Functional organization of human visual areas following lesions of the primary visual cortex

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Introduction (1/2)

- Visual cortex is retinotopically specific

- V1 damage: common visual cortical injury
  - Occurs most often as a result of stroke
  - Loss of conscious vision in the affected region of the contralateral visual hemifield (scotoma)
  - No accepted treatment options for people with visual cortical damage
Understanding brain repair processes is important in order to design treatments aimed at enhancing the ability of the nervous system to recover after injury.

Important to study in detail how the adult human brain reorganizes after injury.
To study the organization of the visual cortex in patients with post-chiasmatich lesions suffering from homonymous visual field defects

1. How does the organization of the spared primary visual cortex change following partial V1 damage?

2. How does the organization of higher visual areas (hV5/MT+) change following V1 damage?
   - How responses of the visual cortex are affected by simulated visual field scotomas in healthy subjects?
Methods

- 5 patients with quadrantanopia
- fMRI measurements during the presentation of a moving bar stimulus (square-checkerboard bars; 100% contrast; width: 1.875°, moving step: 0.9375° each TR (2s); 8 directions; visual field radius: 11.35°)

- Fixation + eyetracking
- 5 control subjects
- Artificial scotoma condition (or AS)
Population Receptive Field model (pRF)

pRF model:  (Dumoulin and Wandell, NeuroImage, 2008)
Patients

- **P1**: A patient with partial V1 lesion in the right hemisphere resulting in left quadrantanopia

- **P2**: A patient with a right superior quadrant defect from a temporal optic radiation infarct on the left hemisphere

- **P3**: A patient with a right superior quadrant defect following a lesion of the left inferior calcarine cortex
Retinotopic Mapping

- Retinotopic organization similar to controls

- V1 activity in locations corresponding to the visual field scotoma
Visual Field Coverage of spared V1

Visual Field Test

AS

Humphrey Pattern Deviation

Visual Field Coverage

Normalized  Non-normalized

Control with AS

P1 Right V1

P2 Left V1

P4 Left V1

Normalized  Non-Normalized

Left V2v

Normalized  Non-Normalized

Left V2d

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pRF center location distributions

Normalized Number of Voxels

Elevation (deg)

Normalized Number of Voxels

Elevation (deg)

Patient

AS Controls

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**pRF size**

Near the scotoma border

Away from the scotoma border
Part 1 – Conclusions

1. We observed no large-scale changes in the spared-V1 topography of 5 patients with partial V1 or optic radiation lesions.

2. A limited degree of reorganization
   - The distribution of pRF centers in spared V1 shifted slightly towards the scotoma border.
   - pRF size in spared V1 increased slightly near the scotoma border.

3. The visual field coverage maps of the spared V1 area do not generally match exactly the area of the dense perimetric scotoma
   - pRF maps overlap significantly with dense regions of the perimetric scotoma.
   - pRF maps failed to cover seeing locations in the perimetric map.

4. pRF mapping provides information about the functional properties of spared visual cortex complementary to that provided by standard visual field perimetry maps and may help identify visual field locations that have higher potential for rehabilitation.

(Papanikolaou et al., PNAS, 2014)
Aim

To study the organization of the visual cortex in patients with post-chiasmatic lesions suffering from homonymous visual field defects

1. How does the organization of the spared primary visual cortex change following partial V1 damage?

2. How does the organization of higher visual areas (hV5/MT+) change following V1 damage?
   - How responses of the visual cortex are affected by simulated visual field scotomas in healthy subjects.
Population Receptive Field (pRF) Topography

- Detailed pRF structure – Ideal for studies of pRF reorganization
- Reliable pRF eccentricity estimates
- Improved pRF center localization near the stimulus border

(Lee, Papanikolaou et al., NeuroImage, 2013)
hV5/MT+ in AS subjects

- 5 healthy subjects
- Only ~15% of voxels become unresponsive under the AS stimulus
- pRF shifts
LAS model

- Liner-AS (LAS) model: pRF linear expectations arising by the lack of stimulation inside the AS region

