Orientation-selective adaptation to first- and second-order patterns in human visual cortex

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What are first- and second-order patterns?

- **First-order**: vary in luminance; can be detected by linear filters
- **Second-order**: do **not** vary in luminance; **cannot** be detected by linear filters
Filter-rectify-filter (FRF) model of second-order vision

First stage: many small-scale linear filters
Rectify output of first stage filters
Second stage: Sum rectified output with large-scale linear filter

Predicts separate mechanisms for first- and second-order vision
Separate mechanisms?

- **Psychophysics**: different mechanisms for first- and second-order vision

- **Electrophysiology**: first-order neurons as early as V1; second-order neurons in extrastriate visual cortex of cats (area 18) and macaques (V2, V4, V5/MT)

- But many second-order neurons also selective for first-order patterns (cue invariance) - not predicted by FRF

- **Neuroimaging**: anatomical segregation of first- and second-order vision in humans? conflicting results
Open questions

• Anatomical segregation? Are any human visual areas *specialized* for first- or second-order vision?

• Multiple second-order mechanisms? Are *different* types of second-order patterns (contrast, orientation) processed by the *same* mechanism?

• Cue-invariance? Are there neurons that respond *both* to first- and second-order patterns?
Approach

• Adapt orientation-selective neurons
• Measure responses to adapted & orthogonal stimulus orientation with fMRI
• Event-related design
• Use independently identified visual area ROIs
Stimulus conditions

LM:LM
First-order luminance

CM:CM
Second-order contrast
Second-order orientation

OM:OM
Second-order orientation

LM:OM
First-order luminance

Cross-modal

Unimodal
## Trial types

<table>
<thead>
<tr>
<th>Trial types</th>
<th>Adapter orientation</th>
<th>Probe orientation</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Parallel trials</strong></td>
<td><img src="image" alt="Parallel Adapter" /></td>
<td><img src="image" alt="Parallel Probe" /></td>
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<tr>
<td><strong>Orthogonal trials</strong></td>
<td><img src="image" alt="Orthogonal Adapter" /></td>
<td><img src="image" alt="Orthogonal Probe" /></td>
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<tr>
<td><strong>Blank trials</strong></td>
<td><img src="image" alt="Blank Adapter" /></td>
<td>blank screen</td>
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</table>
Trial structure

Unattended perifoveal stimulus (1.5-5 deg)

Adapter 4 s
ISI 1 s
Probe 1 s

Total trial length: 7.2 s
fMRI methods

- 3 subjects
- 8 scanning sessions per subject
- 280 trials per stimulus condition and trial type
- Siemens Allegra 3T, quadrature surface coil
- BOLD EPI, 19 slices perpendicular to calcarine sulcus, TR=1.2s, TE=30ms, FA=75
- Bite bar & motion correction with FSL
Visual area ROIs

- **V1**
- **V2**
- **V3**
- **V3A**
- **V7**
- **hV4**
- **VO1**
- **LO1/LO1**
- **LO2**
- **V5/MT**
- **pLOC**

Orientation markers:
- dorsal
- lateral
- medial
- ventral

Scale: 1 cm
Results:
Unimodal adaptation - first-order (LM:LM)
Orientation-selective adaptation to first-order patterns in V1

**Response amplitude (A):**

$$\bar{R} = \frac{1}{N} \sum_{i=1}^{N} R_i$$

$$A_i = \frac{R_i \cdot \bar{R}}{||\bar{R}||}$$
Adaptation to first-order patterns: luminance (LM:LM)

Adaptation index:

$$I_A = \frac{A_\perp - A_\parallel}{|A_\perp| + |A_\parallel|}$$
Adaptation indices: first-order patterns (LM:LM)

- Adaptation indices constant across visual areas
- No significant differences between V1 and extrastriate visual areas
- Adaptation in V1 can account for adaptation in extrastriate visual areas
Results:
Unimodal adaptation - second-order
(CM:CM & OM:OM)
Adaptation to second-order patterns: contrast (CM:CM)
Adaptation to second-order patterns: orientation (OM:OM)
Adaptation indices: second-order patterns (CM:CM & OM:OM)

- Adaptation indices greater in extrastriate areas than in V1
- Suggests additional adaptation in extrastriate visual cortex
Cue invariance?
Cross-modal adaptation (LM:OM)
No consistent cross-adaptation between first- and second-order patterns (LM:OM)
Conclusions

• Results consistent with FRF model

• First-order neurons in V1

• FRF second-stage neurons both in V1 and extrastriate areas (feedback to V1?)

• Different second-order patterns processed in same visual areas

• No evidence of cue-invariant neurons

• Selective attention is not required for first- or second-order pattern adaptation
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