Correlation between brain areas

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Neocortex is a mosaic of interconnected brain areas

- Reaches (Area MIP)
- Reaches (PMd)
- Saccades (FEF)
- Grasping (PMv)
- Saccades (Area LIP)
- Grasping (Area AIP)
Electrical signals in the brain

- Single/multiple cell ~ 1-100 cells
Eye movement task

Cue Delay Move

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 \(^{(\text{Mitzdorf, 1985})}\)

• 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

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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

\[ t_n \]
Spike times

Coherency

Low

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

Spikes

Field

Spectrum
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]

Multitaper estimate
- Nine Trials [5,9]
Example I: LFP spectrograms

Multitaper estimate
- Single Trial

Multitaper estimate
- Nine Trials

![Graph showing LFP spectrograms with multitaper estimates for single and nine trials.](image)
Example I: LFP spectrograms

Multitaper estimate
- 95% Chi2

Multitaper estimate
- 95% Jackknife

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

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

[Cue]  [Saccade]

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 500 ms
Stimulus S1 100 ms
Delay 800 ms
Stimulus S2 100 ms
S1 700 ms
S2 700 ms
FP dims 650 ms
FP disappears

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?

- Reaches (Area MIP)
- Reaches (PMd)
- Saccades (FEF)
- Grasping (PMv)
- Saccades (Area LIP)
- Grasping (Area AIP)
Time

Sensory processing

Choice process

Motor processing

Cue onset

Movement onset
Time

Sensory processing

Cue onset

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 task

- Free to choose where to reach

Example configuration

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

Instructed search task

- Instructed to circle, then square, then triangle
Movement sequences are variable during free search

Free search

0.25

Instructed search

1.00

Sample configuration

0.23
• Freely-made choices lead to variable outcomes across trials
PMD spiking transiently correlates with MIP fields.
PMd spiking transiently correlates with MIP fields
 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 fields

Example recording

Free search

Time from C

Frequency (Hz)

Cue Onset Reach

100 10 0
90 9 0
80 8 0
70 7 0
60 6 0
50 5 0
40 4 0
30 3 0
20 2 0
10 1 0
0 0 0

z-trans Coherence

Frequency (Hz)

Instructed

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

\[
C_{X|Y}(f) = \frac{C_{X|N}(f) - C_{XY}(f)C_{Y|N}(f)}{\sqrt{1 - |C_{XY}(f)|^2(1 - |C_{Y|N}(f)|^2)}}
\]
Partial spike-field coherence

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

PMd spiking → MIP LFP

PMd LFP

MIP spiking ← PMd LFP

MIP LFP

74% (140/190)

70% (70/101)
Population analysis.

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