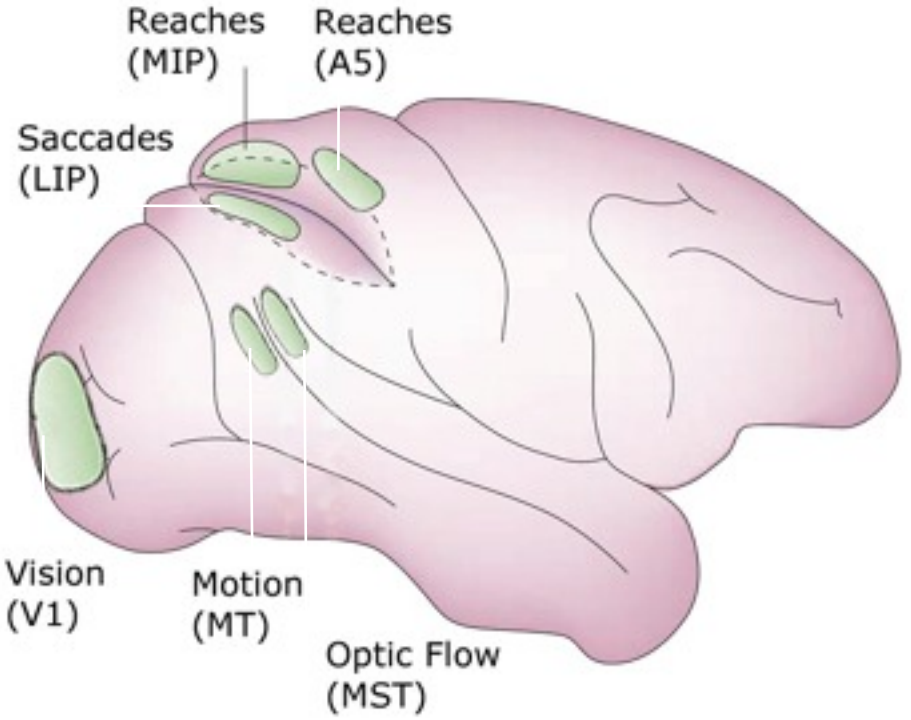
Spiking and field activity in area LIP are spatially tuned.

- Spike-field coherency may reflect cortical columns

Significant for clinical applications.

- Development of neural prosthetic devices
- Brain-computer interfaces

LFP tuning is widespread in cortex



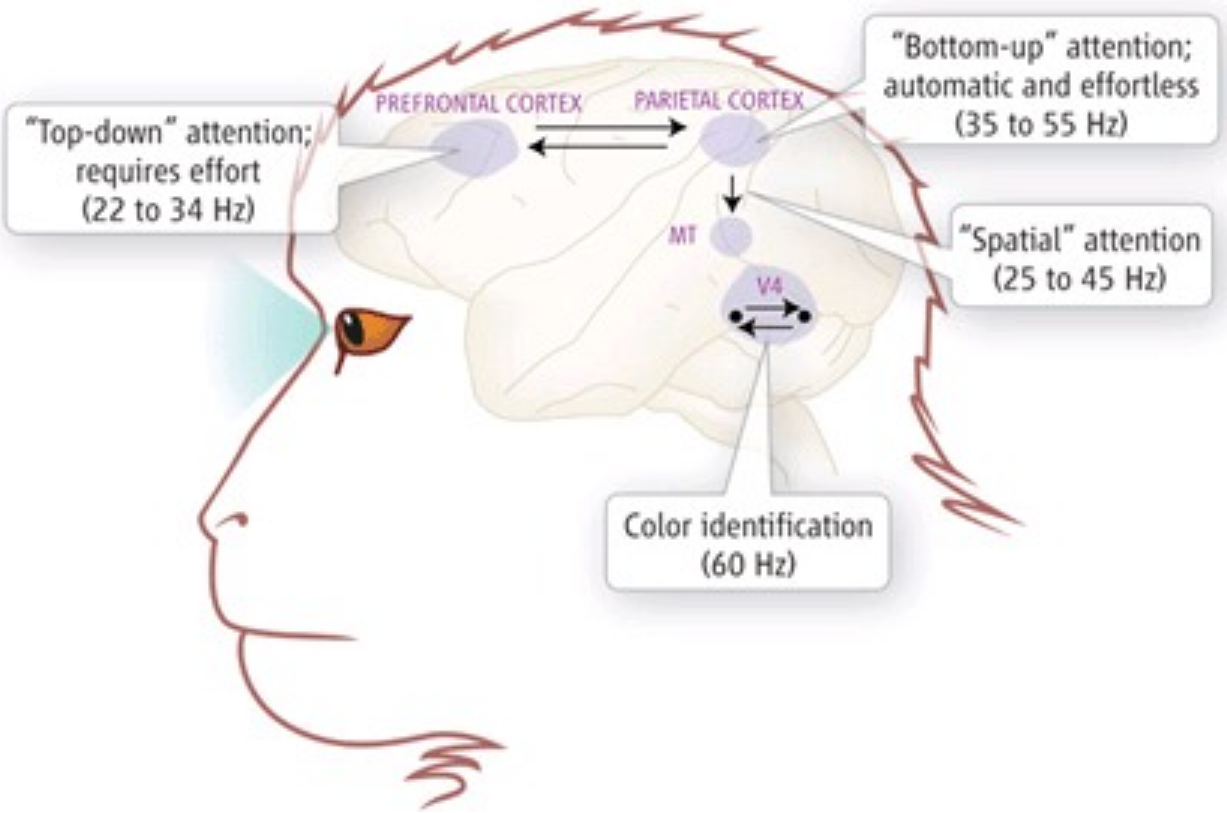
Hans Scherberger: MIP

Brian Lee: MST/MT

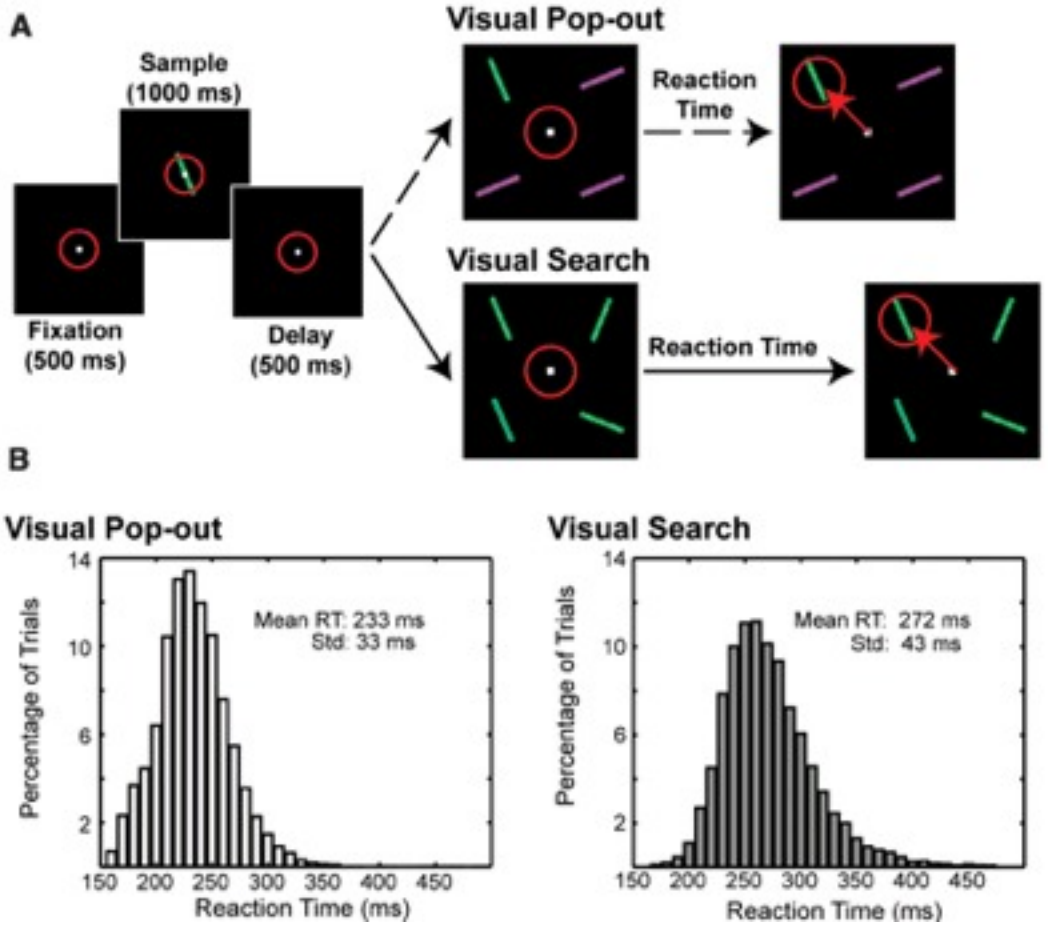
Zoltan Nadasdy: V1

Spatial tuning exists at different frequencies and length scales

- Clinical applications
- What can this teach us about the brain?

