Decorrelated Neuronal Firing in Cortical Microcircuits

AS Ecker, P Berens, GA Keliris, M Bethge, NK Logothetis and AS Tolias
Science, 2010

April 21, 2010
Outline

1. Introduction
2. In-vivo recordings using arrays of tetrodes
3. Spike count correlation for grating stimuli
4. Spike count correlation for natural images
5. Factors that could lead to spike count correlations unrelated to presynaptic noise
6. Implications for cortical models
Introduction

- Correlated trial-to-trial variability among neurons has been observed in various cortical areas.
- This is thought to reflect the functional connectivity of the circuit.
- Nearby neurons are believed to be densely connected and share common input.
Spike count correlation

\[ r_{sc} = \left\langle \frac{\text{Cov}[x, y|\theta]}{\sqrt{\text{Var}[x|\theta]\text{Var}[y|\theta]}} \right\rangle_{\theta} \]

with

- spike count vector \( x = (x_1, \ldots, x_i, \ldots, x_n) \) of neuron 1
  \( (x_i \) holds the spike count of trial \( i \)\)
- spike count vector \( y = (y_1, \ldots, y_i, \ldots, y_n) \) of neuron 2
  \( (y_i \) holds the spike count of trial \( i \)\)
- \( \theta \ldots \) condition

"Noise correlation" - caused by random fluctuations in the activity of neurons presynaptic to a pair of cells

Previous papers report \( r_{sc} \) in the range of 0.1 to 0.3
Technical challenges to measure noise correlations

1. It is difficult to control for internal variables (e.g. motor plans, attention, ...).
2. Moving electrodes - positions are not stable
3. Spike sorting - suboptimal single-unit isolation
4. Correlations may arise from spontaneous oscillations under anesthesia.
Tetrodes provide a superior quality of single-unit isolation of nearby neurons.
Single units recorded from one tetrode

First principle component of spike waveform for all pairs of tetrode channels
Cells had highly overlapping receptive fields.

Simulations with drifting and static gratings with 16 orientation.
$r_{sc}$ of pairs of neurons

- average $r_{sc}$ value of 0.02
Experimental setup

- Recordings of 917 single units of V1 of two awake macaque monkeys
- 407 (monkey 1: 262, monkey 2: 145) of those single units were used for the analysis
- 1907 (monkey 1: 1335, monkey 2: 572) simultaneously recorded pairs
- 406 (monkey 1: 361, monkey 2: 45) pairs recorded by same tetrode
$r_{sc}$ of pairs of neurons recorded by the same tetrode

- $r_{sc} = 0.005 \pm 0.004$
- red: sampled from artificial spike trains with $r_{sc} = 0.01$
- blue: sampled from artificial spike trains with $r_{sc} = 0.01 \pm 0.01$
$r_{sc}$ compared with previous reported values
$r_{sc}$ for all pairs of recorded neurons

$\quad n = 1907$

- $r_{sc} = 0.010 \pm 0.002$
Dependence of $r_{sc}$ on tuning and distance

- Cells with similar tuning have slightly higher correlations
- $r_{sc}$ does not depend on the distance between neurons
Spike count correlation for natural images

- Recordings of 92 well isolated single units of one macaque monkey
- 329 simultaneously recorded pairs
Spike count correlation for natural images

- $r_{sc} = 0.001 \pm 0.005$
- $r_{sc}$ depends weakly on the distance of the receptive field
Factors that could lead to spike count correlations unrelated to presynaptic noise

1. It is difficult to control for internal variables (e.g. motor plans, attention, ...).
2. Moving electrodes - positions are not stable
3. Spike sorting - suboptimal single-unit isolation
4. Correlations may arise from spontaneous oscillations under anesthesia.
Assumption: Neurons’ firing rates are gain-modulated by a common underlying process.

Shared modulation of 15% can lead to a correlation of about 0.2.

It is nearly impossible to control precisely the effects of attentional state, reward expectancy, task-solving strategy, or other cognitive factors.

In contrast to V4 or MT, Area V1 may be much less affected by such modulations.
Moving electrodes - positions are not stable

- Movements most likely affect all neurons recorded by one electrode
- This can be modeled as a common gain modulation.

- The recordings were extraordinarily stable.
- They were able to track neurons over several days.
Spike sorting - suboptimal single-unit isolation

Decorrelated Neuronal Firing in Cortical Microcircuits
Correlations may arise from spontaneous oscillations under anesthesia

- Up and down states or even subtle variations in the anesthesia will act as common gain modulation.
Implications for models of cortical circuits

Current view on correlations is based on two major assumptions:

- Nearby neurons receive a substantial amount of common input
- Common input leads to correlations

At least one of these assumptions cannot be correct!!!
Assumption 1: Nearby neurons receive a substantial amount of common input

- (Shadlen and Newsome, 1998) inferred from the measured spike count correlation that nearby cells share 30% of their inputs.
- The data of this study suggests that at most 5% of the inputs are shared.
- Anatomical studies report ≈ 10% common inputs
Assumption 2: Common input leads to correlations

- A dynamic balance of excitatory and inhibitory fluctuations counteracts Correlations
  see e.g. (Renart et al. 2010)

- Such a mechanism might be a crucial prerequisite of hierarchical cortical processing
Impact of correlation strength on encoding accuracy

- Cramer-Rao bound - minimum achievable decoding error

![Graph showing the impact of correlation strength on encoding accuracy.](image)

- \( \langle r_{sc} \rangle = 0.12 \)
- \( \langle r_{sc} \rangle = 0.01 \)
- \( r_{sc} = 0 \)
Thank you for your attention!
Feel free to ask questions!