# Spatial and temporal integration of binocular disparities in the primate brain

Yseult Héjja-Brichard

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***Jury***

*Claire Wardak Univ. de Tours*

*Peter Janssen KU Leuven*

*Kristine Krug Uni. of Oxford*

*Jean-Marc Devaud Univ. Paul Sabatier*

# Context of the thesis

**Horizontal binocular disparities**

# Key ingredients for stereopsis

- Binocular overlap
- Good visual acuity in both eyes
- Accurate coordination between the eyes in all gaze directions
- Ability of the brain to fuse two slightly different retinal images


*Héjja-Brichard Y & Cottereau BR. Parlons Science – Muséum de Toulouse*

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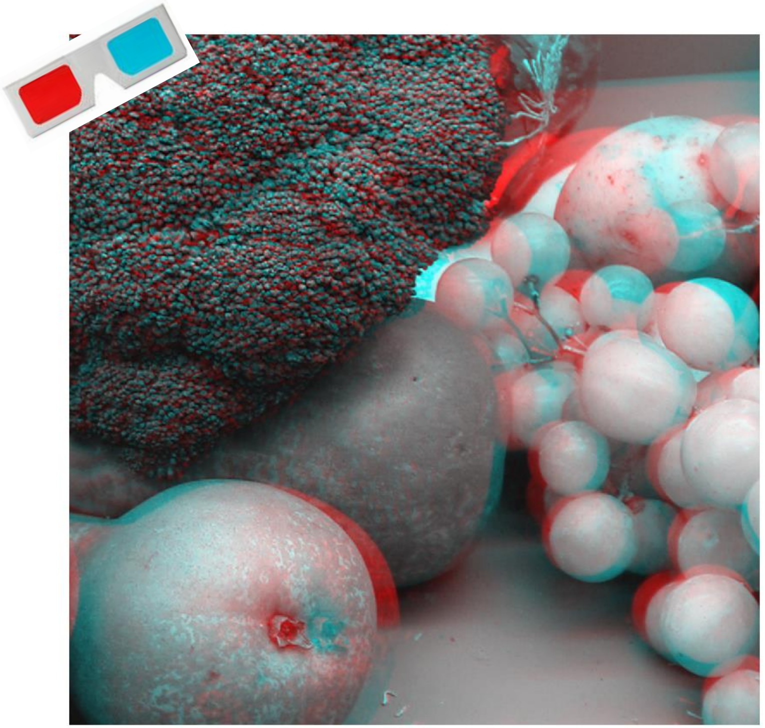
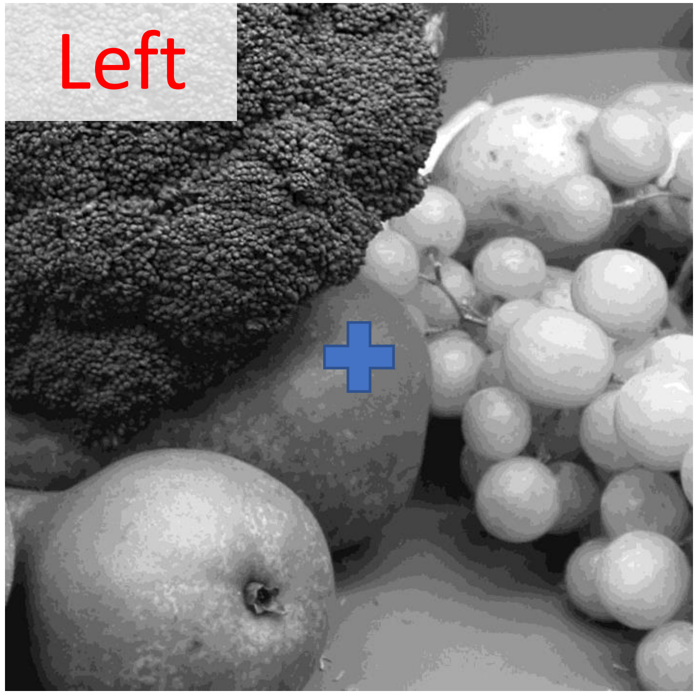
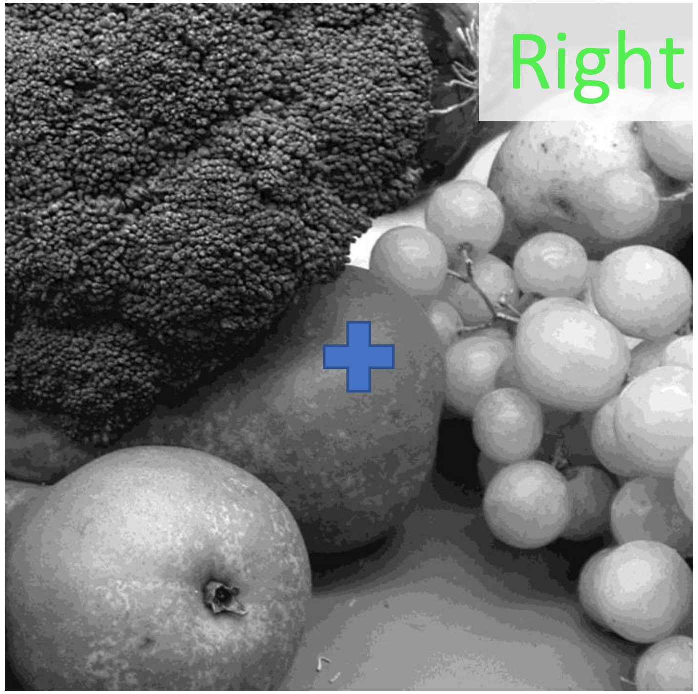
***Horizontal binocular disparities***