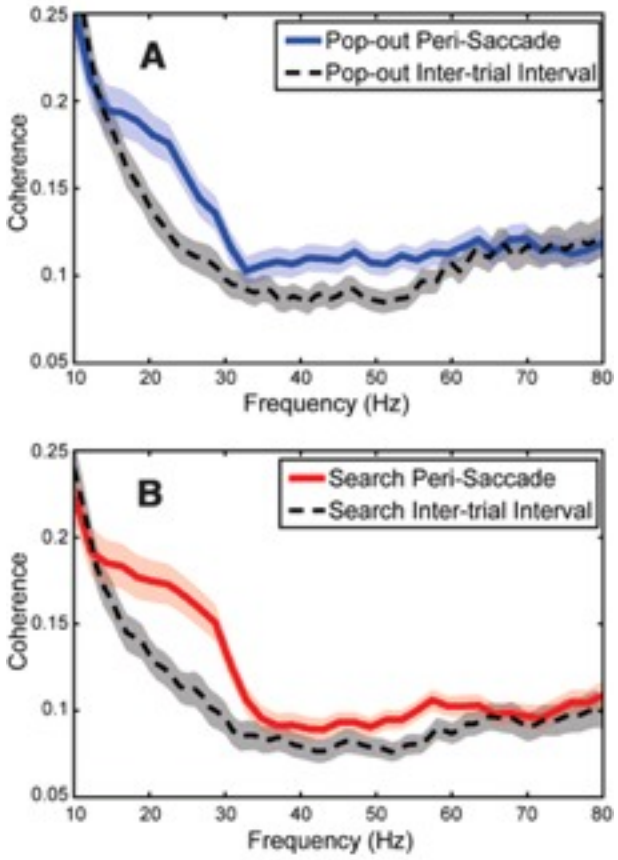

"Top-down" attention; requires effort (22 to 34 Hz)
PREFRONTAL CORTEX
PARIETAL CORTEX
"Bottom-up" attention; automatic and effortless (35 to 55 Hz)
MT
"Spatial" attention (25 to 45 Hz)
V4
Color identification (60 Hz)

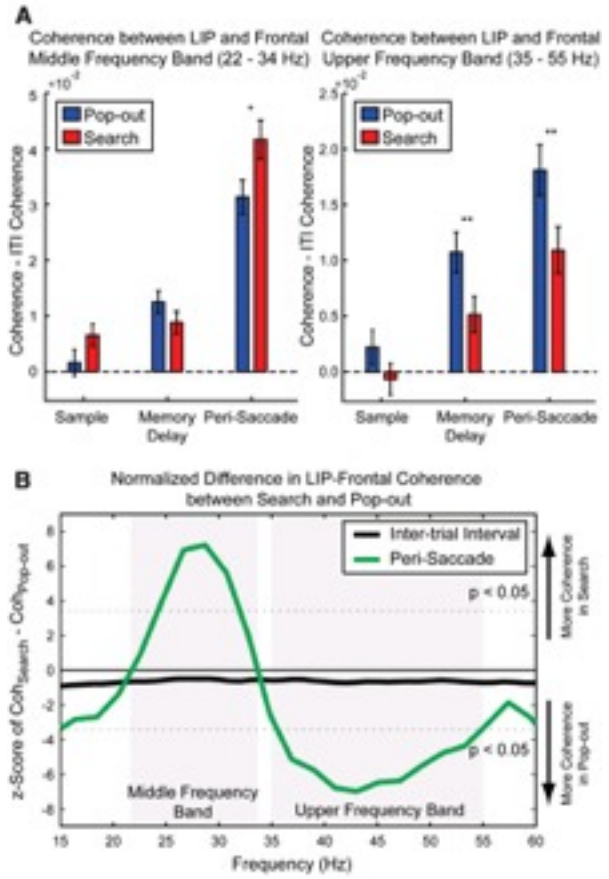
Bottom-up and top-down attention



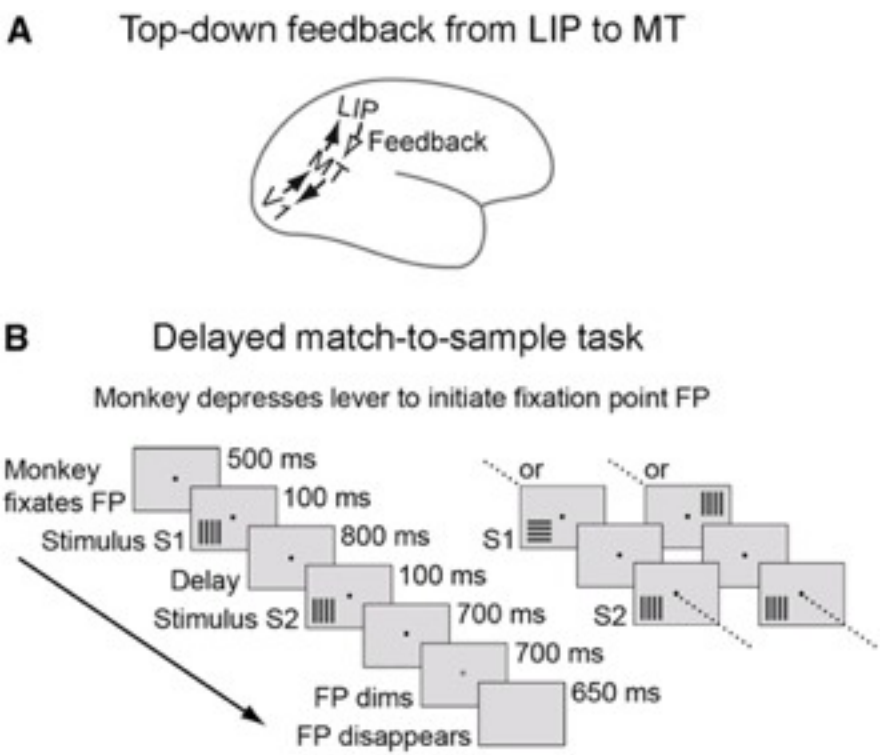
Buschman and Miller (2007)

Coherence between LIP and FF is modulated by type of attention

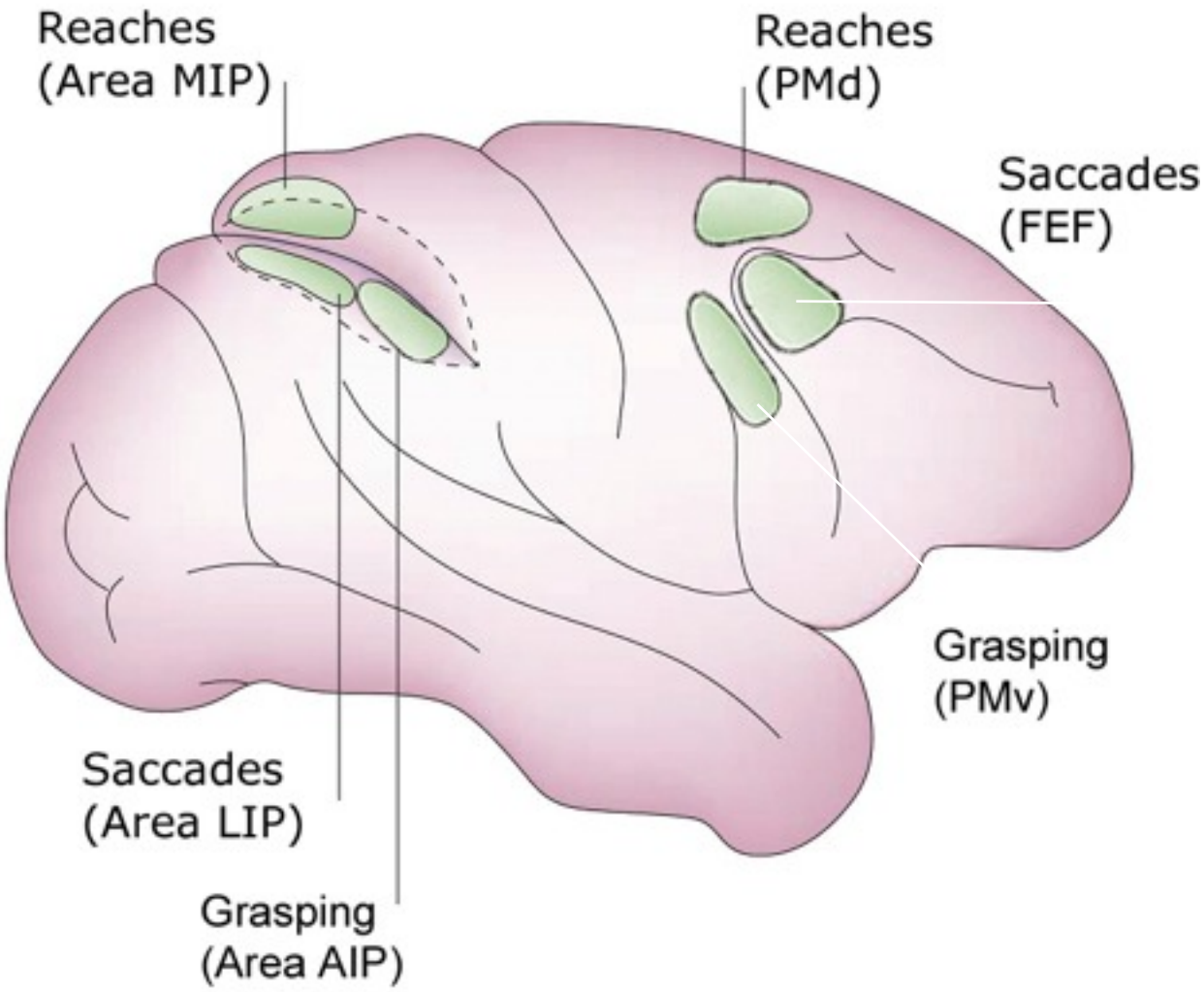




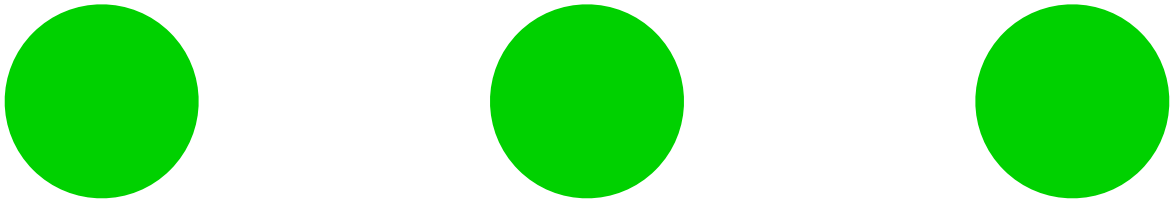
Buschman and Miller (2007)


A
Top-down feedback from LIP to MT
LIP
Feedback
MT
V1
B
Delayed match-to-sample task
Monkey depresses lever to initiate fixation point FP
Monkey fixates FP
500 ms
100 ms
Stimulus S1
800 ms
Delay
100 ms
Stimulus S2
700 ms
700 ms
FP dims
650 ms
FP disappears
or
or
S1
S2
Monkey releases lever when FP dims if S1 matches S2
or when FP disappears if S1 does not match S2

How are movement planning areas activated by decision making?

