Spatiotemporal dynamics during binocular rivalry

left eye  right eye  Percept

dominance in percept

--- t ---
Working hypothesis: neural activity in primary visual cortex is conscious visual awareness
Perceptual traveling waves

Display

left eye

right eye

Percept

Latency
L / R / N

Wilson, Blake & Lee (2001)
Functional magnetic resonance imaging
Prediction: traveling waves of cortical activity
Perceptual and neural traveling waves

Peak fMRI response

Percept

Macaque visual areas
Defining visual cortical areas

PhACT

Physiology  Architecture  Connections  Topography
Retinotopy (human V1)

Visual Disturbances Following Gunshot Wounds of the Cortical Visual Area

Based on observations of the wounded in the recent Japanese wars
German edition first published in 1909

Tatsuji Inouye (1880-1976)

Horton & Hoyt, 1991
Retinotopy (human V1)
Retinotopy (monkey V1)

Tootell, Silverman, Switkes, & DeValois (1982)
Retinotopy

Radial component

Angular component

Retinotopy: radial component

Brewer, Wandell, & Logothetis

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Cortical segmentation & flattening

- Extract cortical surface
- Cut and flatten

Jonas Larsson

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Retinotopy: angular component

Larsson & Heeger
Visual cortical areas

- V1
- V2
- V3
- V3A/B
- V4
- V7
- IPS1
- IPS2
- LO1
- LO2
- MT
Monkey visual areas from fMRI

Brewer, Press, Logothetis, & Wandell (2002)
Alignment across scanning sessions

Spatial & temporal scales

- Brain
- MEG & ERP
- Functional MRI
- PET
- Lesions
- Optical dyes
- TMS
- Microlesions
- Multi-unit recording
- 2-Deoxyglucose
- Single unit
- Patch clamp
- Light microscopy

Log size (mm) vs Log time (sec)
Hemodynamics

(A) Control state

Heart

lung

Arterial

OEF: 0.4

Venous

60

40

(B) Active state

Heart

lung

Arterial

OEF: 0.4/1.2

Venous

63

37

Brain

Brain
Metabolism, hemodynamics, & MRI

Heeger & Ress, Nature Rev Neurosci, 2002
The linearity hypothesis

fMRI signal is approximately proportional to a measure of local neural activity, averaged over a spatial extent of several millimeters and over a time period of several seconds.

Boynton et al, J Neurosci, 1996
Hemodynamic impulse response function

Boynton et al, J Neurosci, 1996
Temporal summation

Boynton et al, J Neurosci, 1996
fMRI spatial and temporal resolution

Time series of fMRI images

Typical frame time: 1-2 sec

Typical pixel size: 2-3 mm
Temporal resolution is limited by SNR

Brief pulse of neural activity
fMRI and electrophysiology are complementary

“fMRI constitutes a complement, not a poor-resolution substitute, to invasive techniques... an indicator for a multitude of functionally relevant processes, circumventing some of the biases observed for electrodes... it deserves interpretations that acknowledge its stand as a separate signal.”

Bartels, Logothetis, & Moutoussis, TiNS, 2008
Predicted and measured responses

Activity correlates with perceived latency

Infer ~115 ms timing difference over ~3.5 mm distance.

Estimating neural activity

Local contrast

Neural activity

FMRI response

time to peak
peak amplitude

--- t ---
Model of cortical activity & hemodynamic response

Local contrast

Neural activity

Hemodynamic impulse

Predicted fMRI response

\[ e^{-t/\tau_1} \sin(2 \pi f_1 t) - a e^{-t/\tau_2} \sin(2 \pi f_2 t) \]
Estimated neural latency

Ave speed = 2 cm/sec

Estimated neural latency (sec)

Distance (cm)

Observer
- DN
- PN
- SL

Attention signals in V1

Gandhi, Heeger, & Boynton, PNAS (1999)
Diverted attention

left eye  right eye

C2DA3B42D...

Detect repetition

Waves in V1 without attention/perception

Rivalry (perceived)

Diverted attention

Diverting attention eliminates waves in V2 & V3

Waves measured with VDSI in monkey V1

Zhang, Heeger, Blake, Seidemann
Waves measured with VDSI in monkey V1

Zhang, Heeger, Blake, Seidemann
Implications: neural processing hierarchy

Right eye

Left eye

V1

Rest of brain

Attention

Feedback

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Summary

• V1 activity correlated with spatio-temporal dynamics of perceptual waves during binocular rivalry.

• The velocity of neural waves in V1 matched the latency of perceptual waves.

• Neural waves in V1 were still present when attention was diverted, but weaker in amplitude and faster in velocity.

• V2 and V3 exhibited cortical waves of activity during rivalry but the waves were eliminated when attention was diverted.
Implications

• Neural wave propagation is intrinsic to V1.

• Constrains models of processing and circuitry in V1 (waves are slow relative to action potential propagation and synaptic transmission).
Models and testing them

Periodic perturbation experimental protocol

Kang, Lee, Kim, Heeger, & Blake, J Vis, 2010

Model

Simulations

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