Covert attention and spatial resolution
endogenous spatial attention
exogenous spatial attention
exogenous spatial attention
spatial resolution decreases with eccentricity

- the ability to discriminate two nearby points in space
- depends on receptor size, number, and spacing
- average filter size inversely correlated with preferred spatial frequency
RF/pRF size increases with eccentricity and across visual areas

Freeman & Simoncelli, 2011
Winawer & Horiguchi, 2015
Carrasco & Barbot, 2015
attention and spatial resolution

• affects performance: search, acuity, crowding, texture segmentation

• changes the appearance of spatial stimulus attributes; e.g. gap size

  reviews: Carrasco & Yeshurun, PBR 2009
  Carrasco, Vis Res 2011; Carrasco & Barbot, CSH: Cognition 2015

• changes receptive filed size, structure and position

• linking psychophysical and neurophysiological evidence

attention alters RF profiles

a | The left panel shows that responses to a preferred stimulus (represented by a purple vertical bar) and a non-preferred stimulus (represented by a green horizontal bar) presented simultaneously inside a neuron’s receptive field (RF; represented by a black line) reflect an average between the neuron’s response to the preferred stimulus presented alone (light purple line) and the response to the non-preferred stimulus presented alone (light green line). Attention biases this average response in favour of the attended stimulus. Attention on the preferred stimulus enhances the response (dark purple line), whereas attention on the non-preferred stimulus reduces the response (dark green line). The panels on the right show hypothetical changes in RF profile (indicated by orange shading). The results are consistent with a shrinkage of the RF around the attended stimulus as well as a shift towards the attended stimulus.

b | Attention on a stimulus inside the RF (red dot) shifts and shrinks the RF towards and around the attended stimulus (right panel) compared with the same stimulus configuration when attention is allocated elsewhere (left panel).

c | Attention on a stimulus near (but not inside) the RF shifts and expands the RF towards the attended stimulus (red dot in the right panel) compared with the same stimulus configuration when attention is allocated elsewhere (left panel).
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Anton-Erxleben & Carrasco, NRN 2013
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Anton-Erxleben & Carrasco, NRN 2013
RFs can shrink or expand with attention

Wolmersdorf et al. 2006; Anton-Erxleben et al. 2009; Niebergall et al. 2011
visual search

b

Set-size or target eccentricity

Reaction time or error rate

Without attention
With attention

Anton-Erxleben & Carrasco, NRN 2013
SEARCH: cortical magnification & exogenous attention

Carrasco & Frieder 1997

Carrasco & Yeshurun 1998

Carrasco & Barbot 2015
acuity

Anton-Erxleben & Carrasco, NRN 2013
exogenous attention: acuity task

Yeshurun & Carrasco, VisRes 1999
ACUITY: macaques

Golla et al. 2004

exogenous

endogenous

Yeshurun & Carrasco 1999

Montagna, Pestilli & Carrasco 2009

Carrasco & Barbot 2015
heightened resolution is not always optimal
texture segmentation - performance f (resolution)

eg, Gurnsey et al. 1996; Kehrer 1989, 1997; Morikawa 2000; Potechin & Gurnsey 2003
texture segmentation

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**Figure e:**
- **Performance** as a function of **Target eccentricity**.
- Two curves indicate optimal performance with and without **attention**.
- The graph shows two distinct regions:
  - **Optimal performance without attention**.
  - **Optimal performance with attention**.

**Figure f:**
- **Without attention**:
  - Optimal filter size.
- **With attention**:
  - Optimal filter size.
exogenous attention improves or impairs performance by increasing resolution

Yeshurun & Carrasco, Nature 1998
EXO attention improves or impairs performance by increasing resolution for small texture scale (viewing distance: 57 cm) or large texture scale (viewing distance: 28 cm).
contrast sensitivity function
Adaptation reduces perceived contrast

move your eyes along the horizontal bar
adaptation reduces sensitivity
EXO: selective adaptation to spatial frequencies

Exogenous attention enhances resolution by increasing the sensitivity of small, high-SF filters

Carrasco, Loula & Ho, 2006
flexible resolution?

SEURAT

DALI
Exogenous attention

Endogenous attention

Yeshurun, Montagna & Carrasco, 2008

Yeshurun & Carrasco, 1998
## Attention and Spatial Resolution

<table>
<thead>
<tr>
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*Small filters’ sensitivity*

### Automaticity

**Valid**

- Performance

**Neutral**

- Performance

### Flexibility

**Valid**

- Performance

**Neutral**

- Performance
endogenous attention

Adaptor

- Pre-adaptation (180s)
- Top-up adaptation (4s)

Fixation (500)

Precue (300)

ISI (200)

Texture display (50)

ISI (200)

Time (ms)

Post-cue (300)

Valid

Neutral

Display: 38x50 lines

Target: 4x2 lines

Yes-No Detection Task:
Q: Texture target present or absent?

