Neural Correlates of Attention and Perception

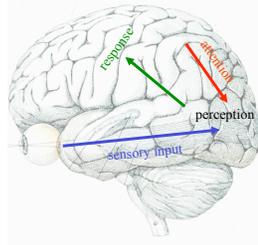David J. Heeger
New York University
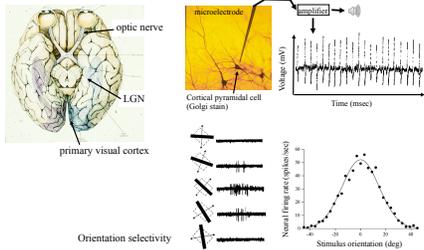

Attention & perception
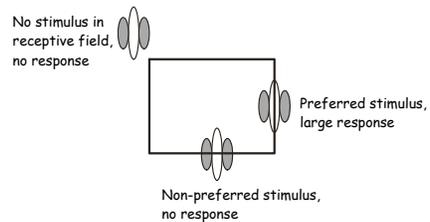
David Ress

response
attention
perception
sensory input

Primary visual cortex (V1)

optic nerve

microelectrode
amplifier

Voltage (mV)

Time (msec)

LGN

Cortical pyramidal cell
(Golgi stain)

primary visual cortex

Orientation selectivity

Neural firing rate (spikes/sec)

Stimulus orientation (deg)

Orientation selectivity

No stimulus in
receptive field,
no response

Preferred stimulus,
large response

Non-preferred stimulus,
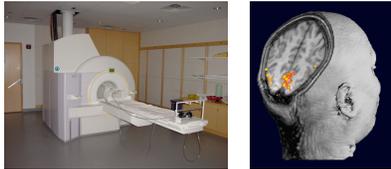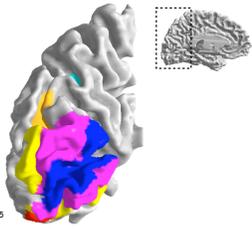no response

Attention signals in V1
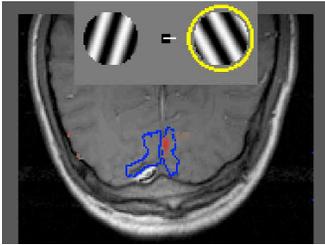
Gandhi et al, PNAS, 96:3314-, 1999

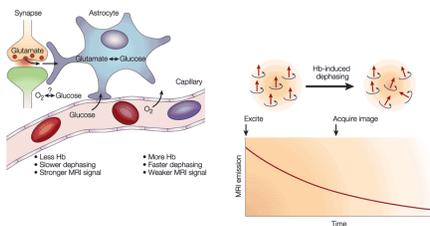## Functional magnetic resonance imaging

Visual areas: retinotopy
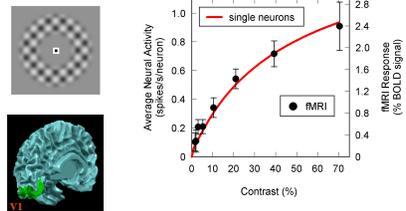

Engel et al, Nature, 1994

Sereno et al, Science, 1995
DeYoe et al, PNAS, 1996
Engel, Glover, & Wandell, Cereb Cortex, 1997

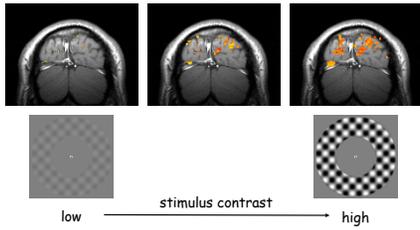## Metabolism, hemodynamics, & MRI

Heeger & Ress, Nature Rev Neurosci, 2002

fMRI responses & neural firing rates

Heeger et al, Nature Neurosci, 3:631-, 2000

Responses increase with contrast

low ⟶ stimulus contrast ⟶ high

Part I: Attention and Pattern Detection

Pattern detection protocol

stimulus present   OR   stimulus absent

detection period   response period

1 second

auditory cue

18 seconds
intertrial
interval

auditory cue
trial beginning

auditory cue
trial beginning
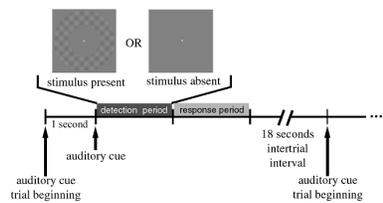
Strong response when stimulus present

Individual trial
time series

mean, std. error

average of 296 trials
subject: DBR

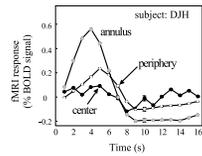fMRI response
(% BOLD signal)

Time (s)

Large response when stimulus absent

- Base response when stimulus absent — attention?
- Small increment when stimulus present — sensory signal?