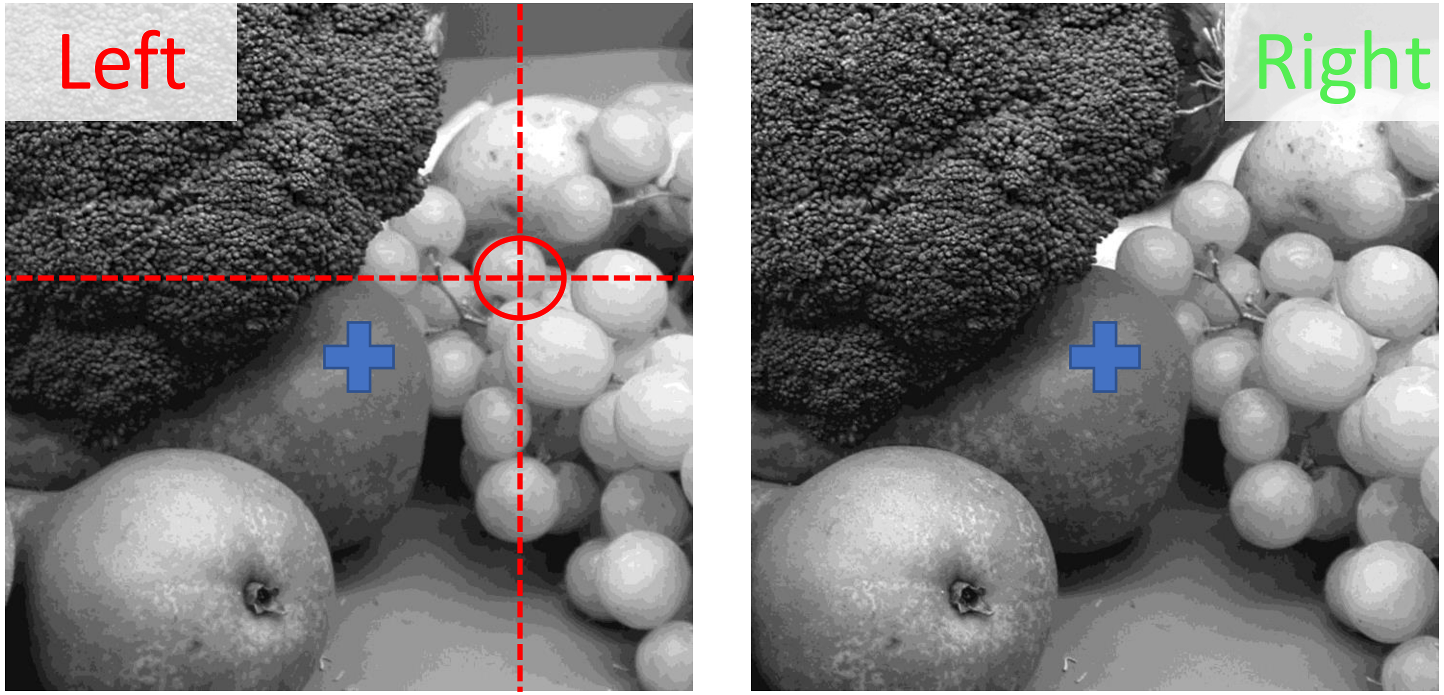


# Horizontal binocular disparities



# Horizontal binocular disparities



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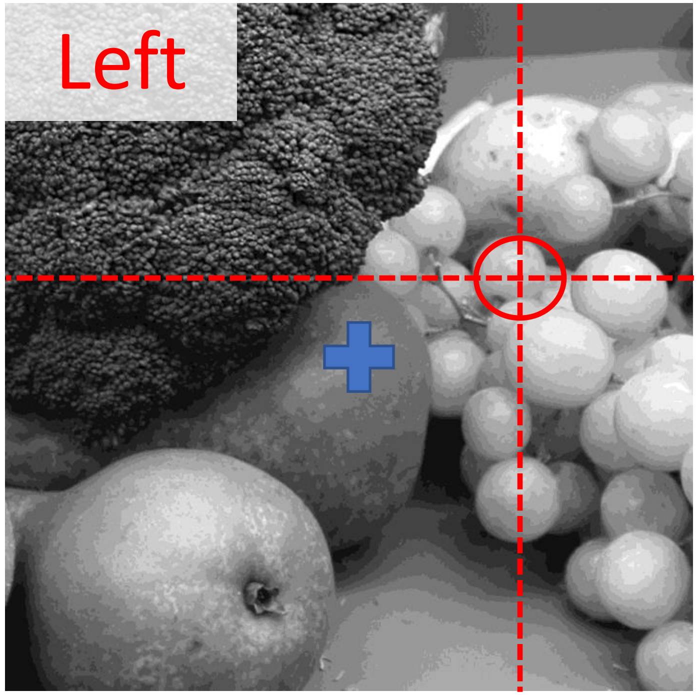