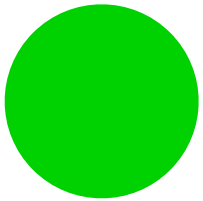


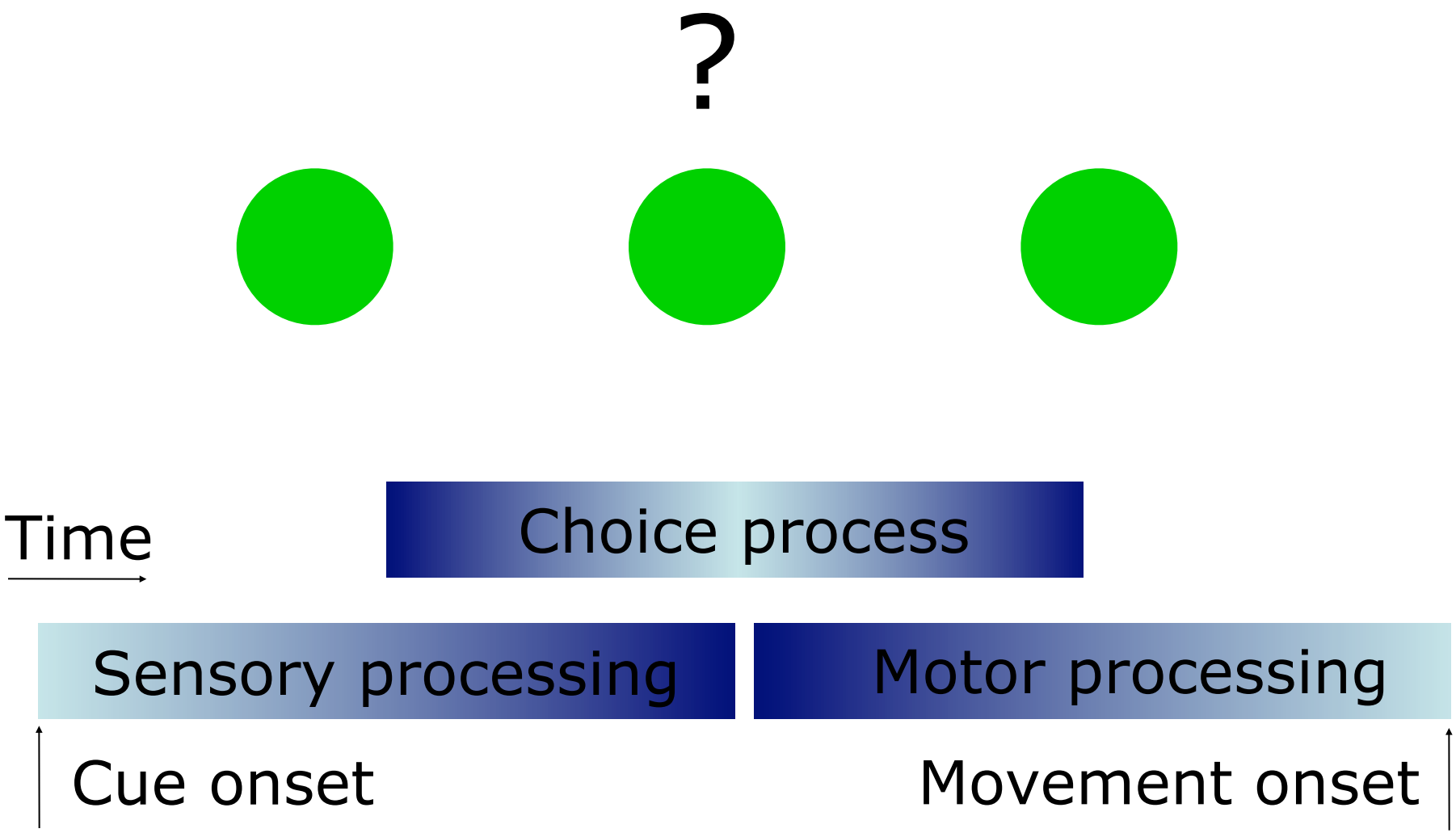
?

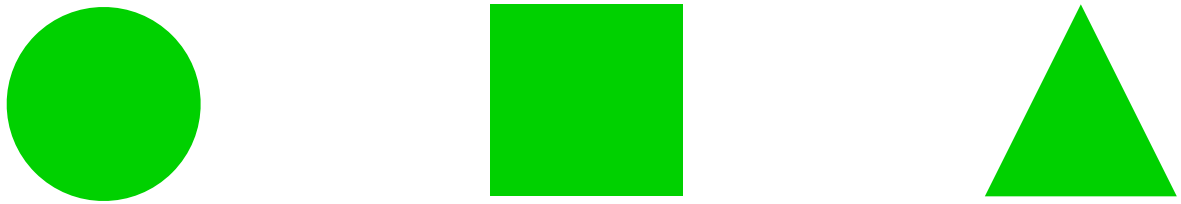


?

?




?
Time
Choice process
Sensory processing
Motor processing
Cue onset
Movement onset



Time

Sensory processing

Motor processing

Cue onset

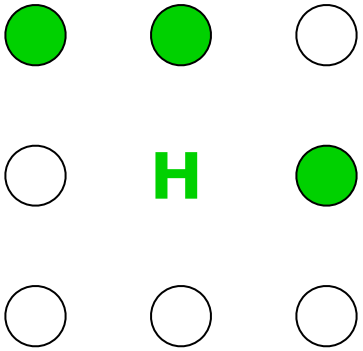
Movement onset

- Movement planning occurs across a multiple cortical areas

- Is there evidence for a between frontal and parietal cortex?

- Make simultaneous spike and field recordings in PMd and MIP.

