Feature-based attention
Measuring feature-similarity gain

Martinez-Trujillo & Treue
Attention and stimulus saliency

stimulus

Response
# spikes

MT directional columns

saliency

attended
unattended
Measuring feature-similarity gain (Example MT neuron)
Measuring feature-similarity gain (Population data)

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

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

Response

upward preferring units

More adaptation for an upward test stimulus when attending ‘up’ vs. ‘down’

Response

downward preferring units
Adapting stimulus

- 20°
- +20°

- Time (s)

- Spatial frequency (cpd)

0 1 2 3 4

- Time (s)

- Spatial frequency (cpd)

0 1 2 3 4
Behavior: tilt aftereffect (n=8)

Pre-adaptation (40 s)

Adapter (4 s) 1 s Test (0.5 s)

Perceived vertical

Perceived horizontal

Perceived - objective orientation (deg)

Attend +20 Attend -20

Attend +20 Attend -20
fMRI: adaptation procedure

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

... 1 s 1.2 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)

- 0.4
- 0.2
- 0
- 0.2
- 0.4
- 0.6
- 0.8

V1

V2

Time (s)

fMRI response (%)

Attended

Unattended

adapter
test
Attention Modulation Index

\[
\frac{R_{\text{attn}} - R_{\text{unattn}}}{R_{\text{attn}} + R_{\text{unattn}}}
\]

![Graph showing AMI values for different areas (V1, V2, V3, hV4, LO1, LO2, V3A/B, V7). The x-axis represents the areas, and the y-axis represents the AMI values. The data points are accompanied by error bars representing standard error.](image-url)
correlation between behavior and imaging results
A model relating behavioral and imaging results

Model assumptions

Model predictions

Dragoi et al, 2000, 2001
Conclusions

• Combination of psychophysics and imaging 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, suggesting a feed-forward mechanism.
  – significant correlation between TAE and AMI only in V1.
Location cue

$\quad d'_{\text{valid}} - d'_{\text{neutral}}$

Direction cue

$\quad d'_{\text{valid}} - d'_{\text{neutral}}$

$C_{\text{valid}} - C_{\text{neutral}}$

$C_{\text{valid}} - C_{\text{neutral}}$

Cue-target SOA (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

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)
Response gain change with low uncertainty

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

$\begin{align*}
\text{Valid} \\
\text{Invalid}
\end{align*}$

$\begin{align*}
\text{Performance (d')} \\
\text{Contrast (%)}
\end{align*}$

Valid
Invalid

$d'_{\text{max}}$
$p<0.001$

$c_{50}$
$p=0.613$

$\begin{align*}
d'(c) &= d'_{\text{max}} \frac{c^n}{c^n + c_{50}^n}
\end{align*}$
High-uncertainty experiment
(large attention field)

Pre-cue

Stimulus display 1
Stimulus display 2
Response gain change with high uncertainty

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

Performance ($d'$)

Contrast (%)

Valid
Invalid

$d'_{\text{max}}$
$p < 0.001$

$c_{50}$
$p = 0.87$
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

Accuracy (% correct)

Orientation ranges (deg)

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

0  0.5  0.6  0.7  0.75
Attention effects for
large attention field

A
Valid
Invalid

Accuracy (% correct)
15-24 27-36 39-51 54-63 66-75
Orientation ranges (deg)

B

Accuracy (% correct)
±45 near ±45 far ±45
Orientation ranges (deg)
Feature-based attention enhances performance by increasing response gain, supporting NMA.
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

Response

Threshold

Direction

External Noise
External noise with global motion

Low noise \rightarrow \text{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
- Response 3000 ms

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

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

- AC
- SL
- TL

- ○○ Attention cue
- ● Neutral cue

b. Feature-based attention:

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

- AC
- SL
- TL
Feature-based attention at a peripheral location

--- Attention cue
- Neutral cue

Threshold (directional angle)

External noise (directional S.D.)
Attentional filters

**a.**

- **Gain:** 1.77
- **Slope:** 0.0032 deg

**b.**

- **Spatial attention** - gain only
  - Gain: 1.44
  - Slope: 0.0032 deg

- **Feature-based attention** - gain & tuning
How attention modulates population response

Spatial attention:

Feature-based attention:

Firing rate (spike/sec)

Direction

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

b. global integration + MLE

a. sub-sampled response

Gain

Tuning

External noise

External noise

Firing rate

Preferred direction

Gain

Baseline

Tuning

stimulus
FBA

- Effective across the visual field, even at unattended or irrelevant locations
- Temporal dynamics are slower than for spatial attention
- NMA: for orientation, responses are mediated by RG
- Gain and tuning