**Artificial Scotoma (AS) stimulation modeled with the AS stimulus**

For each voxel

- Stimulus protocol $AS(x,y,t)$
- Stimulus presentation
- $pRF$ vector $p(x,y)$
- HRF: $h(t)$
- Solve for $p$
- $d(t) = h(t) * S(t)p$

**LAS model**

For each voxel

- Stimulus protocol $AS(x,y,t)$
- Stimulus presentation
- $pRF$ topography derived from full field stimulation
- $AS$ stimulus
- Generated BOLD signal $d(t)$
- Solve for $p$
- $d(t) = h(t) * S(t)p$
pRF Topography in AS subjects

FF stimulus

LAS model

AS stimulus

Voxel Topography

Voxel pRF
Visual Field Coverage of hV5/MT+ in AS subjects

FF Stimulus  LAS model  AS stimulus

Right hV5/MT+

Right V1

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pRF changes under the AS

Inferior Quadrant

Superior Quadrant

pRF size (% change)

Fraction of voxels

Elevation (deg)

pRF Amplitude - Inferior Quadrant

pRF Amplitude - within 1° from AS

Distance from the AS-border (Elevation, deg)

Eccentricity (deg)
AS modeled with the full field stimulus

AS stimulation modeled with the FF stimulus

Stimulus presentation

For each voxel

\[ pRF \text{ vector } \]

\[ p(x,y) \]

Solve for \( p \)

\[ d(t) = h(t) \ast S(t)p \]

BOLD signal change (%)

-10 -8 -6 -4 -2 0 2 4 6 8 10

0 0.5 1 1.5

Elevation (deg)

Azimuth (deg)

Eyemovements

Top to Bottom

Bottom to Top
Mapping the pRF border

For each voxel

BOLD signal

HRF: $h(t)$

fft deconvolution

Deconvolved signal

baseline

Top to Bottom

Left to Right

Bottom to Top

Right to Left

Elevation (deg)

Azimuth (deg)

BOLD signal change (%)
hV5/MT+ Coverage in Patients

- Visual field coverage maps of hV5/MT+ overlap with the scotoma
- Regions overlapping with the scotoma covered by both hV5/MT+ and V1
- Regions overlapping with the scotoma covered by hV5/MT+ but not V1 – V1 by-passing pathways
Part 2 – Conclusions

1. pRF estimates in area hV5/MT+ of healthy subjects are nonlinearly affected by a truncated stimulus presented (AS) that simulates a quadrantanopic visual field scotoma
   - pRF centers shift towards the border of the AS, pRF size decreases, pRF amplitude increases near the AS border

2. Erroneous pRF estimates are found inside the area corresponding to the AS, when we used the full bar stimulus model for predicting the pRF topography
   - Due to asymmetric BOLD responses occurring when the stimulus moves from seeing to non-seeing locations of the visual field

3. Area hV5/MT+ in the lesioned hemisphere of patients can still be modulated from visual field locations inside the scotoma
   - In some subjects hV5/MT+ arises in the absence of corresponding area V1 activity suggesting the existence of functional V1-bypassing pathways

4. Area hV5/MT+ activation, even if accompanied by activity in corresponding parts of V1, is not necessarily sufficient to guarantee conscious visual perception, suggesting that the fine coordination of activity patterns across visual areas is an important determinant of whether visual perception persists following lesions of the visual system

(Papanikolaou et al., NeuroImage, 2015)
Ongoing and future research

- Sensitivity of visual areas to motion coherence: Random Dot Kinematograms (RDK)

- Visual rehabilitation training (Huxlin et al., 2007)

- Does rehabilitative training increases the degree of reorganization?

- Visual system rehabilitation using the combination of pRF mapping and real-time fMRI neuro-feedback methods (Papageorgiou et al., 2014)
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Thank you! Questions?


A Papanikolaou, GA Keliris, S Lee, NK Logothetis, and SM Smirnakis. Nonlinear population receptive field changes in human area V5/MT+ of healthy subjects with simulated visual field scotomas; NeuroImage, 2015