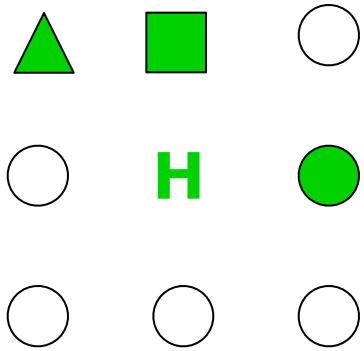
Free search



Example configuration

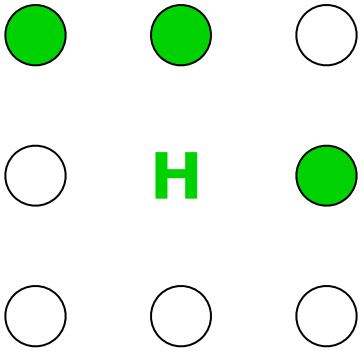
- Free to choose where to reach

Instructed search task



- Instructed to circle, then square, then triangle

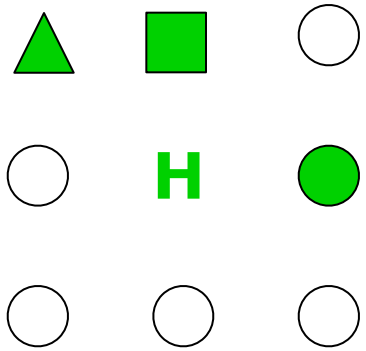
Free search



Example configuration

- Free to choose where to reach

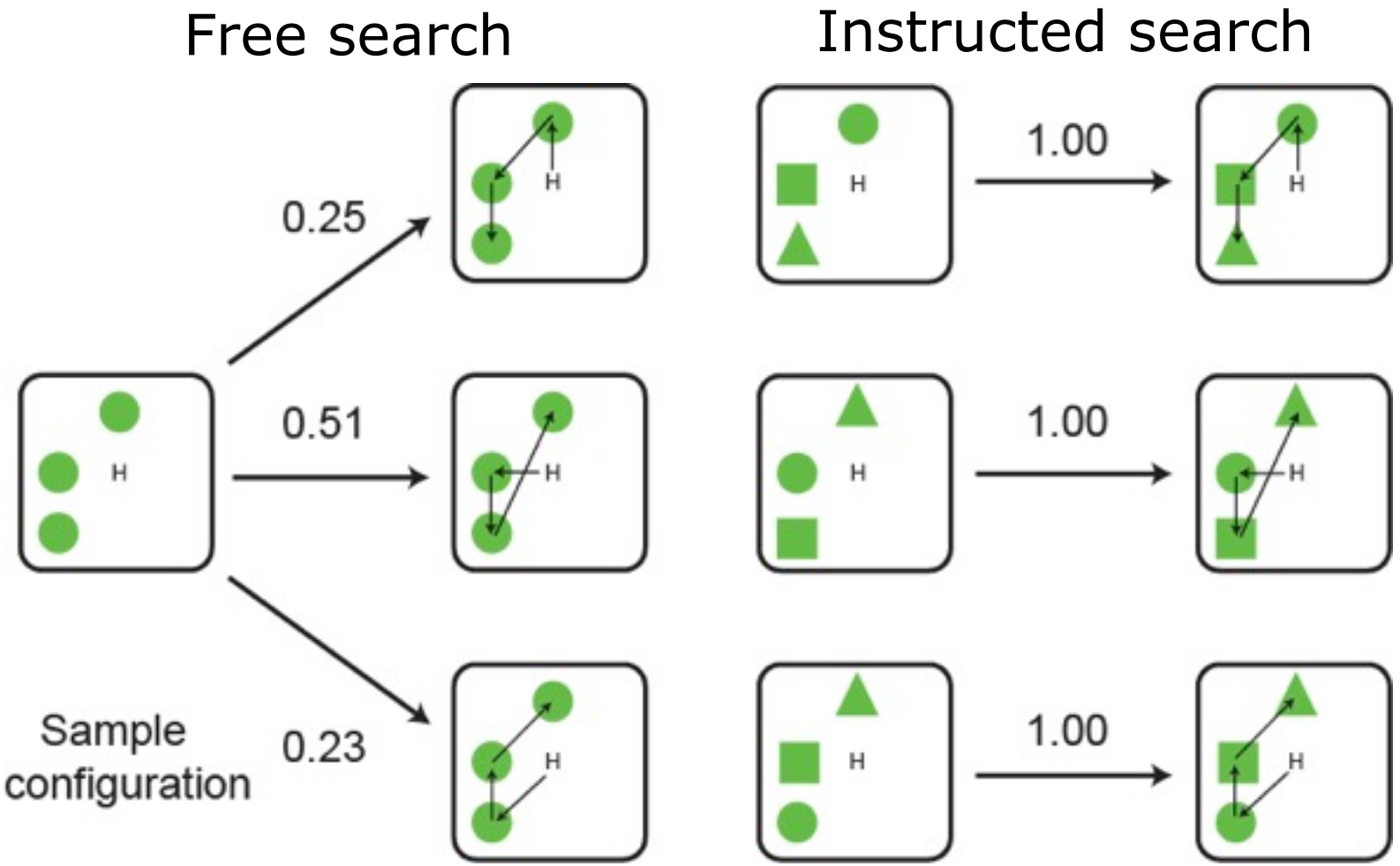
Instructed search task



- Instructed to circle, then square, then triangle

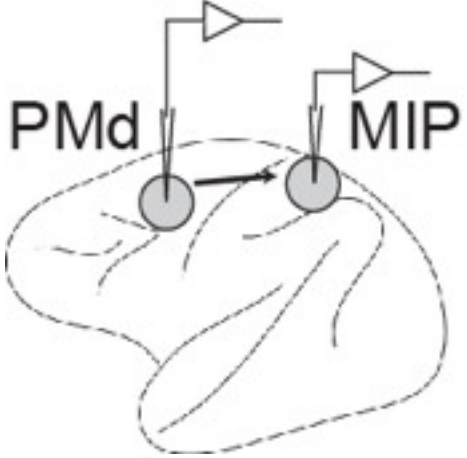
  - Target configurations are the same
  - Movements are the same
  - Reward frequencies are the same

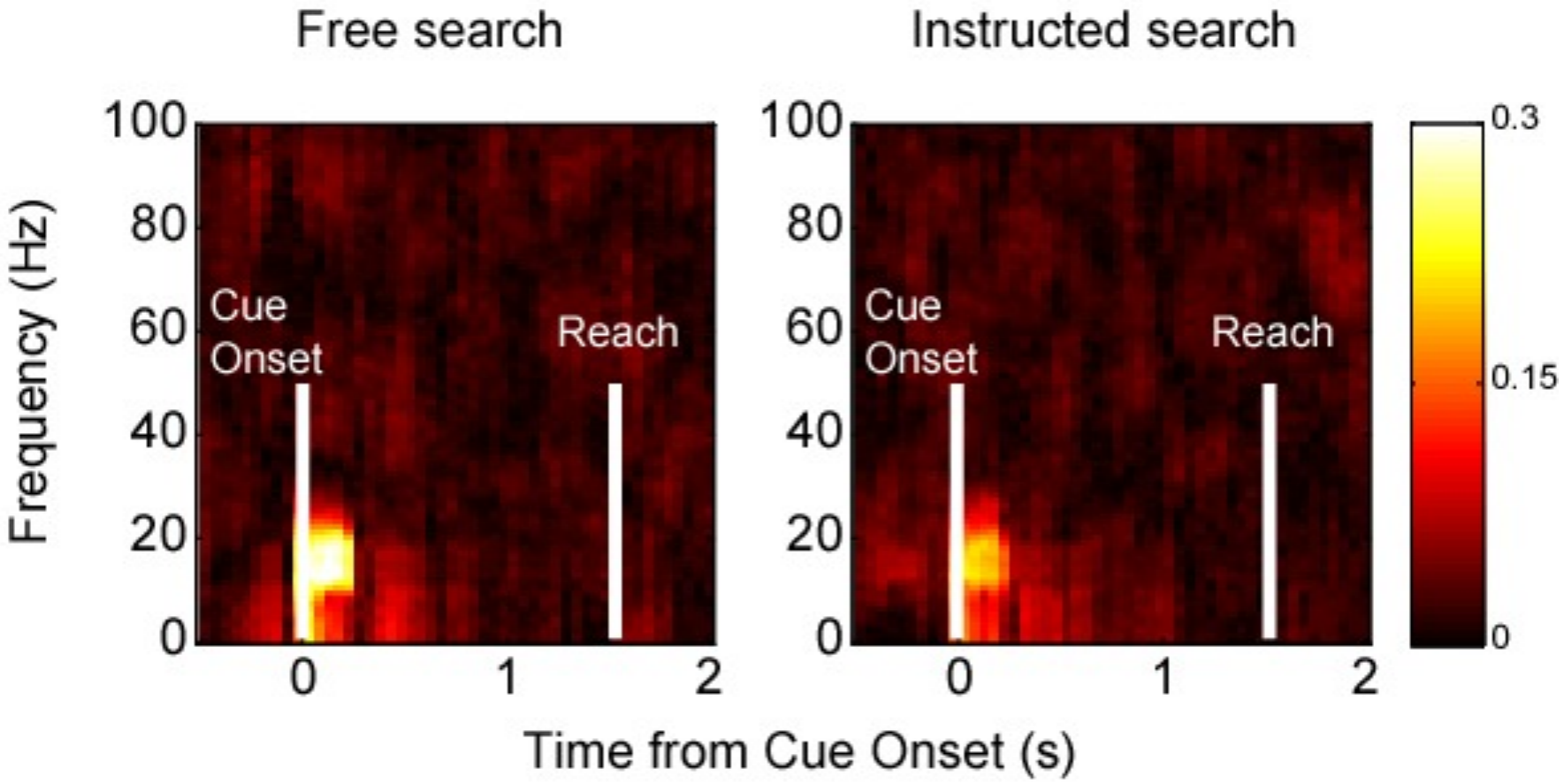
Movement sequences are variable during free search