Stimulus present

Increment

Base response

Stimulus
absent

subject: DBR

fMRI response
(% BOLD signal)

Time (s)

Base response is spatially selective

Analyzed data in each of 3 subregions of V1:

subject: DJH

annulus

periphery

center

fMRI response
(% BOLD signal)

Time (s)

Depends on task difficulty

Modified task difficulty by varying stimulus contrast

Threshold (0.8%) contrast   2x (1.5%) contrast   High (50%) contrast

Pattern present

Pattern absent

subject: DBR

fMRI response
(% BOLD signal)

Time (s)

Variable delay period

OR

stimulus present — stimulus absent

detection period — 1 second — response period

2 – 16 second delay period — 18 seconds intertrial interval — ...

auditory cue trial beginning

auditory cue "respond now"

auditory cue trial beginning

Base response is sustained

Annular ROI, 1.5 – 4.5 deg diameter

Subject DBR

Annular ROI, 15 – 30 deg diameter

Subject DBR

Legend:
2 - 5.5 secs
5.5 - 9 secs
9 - 12.5 secs
12.5 - 16 secs

fMRI response (% BOLD)
Time (sec)
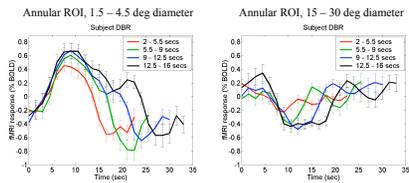
Silver, Ress & Heeger, VSS 2003

Base response predicts performance

r = 0.92
p < 0.001

Performance (d')

fMRI response amplitude
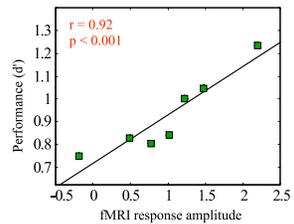
Ress, Backus, & Heeger, Nat Neurosci 3:940-, 2000

Interpretation

• Why is the base response so big?
Small effect in each of a large number of neurons.

• Why doesn't the base response evoke a percept?
Because percepts depends on relative responses of subpopulations of neurons, not overall net increase in activity.
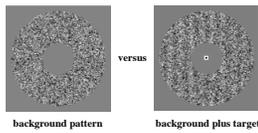
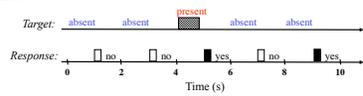• How might the base response improve performance accuracy? Reduce spatial uncertainty.

decision
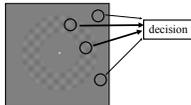
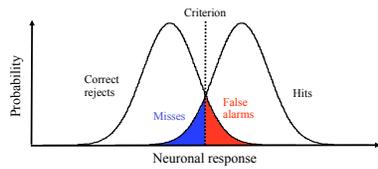## Part II: Perception and Pattern Discrimination

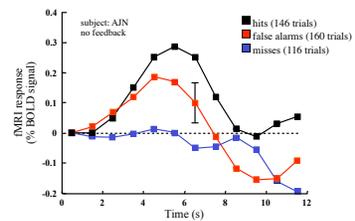---

Pattern discrimination protocol

- Stimulus:

background pattern   *versus*   **background plus target**

- Task:

Target: absent   absent   **present**   absent   absent

Response: no   no   yes   no   yes

0   2   4   6   8   10

Time (s)

Signal detection theory

Criterion

Correct rejects

Misses

False alarms

Hits

Probability

Neuronal response

Response increment predicts percept

subject: AJN
no feedback

■ hits (146 trials)
■ false alarms (160 trials)
■ misses (116 trials)

fMRI response
(% BOLD signal)

Time (s)

Ress & Heeger, *Nature Neurosci*, 2003

Spatially selective

fMRI response amplitude (% BOLD signal)

Stimulus annulus

0.15
0.10
0.05
0
-0.05

V1   V2   V3
Visual area

Periphery

■ Hits
■ False alarms
■ Misses

0.15
0.10
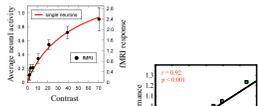0.05
0
-0.05

V1   V2   V3
Visual area

(averaged across subjects)
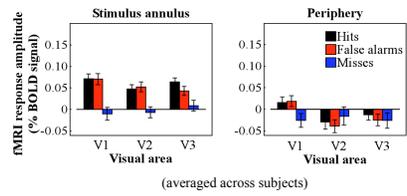
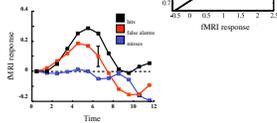Ress & Heeger, *Nature Neurosci*, 2003

Review

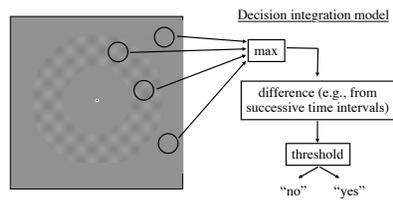1) fMRI signal roughly proportional to average firing rates

2) Attentional signals in V1 predict performance accuracy
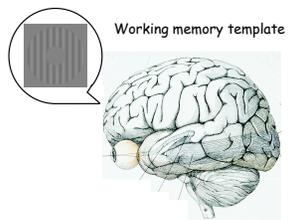
3) V1 activity predicts percept

Attention, perception, & performance

Base response improves performance by emphasizing the relevant neural signals. Percept depends on relative responses.

Decision integration model

max

difference (e.g., from successive time intervals)

threshold

"no"   "yes"

Alternative interpretation

Working memory template

Collaborators

Geoff Boynton
Ben Backus
Michael Silver

David Ress

Retinotopy, gray matter segmentation & flattening:
Brian Wandell, Steve Engel, Alex Wade, Bob Dougherty

MR Physics:
Gary Glover