(1) covert attention
(2) effects on contrast sensitivity
(3) effects on spatial resolution
1. definition
2. linking psychophysical and neurophysiological evidence - NRN, 2013
3. recent studies
vision is limited by spatial resolution

- 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
spatial resolution declines with eccentricity

- retinal receptor density
- ganglion cell density
- mapping of photoreceptors
- receptive field size & density
- cortical magnification
spatial resolution declines with eccentricity

attention and spatial resolution

- benefits performance; e.g. visual search, acuity and crowding
- 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 field size, structure and position

- linking psychophysical and neurophysiological evidence
  
attention alters RF profiles

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 favor 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).
RFs can shrink or expand with attention

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

b

Without attention
With attention

Reaction time or error rate

Set-size or target eccentricity

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
ACUITY: macaques  humans

Eccentricity (deg)

Acuity thresholds (arcmin)

Cued  Neutral  Uncued

Endogenous

Exogenous

Montagna, Pestilli & Carrasco 2009

Yeshurun & Carrasco 1999
Golla et al. 2004

Carrasco & Barbot 2015
optimal resolution?
texture segmentation - performance $f$ (resolution)

e.g., Gurnsey et al. 1996; Kehrer 1989, 1997; Morikawa 2000; Potechin & Gurnsey 2003
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Texture segmentation - performance $f$ (resolution)

![Graph showing performance vs. eccentricity]

- Performance axis
- Eccentricity axis
- Fovea and periphery markers

Graph: Performance vs. Eccentricity
e.g., Gurnsey et al. 1996; Kehrer 1989, 1997; Morikawa 2000; Potechin & Gurnsey 2003
texture segmentation - performance $f$ (resolution)

e.g., Gurnsey et al. 1996; Kehrer 1989, 1997; Morikawa 2000; Potechin & Gurnsey 2003
texture segmentation - performance f (resolution)

e.g., Gurnsey et al. 1996; Kehrer 1989, 1997; Morikawa 2000; Potechin & Gurnsey 2003

- Visual system's effective resolution
- Central Performance Drop
- Periphery
- Performance peak
- Resolution too high
- Resolution too low

Performance

Eccentricity

fovea

periphery
texture segmentation - performance $f(\text{resolution})$

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

(e) Performance vs. Target eccentricity

- Attention
- w/o attention

(f) Without attention
- Optimal filter size

(f) With attention
- Optimal filter size
exogenous attention improves or impairs performance by increasing resolution

Yeshurun & Carrasco, Nature 1998
exogenous attention: resolution tradeoff

EXP.1: SMALL TEXTURE SCALE
EXP.2: LARGE TEXTURE SCALE

Sensitivity (d')

Eccentricity (deg)

Δ Cued - Neutral (deg)

valid neutral invalid
Sensitivity $\left(\frac{1}{\text{Threshold}}\right)$

Contrast

Spatial Frequency (cpd)

Campbell & Robson (68)
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**

- **Small scale**
  - Accuracy graph showing two curves: one for cued and one for neutral stimuli.
  - Eccentricity range: 0 to 10 degrees.

- **Large scale**
  - Accuracy graph showing two curves: one for cued and one for neutral stimuli.
  - Eccentricity range: 0 to 20 degrees.

**Endogenous attention**

- **Small scale**
  - d' graph showing two curves: one for cued and one for neutral stimuli.
  - Eccentricity range: 0 to 10 degrees.

- **Large scale**
  - d' graph showing two curves: one for cued and one for neutral stimuli.
  - Eccentricity range: 0 to 20 degrees.

Yeshurun, Montagna & Carrasco, 2008

Yeshurun & Carrasco, 1998
### Attention and Spatial Resolution

<table>
<thead>
<tr>
<th></th>
<th>EXOGENOUS</th>
<th>ENDOGENOUS</th>
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<tbody>
<tr>
<td>Performance at central locations</td>
<td>impairs</td>
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</tr>
<tr>
<td>Performance at peripheral locations</td>
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</tr>
<tr>
<td>Spatial resolution</td>
<td>increases</td>
<td>either increases or decreases?</td>
</tr>
<tr>
<td></td>
<td>small filters’ sensitivity</td>
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</table>
endogenous attention and texture segmentation

**Adaptor**
- pre-adaptation (180s)
- top-up adaptation (4s)

**Fixation**
- (500)

**Precue**
- (300)

**ISI**
- (200)

**Texture**
- display (50)

**Time**
- (ms)

**Display**
- 7 eccentricities (0–7 deg)

**Valid**

**Neutral**

**Post-cue**
- (300)

**Display:** 38x50 lines
- Target: 4x2 lines

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

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

Adaptation

Performance (d') vs. Eccentricity (deg)

- Fovea
- Periphery

Graph showing performance drop and peak with eccentricity.

Central performance drop (d')

Performance peak (deg)

HIGH SFs

LOW SFs

BASELINE

Adaptation
adaptation shifts peak and modulates CPD
prediction: adaptation × 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
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
adaptation interacts with attention
prediction: adaptation x attention

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

[H2] by either increasing or decreasing sensitivity of small filters
attention interacts with adaptation

Eccentricity (deg)

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<td>Performance (d')</td>
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Eccentricity (deg)

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Eccentricity (deg)

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Δ Valid - Neutral (d')

0.5

0.25

0
**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

baseline

high-SF adaptation

Attentional effect

Carrasco, Loula & Ho, 2006

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

no change

baseline

Attentional effect

Barbot & Carrasco, 2017
endogenous 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 silences attentional benefit at foveal and parafoveal locations

Barbot & Carrasco (2017)
Exogenous attention increases resolution by increasing contribution of high-SF filters

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

Carrasco, Loula & Ho, 2006

Barbot & Carrasco, 2017
attention and spatial resolution

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<td><em>increases or decreases sensitivity of small filters</em></td>
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**AUTOMATICITY**
- valid
- neutral

**FLEXIBILITY**

*Carrasco, Loula & Ho, 2006*
*Barbot & Carrasco, 2017*
covert attention helps overcome limitations of peripheral 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.
RF position and size changes can qualitatively account for behavioral effects in performance

- concentrating processing resources at attended location (shift)
  - population receptive fields (pRFs) shift towards attended area through-out the visual field and the visual system [Klein, Harvey & Dumoulin 2014]

- reducing the area of spatial integration (shrinkage)
  - decreased spatial overlap in BOLD responses for adjacent locations, narrowing of the population’s integration area [Fischer & Whitney 2009]
  - withdrawing attention from periphery results in larger pRFs and blurrier perceptual representation [de Haas et al. 2014]

- attention enhances the visual system’s effective spatial resolution

Anton-Erxleben & Carrasco, NRN 2013