- Freely-made choices lead to variable outcomes across trials

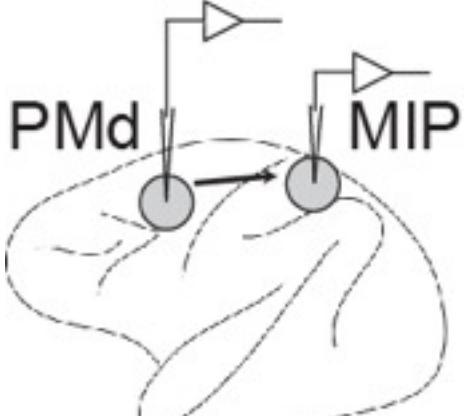
PMd spiking transiently

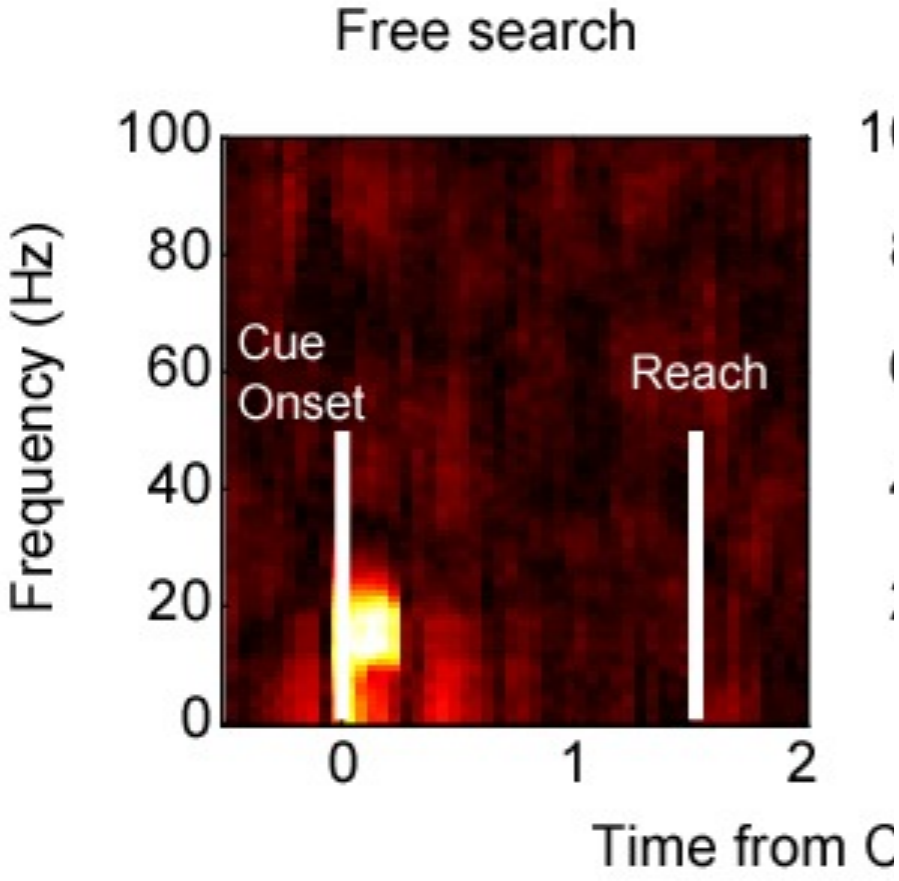


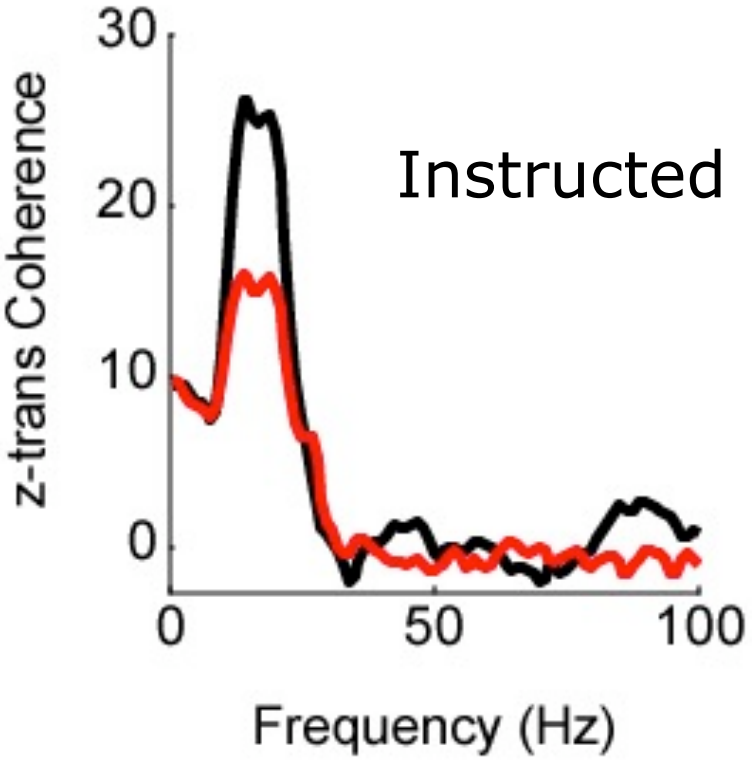


Example recording

PMd spiking transiently

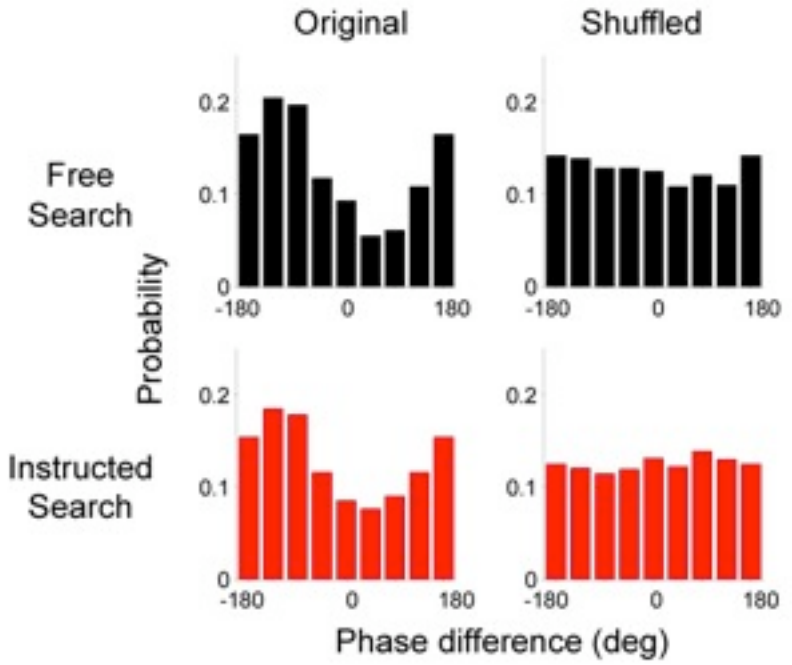






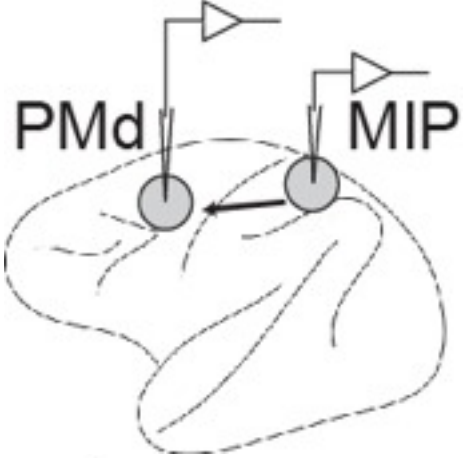
Example recording

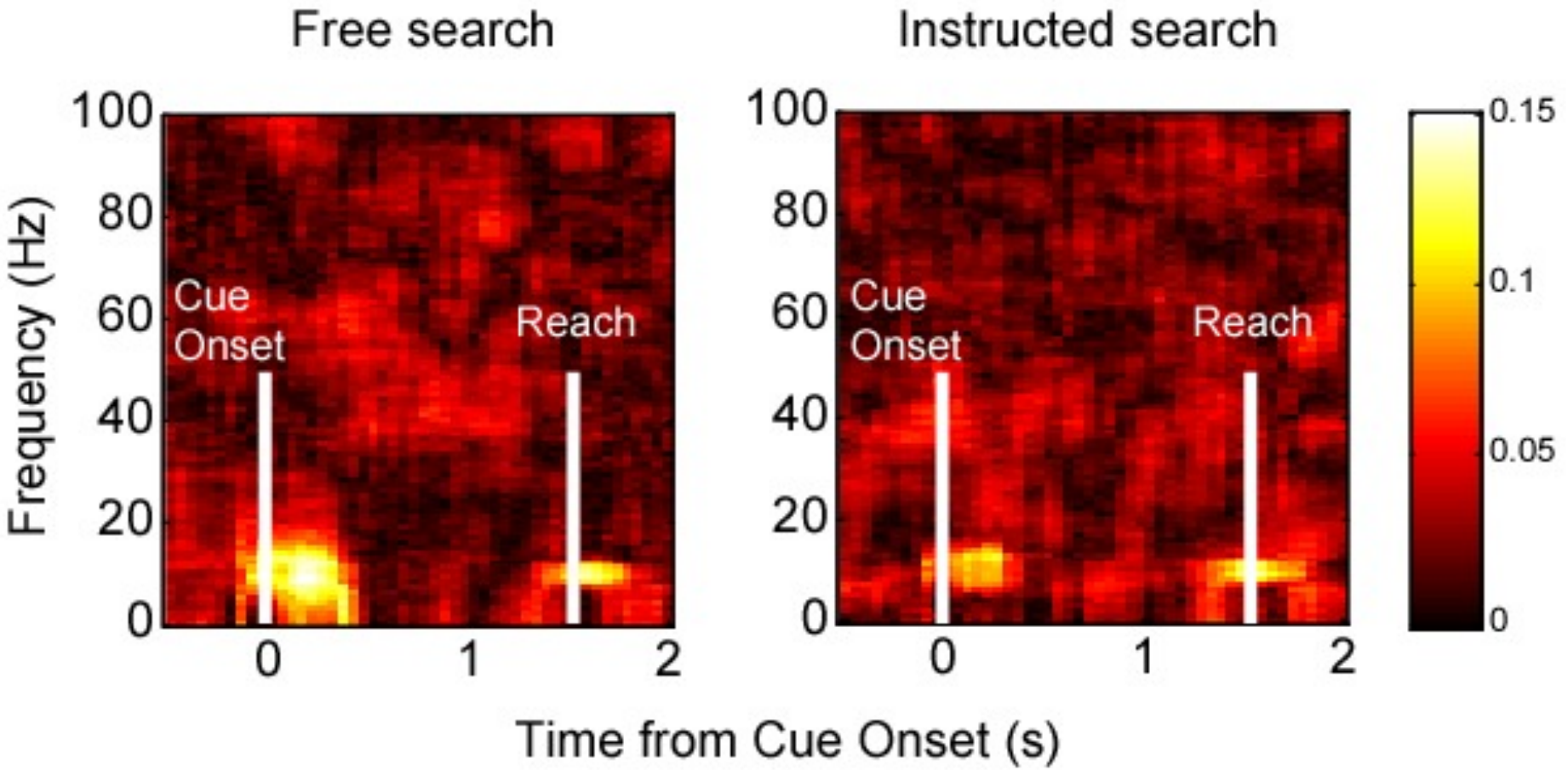
Trial shuffling does not contain a preferred phase



Free search phase = -123° ($p<10^{-9}$)
Instructed search phase = -131° ($p<10^{-4}$)

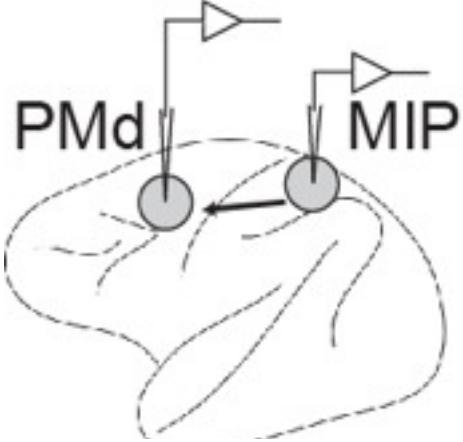
MIP spiking transiently correlates with PMd