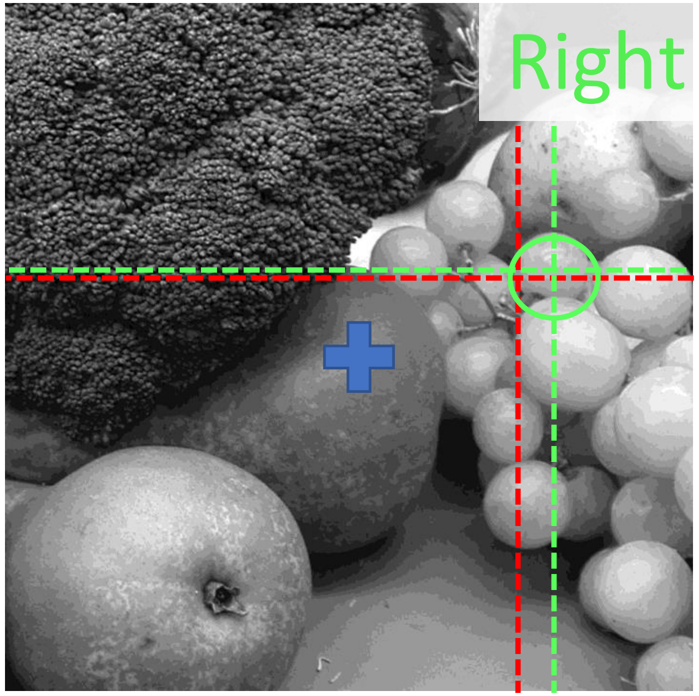

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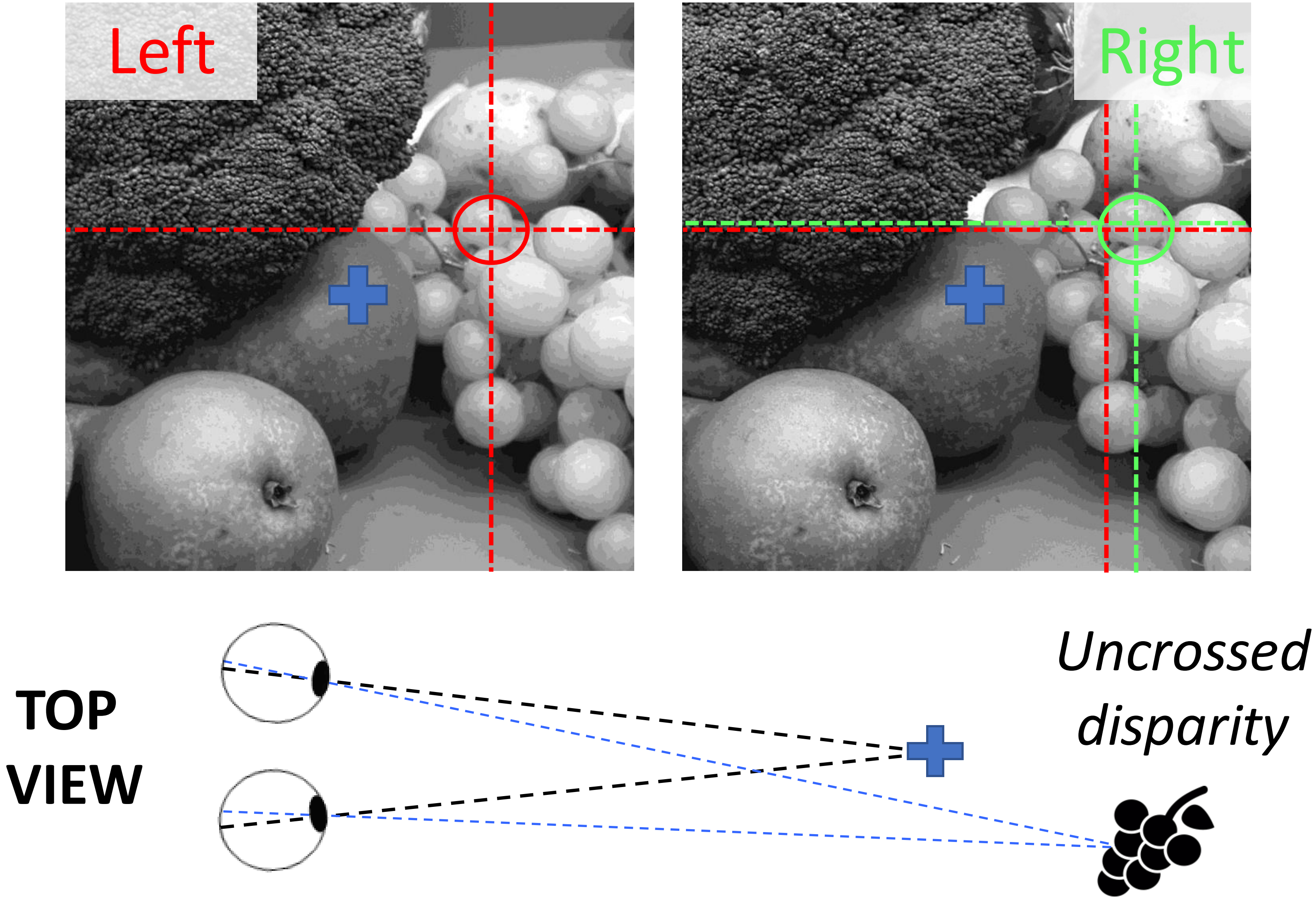

