(1) covert attention

(2) effects on contrast sensitivity
attention improves contrast sensitivity

Precue Trial

- Fixation: 1000 ms
- Cue: 50 ms
- ISI: 50 ms
- Display: 150 ms
- Response cue: 200 ms
- Feedback tone: 1750 ms
Sensitivity (1 / Threshold) vs. Spatial Frequency (cpd)
Campbell & Robson (68)

Sensitivity (1 / Threshold)

Spatial Frequency (cpd)

Contrast

sensitivity (1 / threshold)

Contrast

Spatial Frequency (cpd)
Campbell & Robson (68)

Sensitivity (1 / Threshold) -
Spatial Frequency (cpd) -
Contrast -

Contrast - sensitivity (1 / threshold) -
Spatial Frequency (cpd) -

Contrast -

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contrast -
sensitivity (1)
Carrasco, Penpeci & Eckstein, Vis.Res. 2000
Precue Trial

- Fixation: 1000 ms
- Cue: 50 ms
- ISI: 50 ms
- Display: 150 ms
- Response cue: 200 ms
- Feedback tone: 1750 ms
<table>
<thead>
<tr>
<th>Valid</th>
<th>Neutral</th>
<th>Invalid</th>
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<tbody>
<tr>
<td><img src="image1" alt="Valid Image" /></td>
<td><img src="image2" alt="Neutral Image" /></td>
<td><img src="image3" alt="Invalid Image" /></td>
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<tr>
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<td><img src="image5" alt="Neutral Image" /></td>
<td><img src="image6" alt="Invalid Image" /></td>
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<td><img src="image7" alt="Valid Image" /></td>
<td><img src="image8" alt="Neutral Image" /></td>
<td><img src="image9" alt="Invalid Image" /></td>
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</tbody>
</table>

*Pestilli & Carrasco, Vis. Res. 2005*
Contrast gain

\[ \text{response} = \frac{R_{\max} \ast (N \ast C^n)}{(N \ast C^n) + C50^n} + M \]

Response gain

\[ \text{response} = N \ast \frac{R_{\max} \ast C^n}{C^n + C50^n} + M \]
Endo and Exo protocol

- fixation: 400 ms
- precue
- transient: 40 ms, ISI: 60 ms
- sustained: 150 ms, ISI: 150 ms
- stimulus: 50 ms
- neutral
- response: 1000 ms
Endo: CG and Exo: RG

a. Sustained attention

Accuracy (%) vs. Contrast (%)

b. Transient attention

Accuracy (%) vs. Contrast (%)

Neutral
Cued
Attention and adaptation
Attention and adaptation
Attention and adaptation
Exogenous attention and adaptation

Attention: response gain

~ Ling & Carrasco, Vis. Res. 06

Adaptation: contrast gain

Benefit and cost are similar regardless of adaptation state

Attention overcomes adaptation and restores contrast sensitivity

Pestilli & Carrasco, JoV 07
fMRI indexes brain activity by measuring blood flow. Oxygenated blood flows to brain regions with more neuronal activity. The scanner picks up the different magnetic properties of oxygenated and deoxygennated hemoglobin.
retinotopic mapping
stimulus contrast

low → high
separate cue/stimulus (ROI)

size: 3°
eccentricity: 6°
separation: 1°
contrast: 100%
precue trial

postcue trial
Figures (a) and (b) illustrate the effects of cue condition on accuracy and reaction time, respectively. Accuracy is measured as the proportion of correct responses, while reaction time is given in milliseconds.

- **Figure (a): Accuracy**
  - V-Pre: 0.85
  - I-Pre: 0.78
  - V-Post: 0.70
  - I-Post: 0.65

- **Figure (b): Reaction time (ms)**
  - V-Pre: 820 ms
  - I-Pre: 800 ms
  - V-Post: 850 ms
  - I-Post: 870 ms

Significant differences are indicated by asterisks (*).
EXO attention concurrently increases performance and retinotopically specific stimulus-evoked activity

AMI = \( \text{Peak}_{\text{val-pre}} - \text{Peak}_{\text{baseline}} \) - \( \text{Peak}_{\text{val-pre}} + \text{Peak}_{\text{baseline}} \)

Liu, Pestilli & Carrasco, Neuron 2005
an uninformative peripheral precue concurrently increases performance and retinotopically specific stimulus-evoked activity in early visual areas

cueing effect increases gradually from V1 to V3a (feedback or feedforward?)