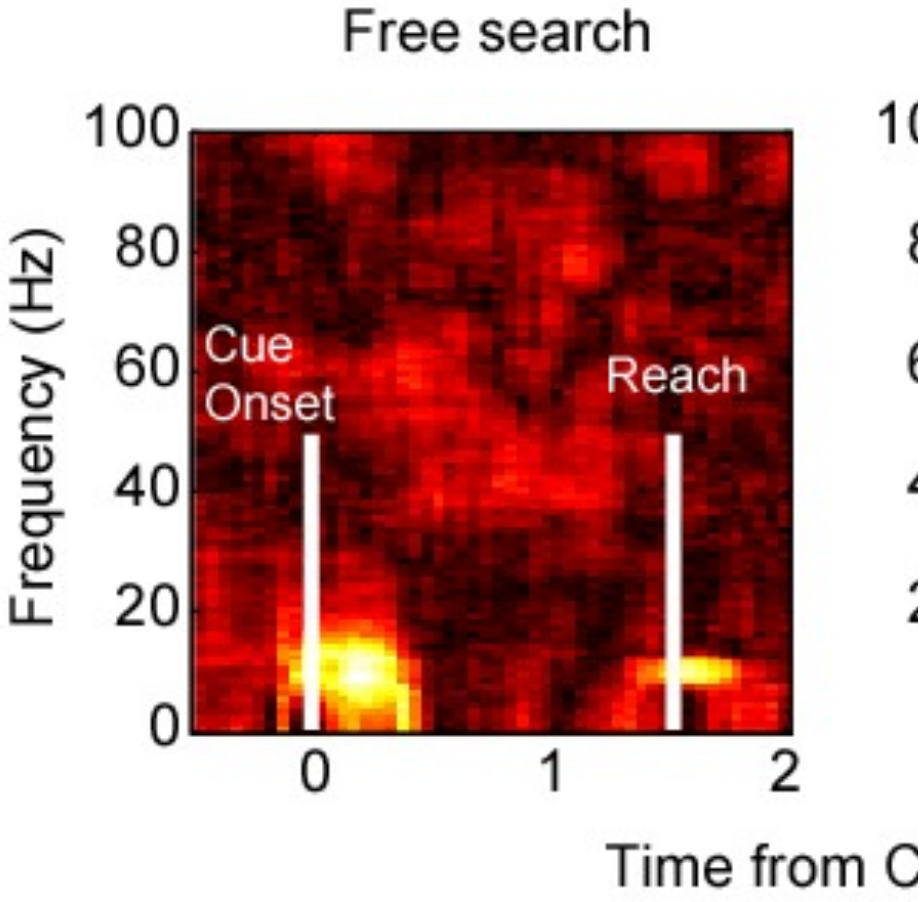


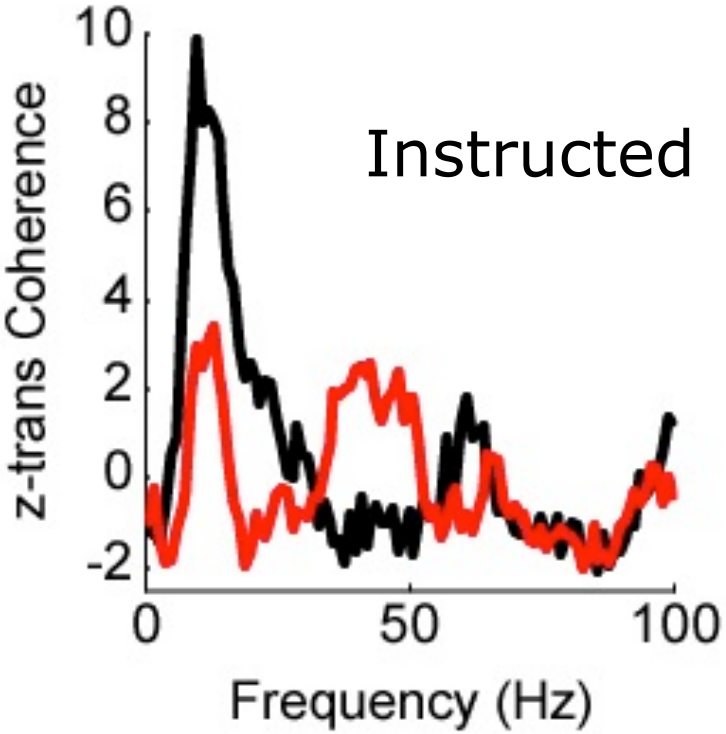


Example recording

MIP spiking transiently correlates with PMd

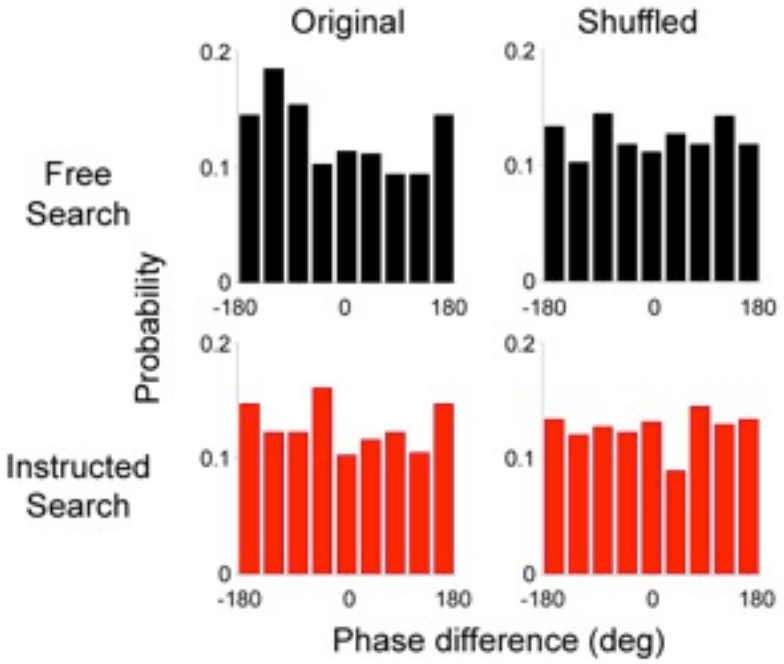






Example recording

MIP spike – PMd field phase histograms



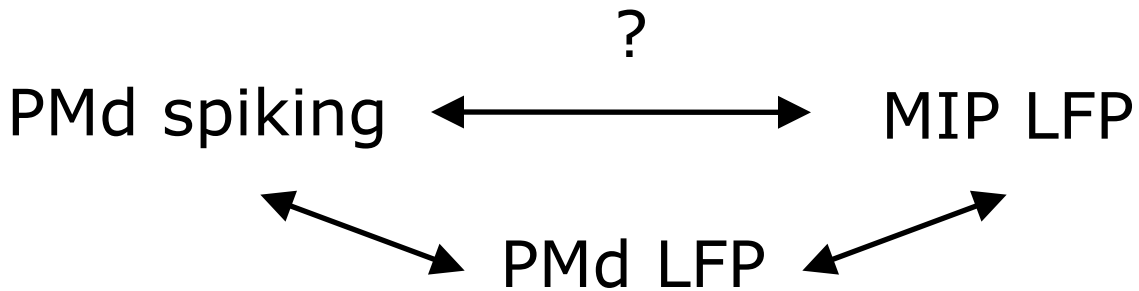
Free search phase = -121° ($p<0.01$)
Instructed search phase = -80° ($p=0.1$)

- Spike-field coherence is not widespread
  - 74/314 (23%) PMd spike – MIP field
  - 43/187 (25%) MIP spike – PMd fields
- Spatially clustered projections between areas
- Strongest between sites with similar preferred directions

Partial spike-field coherence

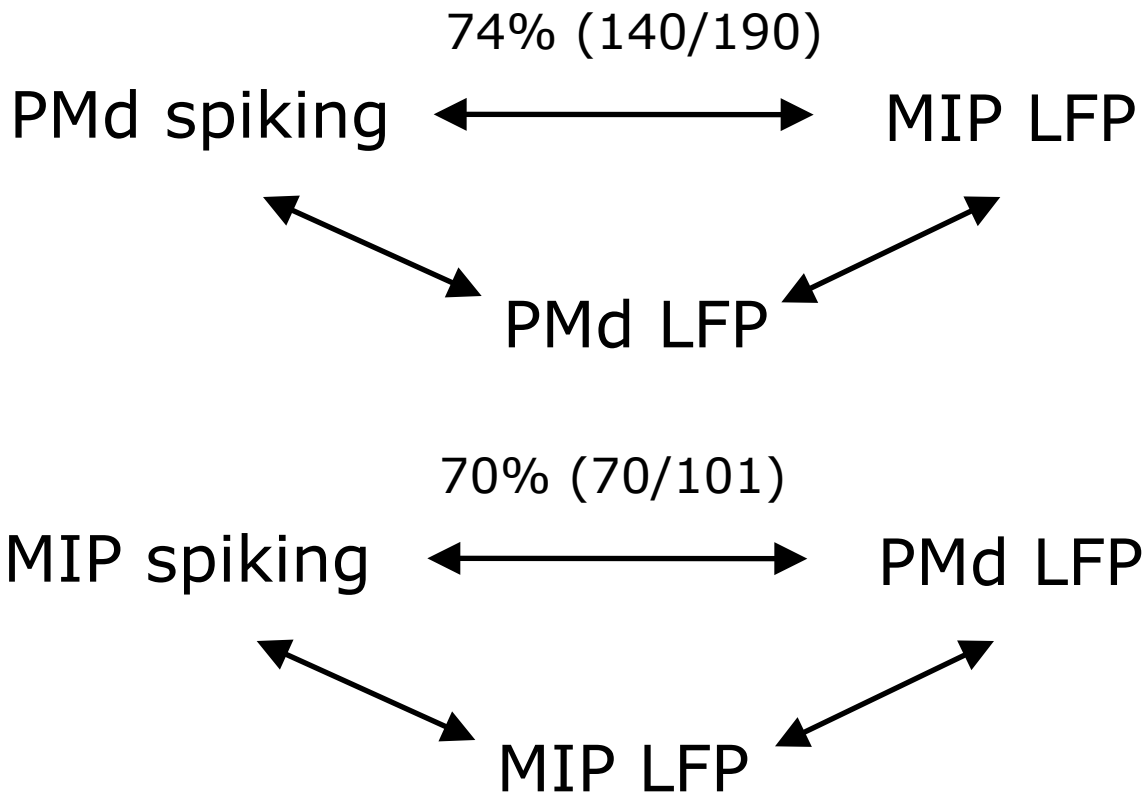
- We also observed spike-field coherence within PMd and MIP