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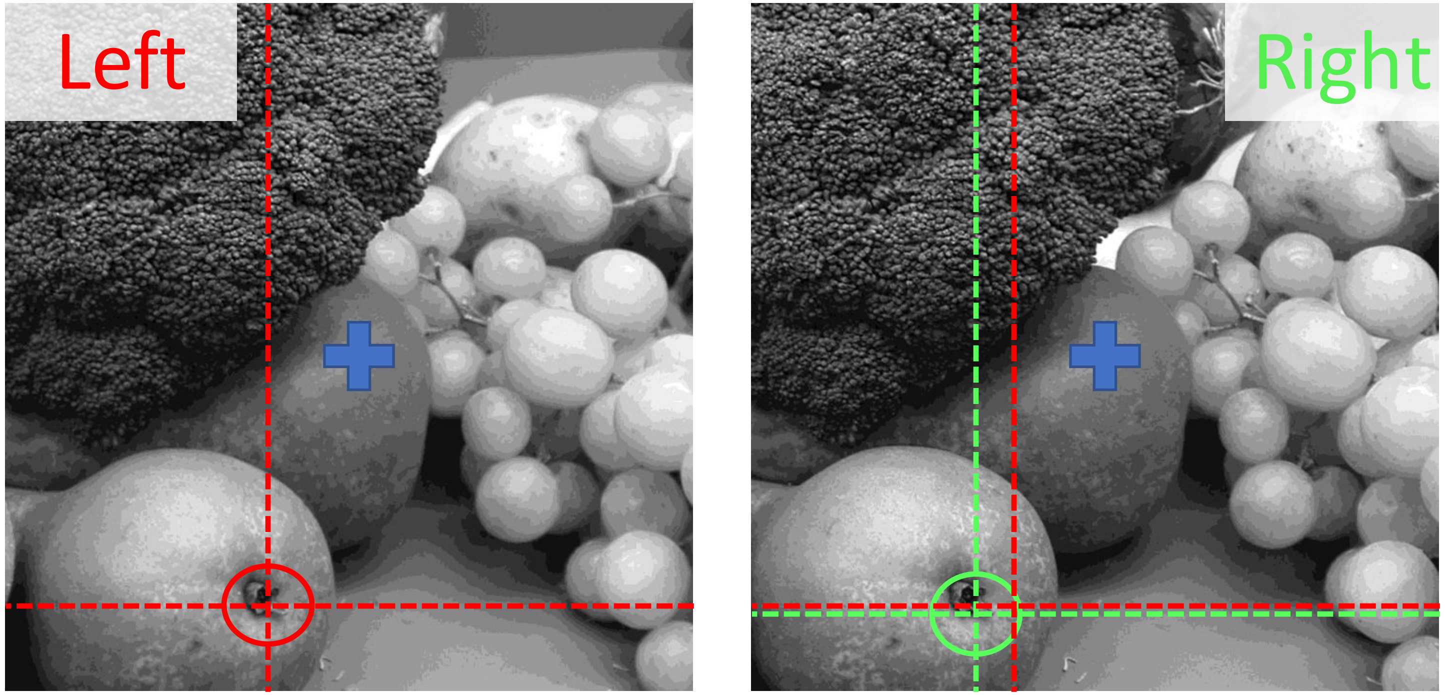