Liu, Pestilli & Carrasco, Neuron 2005
Contrast gain

Response gain

Normalized Response

Log Contrast

Attended
Ignored

Li & Basso, 2008
Martinez-Trujillo & Treue, 2002
Reynolds et al., 2000

McAdams & Maunsell, 1999

Williford & Maunsell, 2006
Contrast gain

Log Contrast

Performance (d')

Attended
Ignored

endogenous attention

Ling & Carrasco, 2006
Pestilli, Ling & Carrasco, 2009
Palmer & Moore, 2009

exogenous attention

Ling & Carrasco, 2006
Pestilli & Carrasco, 2005
Pestilli, Viera & Carrasco, 2007
Pestilli, Ling & Carrasco, 2009

Morrone, Dante & Spinelli, 2004
Huang & Dobkins, 2005
• responses of neurons are divided by a common factor that includes the summed activity of a pool of neurons

• NMA simulates neuronal and behavioral responses and identifies 2 key parameters—size of stimulus and attention field—and makes testable predictions: CG, RG or both

• attention multiplicatively enhances stimulus evoked responses (~stimulus contrast) before normalization

_Reynolds & Heeger, Neuron 2009_
normalization model of attention

Carandini & Heeger, NRN 2011
after Reynolds & Heeger, Neuron 2009
stimulus size and attention field size

Contrast gain

Response gain

Reynolds & Heeger, Neuron 2009
Normalization model of attention

- Exogenous attention
  - Uninformative cues
  - Time (ms)
  - Pre-cue (60)
  - ISI (40)
  - Stimuli (30)
  - Interval (200)
  - Response cue (100)
  - ITI (1050-1550)

- Endogenous attention
  - Informative cues
  - Time (ms)
  - Pre-cue (250)
  - ISI (250)
  - Stimuli (50)
  - Interval (100)
  - Response cue (200)
  - ITI (1250-1500)

large stimulus and small attention field: RG
EXO - large stimulus and small attention field: RG

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

- n=4
- 6K trials / observer
- \( R^2 \geq 0.98 \)

Valid
Neutral
Invalid

\[ d'_{\text{max}} \quad p < 0.05 \]
ENDO - large stimulus and small attention field: RG

Performance (d')

Valid
Neutral
Invalid

Contrast (%)

Contrast (%%)

\[ d'_\text{max} \leq 0.05 \]

\[ R^2 \geq 0.97 \]

n=4
6K trials / observer
small stimulus and large attention field: CG
ENDO - small stimulus and large attention field: CG

Performance ($d'$)

Valid
Neutral
Invalid

Contrast (%)

$d'_{\text{max}}$ n. s.

$c_{50} \ p < .05$

$n=4$

6K trials / observer

$R^2 \geq .98$
EXO - small stimulus and large attention field: CG

Valid
Neutral
Invalid

Performance ($d''$)

Contrast (%)

$c_{50}$ $p < .05$

$d'_{\text{max}}$ n. s.

$n=4$

6K trials / observer

$R^2 \geq .98$
attention effects (f) of stimulus size and attention field size

Exogenous

Endogenous

Mean across 4 observers

Valid Neutral Invalid

Performance (d')

Contrast (%)

Valid Neutral Invalid

Performance (d')

Contrast (%)

c_{50} n. s.

d'_{max} p \leq .05

c_{50} p < .05

d'_{max} n. s.
fMRI protocol to measure the attention field

- Fixation (250 ms)
- Pre-cue (250 ms)
- ISI (1,250 ms)
- Stimuli (50 ms)
- Response (1,000 ms)
- ITI (3,200-6,800 ms)

2 AFC orientation-discrimination task
fMRI protocol to measure the attention field

Attention field size depends on location uncertainty:

- Spread of cortical activity in V1
- For 9/10 hemispheres spread uncertainty > no uncertainty

empirical support for the NMA

- EXO and ENDO attention enhance performance, consistent with CG or RG, depending on the relative size of the attention field and the stimulus

- spatial uncertainty manipulation is effective: attention field is larger with than without uncertainty

- attention multiplies stimulus-evoked activity before normalization

2nd order – orientation discrimination task

attention and 2\textsuperscript{nd} order contrast
EXO attention                   ENDO attention


Does attention intensify the sensory impression?

YES.

Wundt, Helmholtz, Mach & Titchener

James

NO.

Fechner

“The subject is one which well repay exact experiment, if methods could be devised”
What is the orientation of the higher contrast stimulus?
stimuli

standard: 6 or 22%; 2 or 4 cpd

test: 2-80%; 2 or 4 cpd
EXO attention increases perceived contrast

Carrasco, Ling & Read, Nature Neurosci, 2004
EXO attention increases perceived contrast

Carrasco, Ling & Read, Nature Neurosci 2004
ENDO attention and perceived contrast

attention increases perceived contrast
what neural responses underlie apparent contrast increase?

contrast gain

Li & Basso 2008
Martinez-Trujillo & Treue 2002

response gain

McAdams & Maunsell 1999
Martinez-Trujillo & Treue 2002

input baseline

Luck et al. 1997
Reynolds et al. 2000

Cutrone, Heeger & Carrasco, JoV 2014
perceived contrast increases via baseline increase

Cutrone, Heeger & Carrasco, JoV 2014
covert attention increases contrast sensitivity

- increases contrast sensitivity
  - 1\textsuperscript{st} order
  - 2\textsuperscript{nd} order

- affects appearance

- behavior improvement correlates with an increase in fMRI signal in striate and extrastriate cortical areas

- changes in performance and appearance consistent with normalization model of attention