- Correlations in LFP could explain long-range coherence

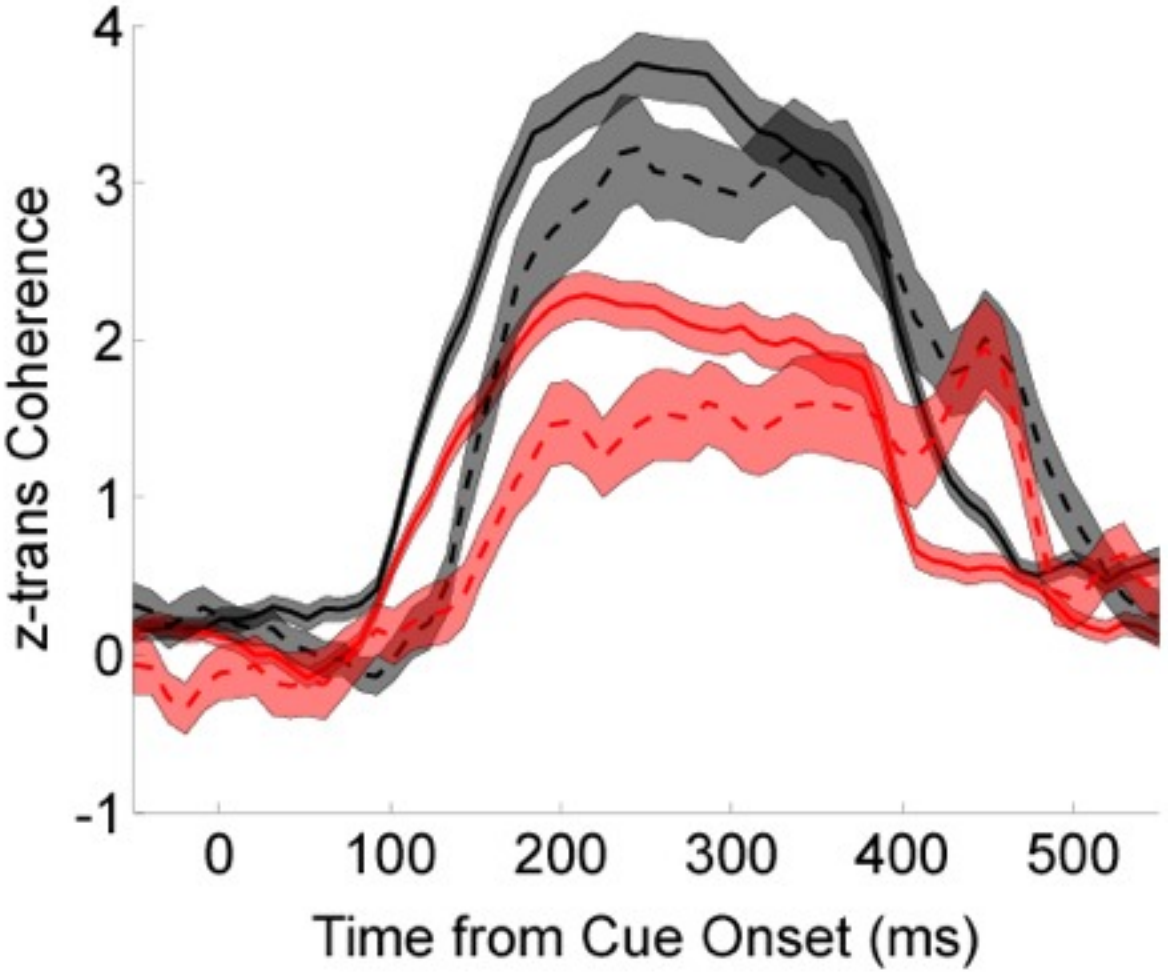


$$C_{XdN|Y}(f) = \frac{C_{XdN}(f) - C_{XY}(f)C_{YdN}(f)}{\sqrt{\left(1-|C_{XY}(f)|^2\right)\left(1-|C_{YdN}(f)|^2\right)}}$$