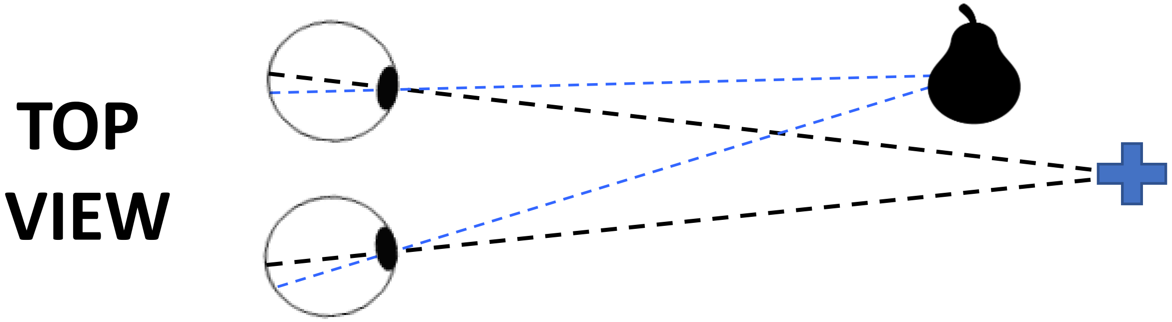
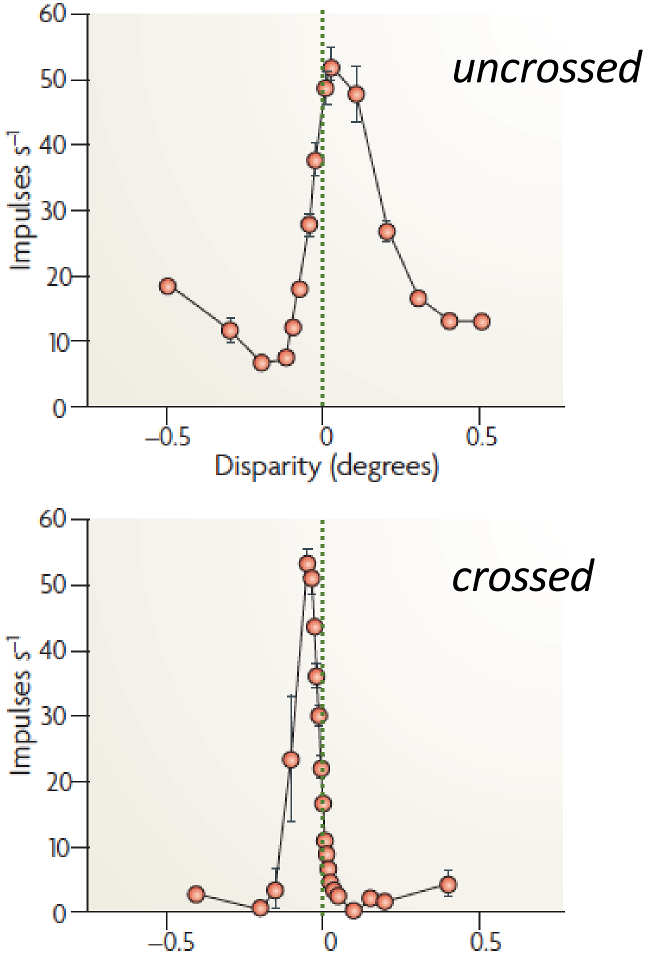



