The retina as a window to the brain
Retinal high-frequency oscillations drive corresponding rhythms in visual cortex

Sarang Dalal
Center of Functionally Integrative Neuroscience
Aarhus University
sarang@cfin.au.dk
“The retina is part of the brain, having been sequestered from it early in development but having kept its connections with the brain proper through a bundle of fibers – the optic nerve.”

– David Hubel
Traditional Framework of Visual Processing
Traditional Framework of Visual Processing

raw visual input
Traditional Framework of Visual Processing

- Raw visual input
- Object position/motion
- Object recognition
This is an overly *cortico-centric* view that assumes the retina only passively relays visual information.
Traditional Framework of Visual Processing

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The Electroretinogram (ERG)

ERG is routine in eye clinics – but medically preferred electrodes are not appropriate for healthy volunteers.

Lesser known but far more comfortable alternative, often used for children: the **DTL fiber electrode**
Retinal Morphology & Potentials

**MEG/EEG**
cortical structure

**ERG**
retinal structure
MEG >> EEG for Visual Gamma

Muthukumaraswamy et al., 2013
ERG has huge SNR

• Huge SNR, high amplitude signals reminiscent of intracranial EEG
• This makes single-trial analyses possible!
ERG has huge SNR

- Huge SNR, high amplitude signals reminiscent of intracranial EEG
- This makes single-trial analyses possible!
• First study to combine DTL electrode with MEG
• Sanity check: visual cortex follows retina by 35 ms
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• Sanity check: visual cortex follows retina by 35 ms
Retinocortical Coherence

ERG (filtered 100-120 Hz)

Time (ms)

ERG Amplitude (µV)

N = 6, $p < 10^{-4}$

retina$\leftrightarrow$cortex information flow

retinocortical coherence
ERG

Phase-locking value

Analytic amplitude (T-statistic across trials)

MEG

105-120 Hz

Phase-locking value

Analytic amplitude (T-statistic across trials)
Propagation times across the visual pathway

Latency of max PLV (ms) (NOT power!)

55-75 Hz
ERG: 26 ms

75-95 Hz
ERG: no PLV peak

105-120 Hz
ERG: 33 ms

120-145 Hz
ERG: 13 ms

Slower
Faster
Response to stimulus offset

Darks Are Processed Faster Than Lights
Stanley Jose Komban, Jose-Manuel Alonso, and Qasim Zaidi

- largely assumed to be cortical phenomenon
- but the retina has dedicated circuitry for “darks”!
Response to stimulus offset

ON

OFF
Response to stimulus offset

ON: 105 – 125 Hz

OFF: 75 – 95 Hz

[Graph showing response to stimulus offset with time in milliseconds and frequency in Hz.]
the timing of retinal responses in the salamander vary with image properties
thought to code image features for later interpretation by the cortex
does this happen in humans?
How do image properties affect retinal responses?

**Insight** Photos stimulate high-frequency responses in the retina; profile very reminiscent of cortical responses

**Hypothesis** These retinal oscillations will also drive cortical oscillations
How do image properties affect retinal responses?

Spatial Frequency
Spectrum

Retinal Responses

**Insight** Variable cortical timing often interpreted as local neural computation – but this variability may be inherited from the retina

**Hypotheses**
1) Spatial frequency content determines precise response timing
2) Cortical responses will inherit corresponding delays
How do image properties affect retinal responses?
How do image properties affect retinal responses?

Preliminary ERG results with IAPS photos
Retinal triage of picture processing: Insights into retino-cortical interaction

Monika M. Zeiller ¹, Britta U. Westner ¹,², Sarang S. Dalal²,¹

¹ Department of Psychology, University of Konstanz, Germany
² Center of Functionally Integrative Neuroscience, Aarhus University, Denmark

Regression: b-wave and N135 Peak Latency

\[ y = 0.025 + 1.024x, r = 0.952, p = 0.001; R = 0.916 \]

Timeline of Latencies

Latency \( N_{135} \) vs. (Latency \( N_{135} \) – Latency \( bwave \): \( F(7, 7) = 6.104, p = 0.029 \)
Magneto\textit{retin}ography

Katila et al., 1981
Magnetoretinography

topography of retinal response
(right eye)

lead field modeled with factor analysis

False source
(without eyes in VOI)

With custom lead field and eyes included
Conclusions & Questions

The retina – an accessible part of the human brain – performs sophisticated processing and its contribution must be considered along with cortical responses.

- For *neural timing* to be a robust marker of **local computation**, the entire visual pathway must be probed – starting at the retina.

- High-frequency retinal oscillations appear to drive corresponding visual cortical activity.

- Might the timing and frequency of these oscillations code features of more complex imagery?

- Does cortex or thalamus talk to the retina?

- Findings will advance our understanding of how neural systems – in general – can process and communicate information.
NEMOlab

Monika Zeiller  Tommy Clausner  Wibke Naumann  Claudia Leupold  Britta Westner  Sabine Leske  Maité Crespo García  Mathis Kaiser  Daniel Wong

erc postdocs and PhD students wanted for new retina-cortex projects - start dates through Spring 2018

cfin.au.dk/nemo sarang@cfin.au.dk