The development of visual cortical activity in normal and lid sutured ferrets

József Fiser

Brandeis University

Chiayu Chiu, David Wagner, Michael Weliky
University of Rochester
Patterned Spontaneous Activity in the Primary Visual Cortex

(Chiu & Weliky JNS 2001)
Visual Cortical Development in Ferrets

- Segregation of LGN projection into ocular dominance columns
- LGN projection to layer 4 completed
- Crude clustering of layer 2/3 horizontal connections
- Maturation of orientation map
- Eye opening

Postnatal Age (days)
Before eye opening: patterned spontaneous activity is thought to have an important role in guiding the establishment and stabilization of developing synaptic connections in the visual system (Ocular Dominance, Orientation columns)

After eye opening: patterned spontaneous activity is thought to be unwanted noise

What happens at eye opening???
Possible resolutions

At eye opening....... 

- Correlated patterns in spontaneous activity disappear (random noise)

- Magnitude of patterned spontaneous activity is negligible compared to visually driven activity

- The animal does not see anything
Method: Multi-electrode recording in the primary visual cortex

- 16 microwires 3.0 or 9.0 mm array
- Primary Visual Cortex
- Lid suture

LGN projection to layer IV completed

0 30 60 90 150

Postnatal Age (days)

eye opening

maturation of orientation tuning and clustered horizontal connections
Development of spontaneous activity

Eye opening
Spontaneous activity after lid suture

**Normal:**

Eye opening

**Lid sutured:**
Development of an oscillatory pattern
Development of temporal and spatial correlations

Temporal Correlations

Spatial Correlations

![Graphs showing time correlation and distance correlation with various data points.

- Time (msec) vs. Correlation (r)
- Distance (mm) vs. Correlation (r)

Legend:
- P24-26
- P29-30
- P35-38
- P44-45
- P71-90
- P128-169

The graphs illustrate the decay of correlation over time and distance, with different markers representing different data sets.
Spatio-temporal correlations after lid suture

Temporal correlations

Spatial correlations

Development of spatial correlations
Summary (Part I)

At eye opening....... 
..correlated patterns in spontaneous activity DO NOT disappear!

Is the level of spontaneous activity negligible compared to visually driven activity ??
Visually evoked responses: Experimental setup

- Awake, head-restrained ferret
- 3 age groups (P30, P45, P90)
- Three interleaved trial types:
  - complete dark (spont.)
  - natural scene movie
  - white noise stimuli
- Compare neural activity under the different conditions

How to make the comparison?
Level of visually driven activity only ~30% higher
After eye opening....... 

correlated patterns in spontaneous activity DO NOT disappear....

...and their contribution to neural activity is NOT NEGLIGABLE compared to the visually driven component!

EVEN IN THE ADULT ANIMAL

How can the animal see??
Standard answer:

Average out the correlated noise

Can we?
Linear Filter Model

Original Image  Measured Cell Filter Properties  Filtered Image
Computing Expected Responses

Contrast = \frac{(\text{max-min})}{(\text{max}+\text{min})}

Energy model of complex cells

Filtered Image

Model output

Impulse Response (Usrey et al., 2003)
Expected neural statistics based on the dynamics of the visual displays
Correlation functions under the three conditions

- **Temporal**
  - Dark spont. activity
  - Natural-scene film
  - Random-noise film

- **Spatial**
  - P30–32
  - P44–45
  - P83–90

Graphs show the correlation functions for different conditions over time and distance.
Does this mean that neural firing does not reflect the structure of the input at all?

No!
Temporal Correlation

neural response P83-90

stimulus input

Spatial Correlation

neural response P83-90

stimulus input

Correlations (r)

- Natural Scene Movie
- White Noise Movie
- Dark Spont. Activity
Neural firing does reflect the structure of the input but only by a 3% modulation in the temporal and a 15% modulation in the spatial correlations.

Is this due to the spontaneous activity or just a cellular developmental or eye movement effect?

No!
Conclusions

• There exist a highly structured spontaneous activity in the primary visual cortex of the awake ferret after eye opening.

• The spatial and temporal structure of this activity develops with age from slow unspecific bursting to rapid synchronized firing.

• Dominant aspects of this evolving structure seem to be linked to internal network dynamics rather than to visual experience, maturity of individual cells or eye movements.

• Visual stimulation changes the firing rate and the second-order correlational structure of the spontaneous neural activity only modestly (albeit significantly).
Why is this interesting at all?

It requires a completely different model of sensory coding in which:

- Neural activity is not exclusively stimulus driven
- Spontaneous activity is not noise but takes part in the coding
- Coding means not a massive change in firing rates but rather a modulating effect by sensory input on the dynamics of cell-assemblies
Thank you!