7 eccentricities (0–7 deg)

n=12
selective adaptation

vertical contrast modulator in carrier noise (6 cpd)

HIGH SFs (2 cpd)

BASELINE (0 cpd)

LOW SFs (0.18 cpd)
selective adaptation

BASELINE
selective adaptation

LOW SFs
selective adaptation

HIGH SFs
prediction: adaptation

Eccentricity (deg)

Performance (d')

High SFs
Baseline
Low SFs

Peripheral

Central performance drop (d')

Performance peak (deg)

Adaptation
adaptation shifts peak and modulates CPD

Selective Adaptation (distributed attention)

Performance peak (deg)

Eccentricity (deg)

Performance (d')

Central performance drop (d')

BASELINE

HIGH SFs

LOW SFs

Low-SF  Baseline  High-SF

Performance peak (deg)

Low-SF  Baseline  High-SF

Central performance drop (d')

Low-SF  Baseline  High-SF

***  *  **  ***  *  **  *
prediction: adaptation x attention

[H1] by increasing sensitivity of either small (high SF) or large (low SF) filters

Attentional effect

\[ \Delta \text{Valid - Neutral (d')} \]
prediction: adaptation x attention

[H1] by increasing sensitivity of either small (high SF) or large (low SF) filters

[H2] by either increasing or decreasing sensitivity of small (high SF) filters
prediction: adaptation x attention

[H1] by increasing sensitivity of either small (high SF) or large (low SF) filters

[H2] by either increasing or decreasing sensitivity of small (high SF) filters

[H3] via a resolution-independent mechanism

Attentional effect
prediction: adaptation x attention

[H1] by increasing sensitivity of either small (lhigh SF) or large (low SF) filters

[H2] by either increasing or decreasing sensitivity of small (high SF) filters

[H3] via a resolution-independent mechanism
attention interacts with adaptation

Results

Eccentricity (deg)

Performance (d')

BASELINE

valid
neutral

HIGH SF

LOW SF

Δ Valid - Neutral (d')
prediction: adaptation x attention

[H1] by increasing sensitivity of either small or large filters

[H2] by either increasing or decreasing sensitivity of small filters

[H3] via a resolution-independent mechanism
small filters mediate the endo attention effect

[H2] by either increasing or decreasing sensitivity of small filters

Barbot & Carrasco (2017)
ENDO attention adjusts resolution to improve performance

• selective adaptation shifts the performance peak and modulates CPD, consistent with changes in the population’s resolution
• adapting to high-SF, but not to low-SF, diminishes the CPD and silences attentional benefit at foveal and parafoveal locations
• attention modulates high-SF filters’ sensitivity at central locations

Barbot & Carrasco (2017)
EXO ≠ ENDO attention

EXO attention increases resolution by increasing contribution of high-SF filters

- **low-SF adaptation**
  - no change

- **high-SF adaptation**
  - baseline

  *Carrasco, Loula & Ho, 2006*

ENDO attention decreases resolution by decreasing contribution of high-SF filters

- **no change**

- **baseline**

  *Barbot & Carrasco, 2017*
attention and spatial resolution

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**Automaticity**
- valid (red)
- neutral (blue)

**Flexibility**
- increases of small filters

*Carrasco, Loula & Ho, 2006*  
*Barbot & Carrasco, 2017*
processing and restore visual performance

- **exogenous** attention automatically increases resolution (e.g., search, acuity), even when detrimental.

- Diverting **exogenous** attention decreases resolution and can improve performance!

- **endogenous** attention flexibly adjusts resolution per task demand to benefit performance.

- **Exogenous** and **endogenous** attention modulate sensitivity of the high-SF selective filters at a given eccentricity.
- **EXOGENOUS** ATTENTION is **automatic**, trades-off contrast sensitivity and spatial resolution at attended and unattended locations

  ‣ increases spatial resolution –search, acuity– even when detrimental for the task –texture segmentation

- **ENDOGENOUS** ATTENTION is a **flexible**, adjusts to task demands to always benefit performance

  ‣ flexibly adjusts spatial resolution per task demand to benefit performance – alleviates the CPD

- EXO and ENDO attention modulate sensitivity of the high-SF selective filters at a given eccentricity
Covert attention helps overcome limitations of perceptual processing and restore visual performance

- RF position and size changes can qualitatively account for behavioral effects in performance

  - *Concentrating processing resources at attended location (shift)*

    - pRF shift towards attended area throughout the visual field and the visual system

      *Klein, Harvey & Dumoulin, 14*

  - Reducing the area of spatial integration (shrinkage)

    - Decreased spatial overlap in BOLD responses for adjacent locations, narrowing of the population’s integration area

      *Fischer & Whiney 09*

    - Withdrawing attention from the periphery results in larger population receptive fields (pRFs) and blurrier perceptual representation

      *de Haas et al., 14*