Feature-based attention
Measuring feature-similarity gain

Martinez-Trujillo & Treue

Fixation

target

Attending

Constant modulation

response

direction

Feature-similarity gain prediction

Fixation

target
Measuring feature-similarity gain (Example MT neuron)

- Attending Fixation
- Attending
- Fixation

Graph showing the relationship between attended direction in degrees away from preferred direction and response. The correlation coefficient is $r = -0.95$. The graph indicates a trend where the response decreases as the attended direction moves away from the preferred direction.
Measuring feature-similarity gain (Population data)

The attentional modulation is a function of the similarity between the cell’s preferred feature and the attended feature.

The equation is:

\[-0.00083 \times \text{(distance from preferred)} + 1.06\]

with an intercept of 1.06 and a slope of -0.00083, where the distance from preferred is measured in degrees.

There are 135 data points (n=135).

The attentional modulation decreases as the attended direction moves away from the preferred direction.
Attention and stimulus saliency

- Stimulus
- Response: # spikes
- MT directional columns
- Saliency

- Attended
- Unattended
Global Spread: Neurophysiology

- Neural responses are modulated by features of distant attended stimuli
  (e.g., Treue & Martinez-Trujillo, 2004; Saenz et al, 2002; Boynton & Serences, 2007)

- Neurons that prefer the attended feature value are ‘boosted’ across the visual field, even at task-irrelevant locations
Spread of feature-based attention

Does feature-based attention modulate neuronal subpopulations in the attended location?

Treue & Martinez-Trujillo, 1999
Saenz, Buracas & Boynton, 2002
Use adaptation to assess feature selectivity

- **Upward preferring units**
  - More adaptation for an *upward* test stimulus when attending ‘up’ vs. ‘down’

- **Downward preferring units**
Adapting stimulus

-20° +20°

Spatial frequency (cpd)

Time (s)
Behavior: tilt aftereffect (n=8)

... Pre-adaptation (40 s) Adapter (4 s) 1 s Test (0.5 s) ...

Perceived vertical

Perceived horizontal

Attended +20 Attended -20
fMRI: adaptation procedure

Pre-adaptation (40 s) Adapter (4 s) Test (1 s)

Attended Unattended Blank
fMRI data acquisition and retinotopic mapping

- Siemens 3T Allegra
- Surface coil
- TR = 1.2 s, 22 slices
fMRI response to the test stimulus (n=8)

- Unattended
- Attended

V1

fMRI response (%)

V2

Time (s)

adapter
test
Attention modulation index

\[
\frac{R_{\text{attn}} - R_{\text{unattn}}}{R_{\text{attn}} + R_{\text{unattn}}}
\]
Correlation between behavior and imaging results

$r = 0.75, p = 0.03$
A model relating behavioral and imaging results

model assumptions

model predictions

Dragoi et al, 2000, 2001
• psychophysics and neuroimaging to investigate the selective power, perceptual consequences, and neural basis of FBA at the location of spatial attention

• FBA enhances activity of neuronal subpopulations when the attended and unattended features are processed in the same retinotopic region
  
  – attentional modulation of orientation-selective fMRI response adaptation
  
  – attentional modulation constant across visual areas; feed-forward mechanism
  
  – significant correlation between TAE and AMI only in V1
Trial sequence

- Fixation: 1500 ms
- Cue: 100 ms
- ISI: 50, 200, 400 ms
- Stimuli: 300 ms

Time

cue 100 ms
ISI

Time

distracters

Time

target

100 ms 200 ms
With identical stimuli and tasks:

Spatial attention affects the selection process earlier than feature-based attention

Given sufficient time between the cue and target, feature-based attention can be as effective as spatial attention

*Liu, Stevens & Carrasco, Vis.Res. 07*
Feature-based attention
Normalization model of attention predicts response gain in both cases

Response gain

Contrast gain

Response gain

Only when orientation bandwidth is unrealistically narrow

Realistic orientation bandwidth
Experimental protocol

Orientation discrimination task: Is orientation of Stimulus 2 CW or CCW of closest orientation in Stimulus 1?
Low-uncertainty experiment
(small attention field)

Stimulus display 1

Stimulus display 2
Response gain change with low uncertainty

4 observers
~3200 trials each
$R^2 = 0.94$

Performance ($d'$)

Contrast (%)

Valid

Invalid

$\frac{d'(c)}{d'_{\text{max}}} = \frac{c^n}{c^n + c_{50}^n}$

$p = 0.613$

$p < 0.001$
High-uncertainty experiment
(large attention field)

Stimulus display 1

Stimulus display 2
Response gain change with high uncertainty

4 observers
~3200 trials each
$R^2 = 0.9$

Performance ($d'$)

Contrast (%)
Did observers spread their attention in the high-uncertainty experiment?

Control experiment:
- High- and low-uncertainty blocks interleaved
- Constant orientation tilt and constant contrast (85%)
- Analysis of same orientation trials

If observers spread their attention, performance high-uncertainty < low-uncertainty
higher uncertainty decreases performance

4 observers
~3200 trials each
Similar performance across orientations

Overall performance

Valid - invalid

Accuracy (% correct)

Orientation ranges (deg)

15-24  27-36  39-51  54-63  66-75  15-75

Accuracy (% correct)

Orientation ranges (deg)

15-24  27-36  39-51  54-63  66-75  15-75
Feature-based attention enhances performance by increasing response gain

Supporting the normalization model of attention
Empirical support for the NMA (RH, 09)

- FBA enhances performance, via RG, regardless of the stimulus size and attention field size

- Feature uncertainty manipulation was effective: Attention field was larger with than without uncertainty, and performance was similar for all orientations

- Results support the predictions of the NMA

Herrmann, Heeger & Carrasco
Vis Res 2012
Neural population response

Gain

Tuning

Equivalent noise curves
External noise with global motion

Low noise → High noise

$P(\theta)$
Sequence of events in a single trial

**a. Spatial attention**
- Fixation: 1500 ms
- Spatial precue: 600 ms
- Stimuli + response cue: 100 ms
- Attention: 3000 ms
- Neutral: 3000 ms

**b. Feature-based attention**
- Fixation: 1500 ms
- Feature precue: 600 ms
- Stimuli + response cue: 100 ms
- Attention: 3000 ms
- Neutral: 3000 ms
a. Spatial attention:

- AC
- SL
- TL

Threshold (directional angle) vs. External noise (directional S.D.)

b. Feature-based attention:

- AC
- SL
- TL

Threshold (directional angle) vs. External noise (directional S.D.)
Feature-based attention at a peripheral location

--- Attention cue
- Neutral cue

Threshold (directional angle)

External noise (directional S.D.)
Attentional filters

**Part a.**
- Graph showing attentional modulation vs. angular difference from attended direction.
- Marked areas indicate gain and tuning.
- Gain: 1.77
- Slope: 0.0032 deg

**Part b.**
- Graph showing attentional modulation vs. angular difference from attended direction.
- Marked areas indicate spatial attention and feature-based attention.
- Gain: 1.44
- Slope: 0.0032 deg

Additional note: The graph illustrates how attentional filters can modulate visual processing based on the angular difference from the attended direction, with specific parameters for gain and slope.
How attention modulates population response

Ling, Liu & Carrasco, Vis Res 09
c. output threshold vs. noise

b. global integration + MLE

a. sub-sampled response

stimulus