Correlation between brain areas

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Neocortex is a mosaic of interconnected brain areas
Electrical signals in the brain

- Single/multiple cell \( \sim 1-100 \) cells

[Image: Microelectrode, Spikes, 5 um]
Eye movement task

Cue

Delay

Move
Eye movement task

<table>
<thead>
<tr>
<th>Cue</th>
<th>Delay</th>
<th>Move</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>120 Hz</td>
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<tr>
<td>2.7 s</td>
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Example neuron during eye movement
Activity is spatially tuned for movements

Cue

Delay

Move

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)
(Barto et al, 2003)

Study interactions between brain areas
How do we analyze spike trains and field potentials together?

- \( v_t \)  
  LFP Voltage

- \( t_n \)  
  Spike times

- Continuous process
- Point process

• Use spectral methods for a hybrid point-continuous process
Spectral intuition

\[ \nu_t \]

LFP Voltage

\[ \text{Spectrum} \]

\[ \text{power} \]
Spectral intuition

\[ \nu_t \]
LFP Voltage

\[ t_n \]
Spike times

\[
= \quad \text{Spectrum}
\]

\[
1/T \quad \text{frequency}
\]
Spectral intuition

\[ \nu_t \]
LFP Voltage

\[ t_n \]
Spike times

\[ \frac{1}{T} \]
Frequency

Coherency

Low

High \( \phi = 0^\circ \)

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

Multitaper estimate
- 95% Jackknife

\[ S \sim \chi^2_{2\,dof - 1} \]

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]
Does LFP reflect movement plans?

How is spiking related to LFP?
Pesaran et al. (2002)
In LIP, gamma band LFP activity shows spatial tuning

Single electrode in Area LIP

Gamma band LFP tuning is similar to spike rate

Single electrode in Area LIP

LIP contains significant spike-field correlations

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)

“Bottom-up” attention; automatic and effortless (35 to 55 Hz)

“Spatial” attention (25 to 45 Hz)

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

B  Delayed match-to-sample task

Monkey depresses lever to initiate fixation point FP

Monkey fixates FP for 500 ms
Stimulus S1 appears for 100 ms
Delay occurs for 800 ms
Stimulus S2 appears for 100 ms
FP dims for 700 ms
FP disappears for 650 ms

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

Cue onset

Sensory processing

Motor processing

Movement onset
• Movement planning occurs across a multiple cortical areas

• Is there evidence for a decision circuit between frontal and parietal cortex?

• Make simultaneous spike and field recordings in PMd and MIP.
Free search

- Free to choose where to reach

Example configuration

Instructed search task

- Instructed to circle, then square, then triangle
Free search

- Free to choose where to reach

Example configuration

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.

Free search

Instructed search

Sample configuration
• Freely-made choices lead to variable outcomes across trials
PMd spiking transiently

Example recording
PMD spiking transiently

Example recording

Instructed

Free search

Frequency (Hz)

Time from C

z-trans Coherence

Frequency (Hz)
Trial shuffling does not contain a preferred phase

Free search phase = -$123^\circ$ ($p<10^{-9}$)
Instructed search phase = -$131^\circ$ ($p<10^{-4}$)
MIP spiking transiently correlates with PMd

Example recording
MIP spiking transiently correlates with PMd

Free search

Example recording

Instructed
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

\[ C_{Xd|Y}(f) = \frac{C_{XdN}(f) - C_{XY}(f)C_{YdN}(f)}{\sqrt{(-|C_{XY}(f)|^2)(-|C_{YdN}(f)|^2)}} \]
Partial spike-field coherence

- LFP activity did not explain MIP-PMd spike field coherence
Population analysis.

43 MIP spike - PMd field
74 PMd spike - MIP field (+/- 150ms window)
Coherence is specific to search.
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.

(B) PMd Spiking

(C) MIP Spiking

- Significant Spike-Field Coherence
- Insignificant Spike-Field Coherence

Time from Search Array Onset (s)
• 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?