Partial spike-field coherence



- LFP activity did not explain MIP-PMd spike field coherence



Free search
PMd Spike - MIP Field

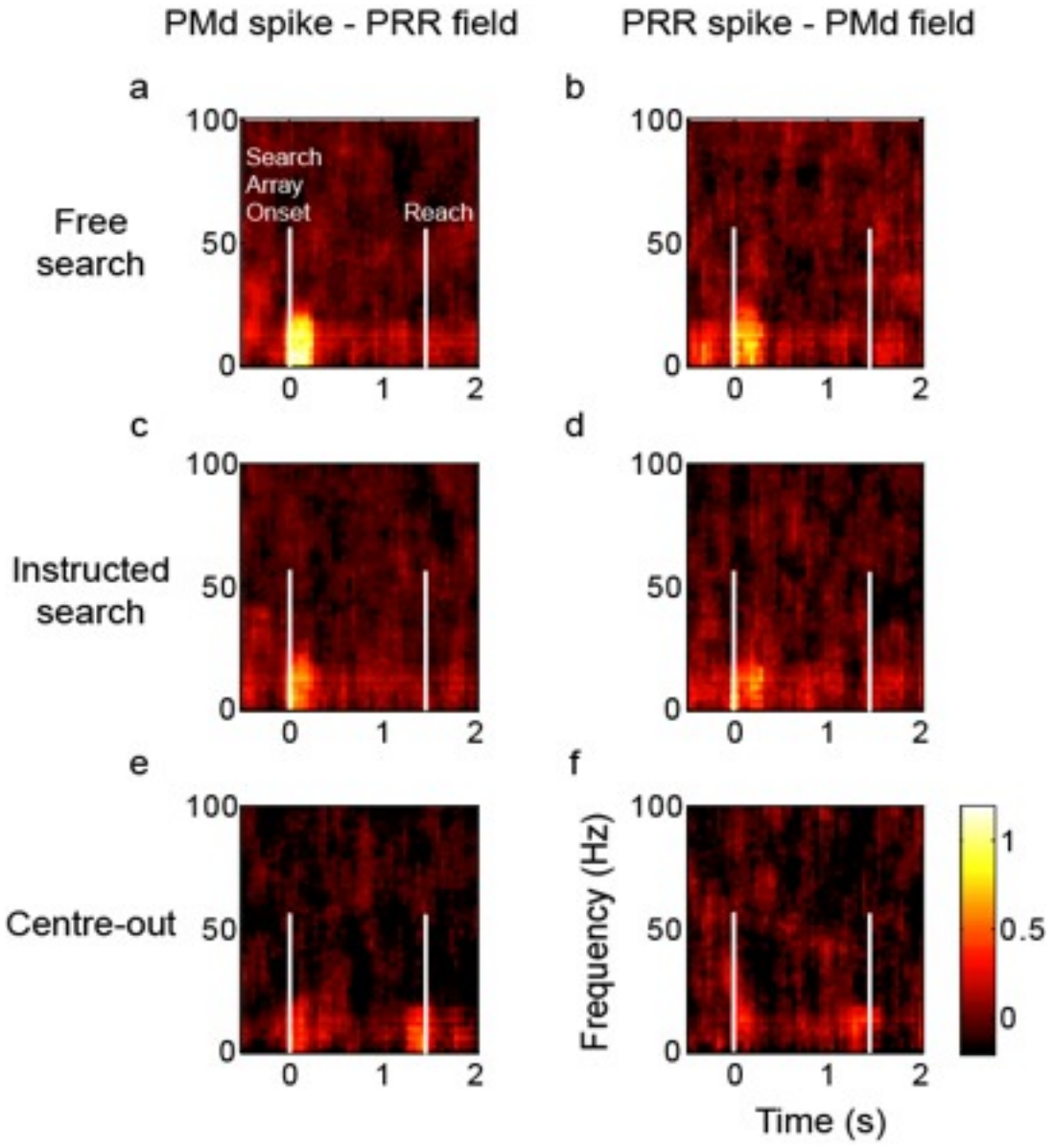
Free search
MIP Spike - PMd Field

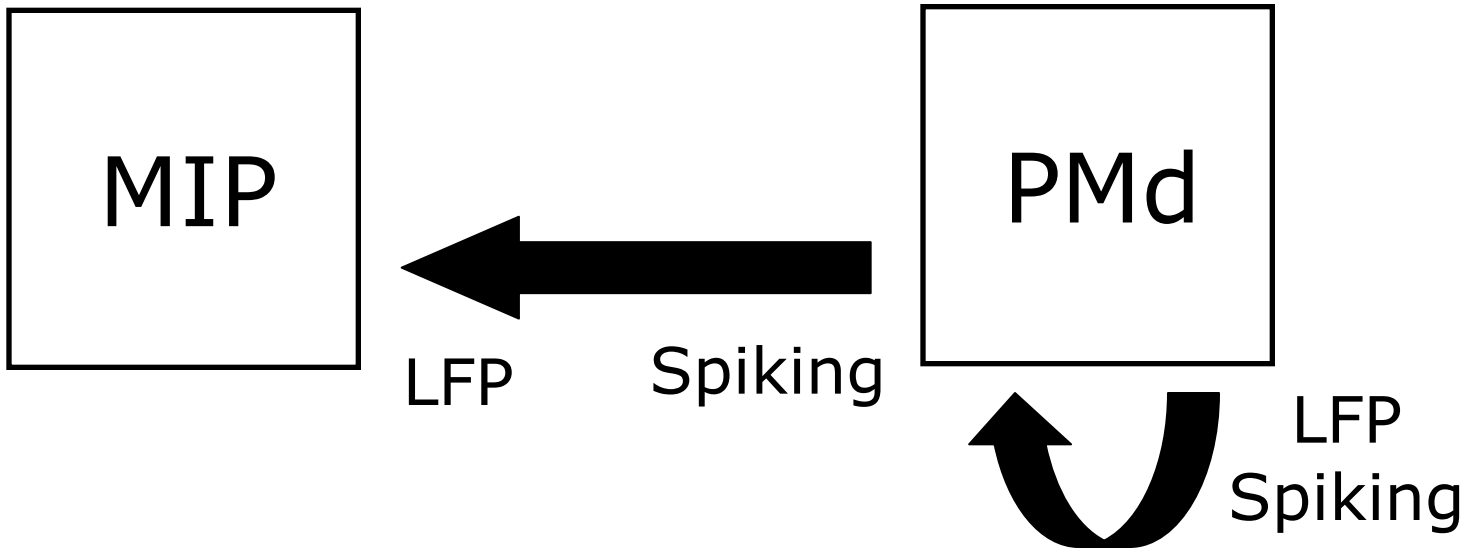
Instructed search
PMd Spike - MIP Field

Instructed search
MIP Spike - PMd Field

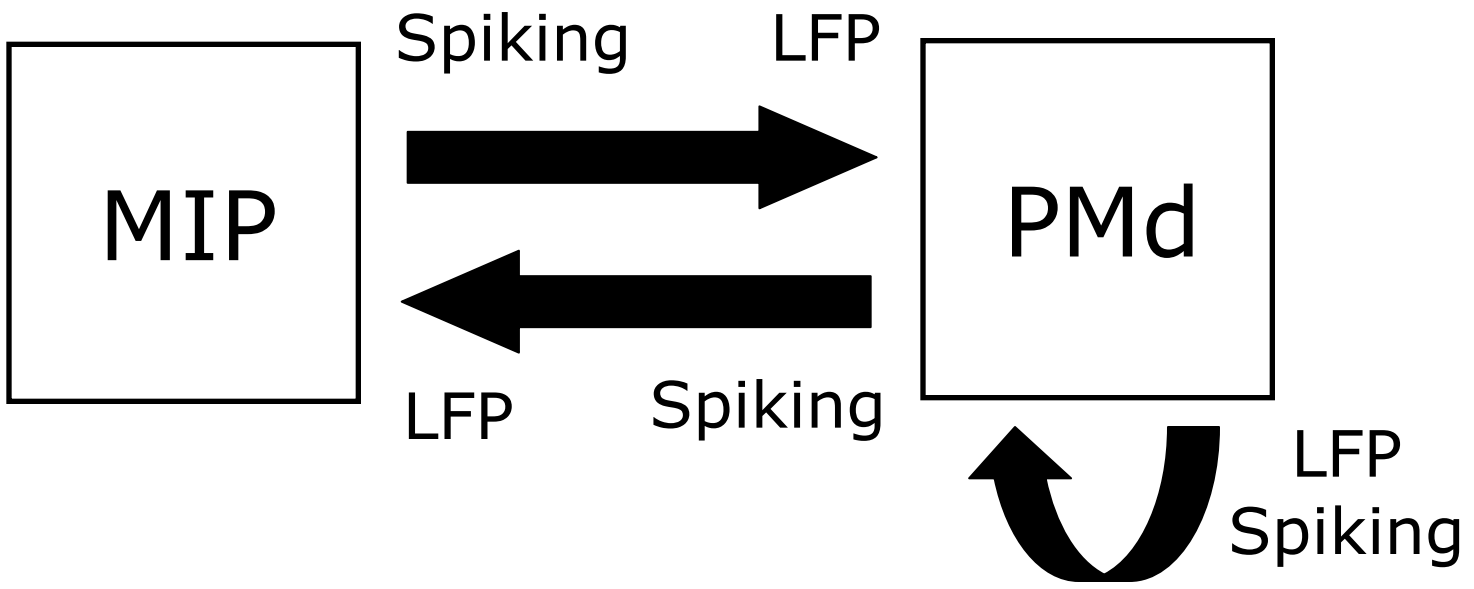
Population analysis.

43 MIP spike - PMd field
74 PMd spike - MIP field
(+/- 150ms window)


PMd spike - PRR field
PRR spike - PMd field
a
b
c
d
e
f
Free search
Instructed search
Centre-out
Search Array Onset
Reach
100
50
0
0
1
2
Frequency (Hz)
Time (s)
1
0.5
0

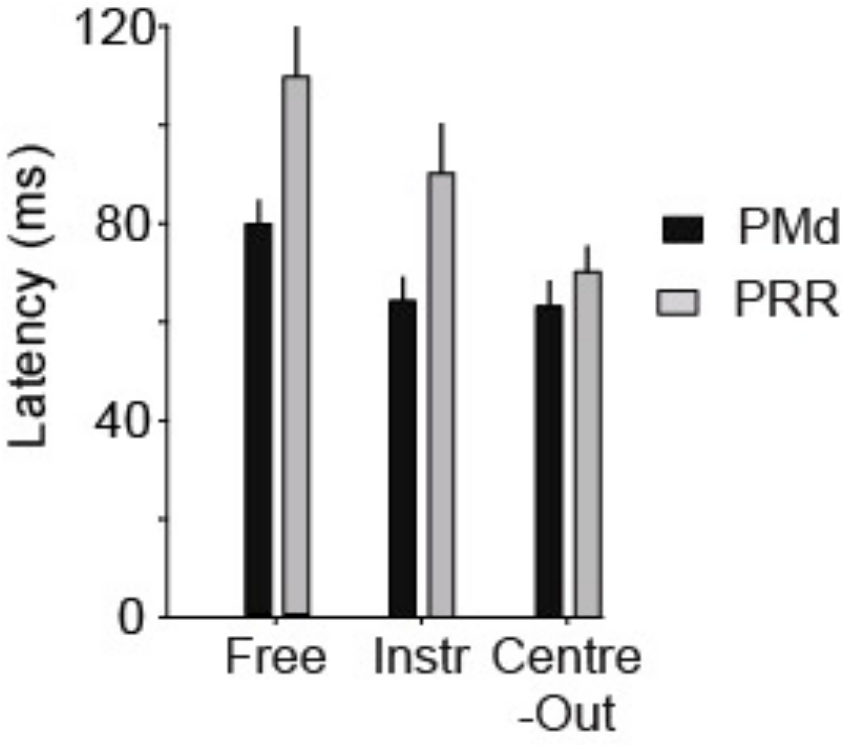


Signal first flows
from frontal to parietal



Then flows from parietal to frontal

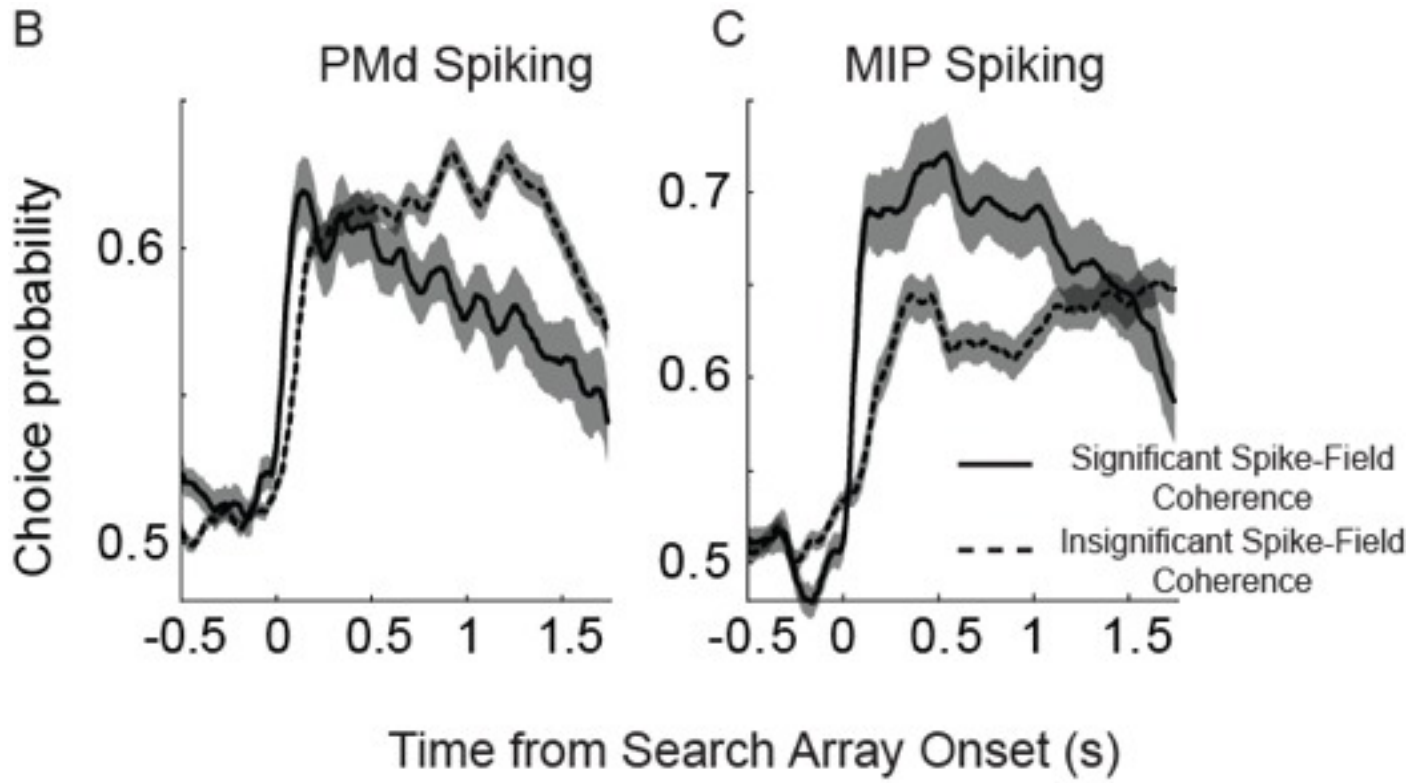
Spike latency showed PMd was activated before PRR



- Correlated spiking across network could reflect integration of information needed to make choice.

- How well does correlated spiking predict the movement choice?

Correlated spiking predicts movement choices better



- Freely-made choices lead to variable outcomes across trials

- Does choice involve a functional interaction between frontal and parietal cortex? Is there a decision circuit in play?