*Crossed Disparity*

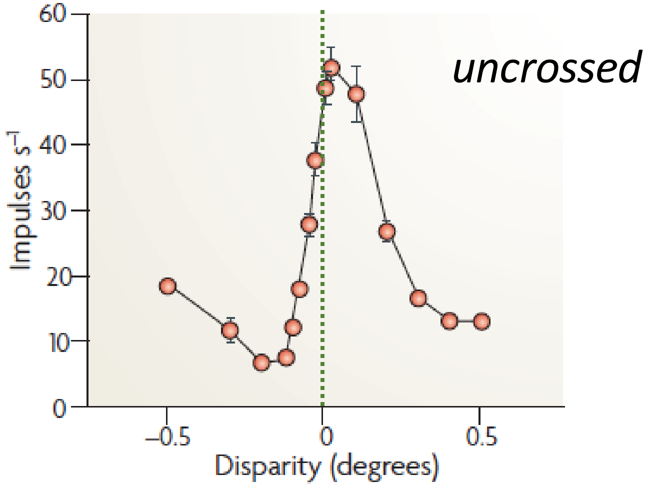
# Integration of binocular disparities

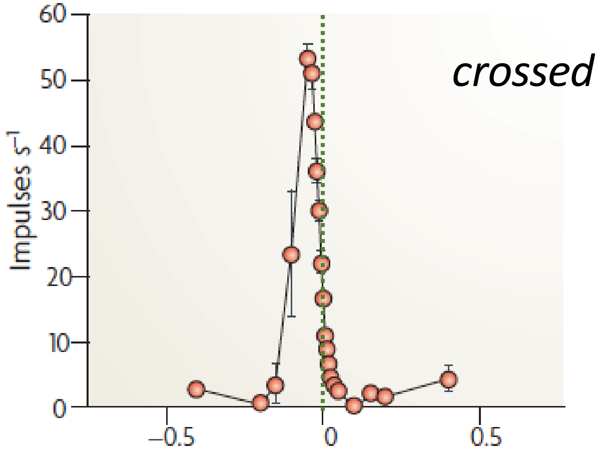




*Parker, 2007*

# Integration of binocular disparities

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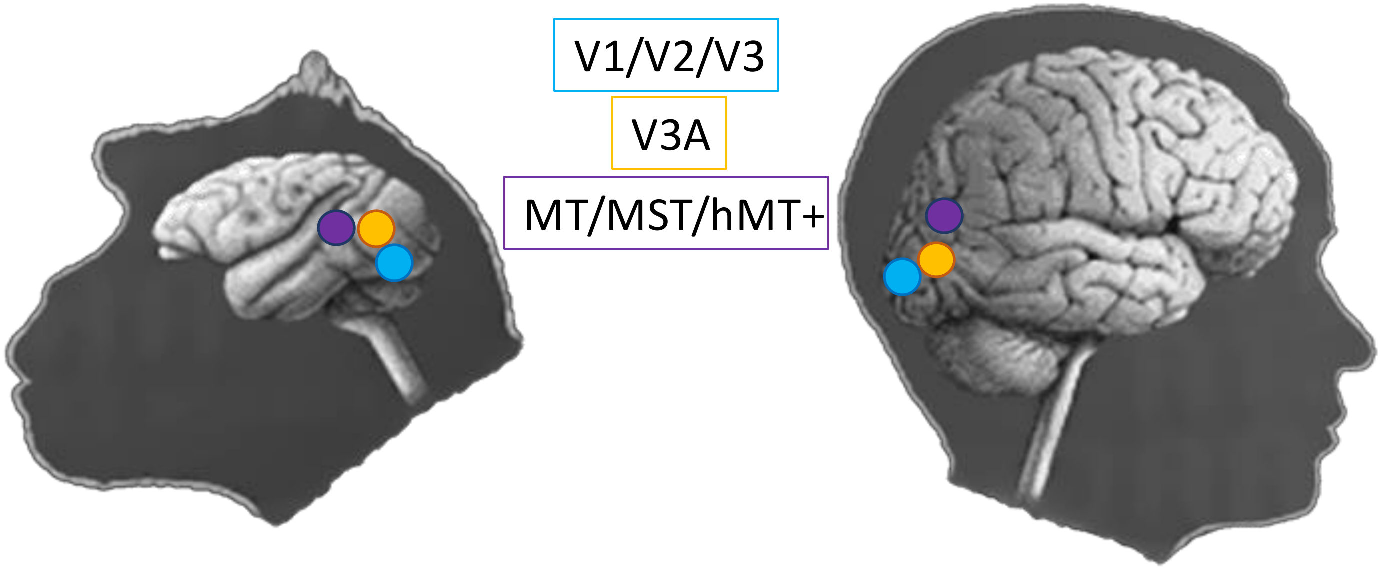
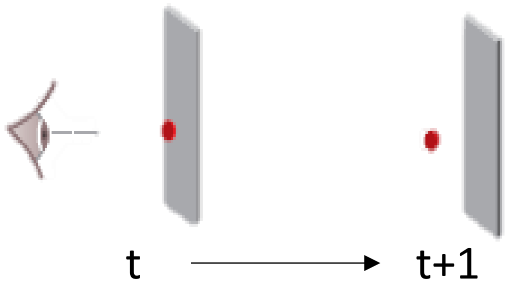


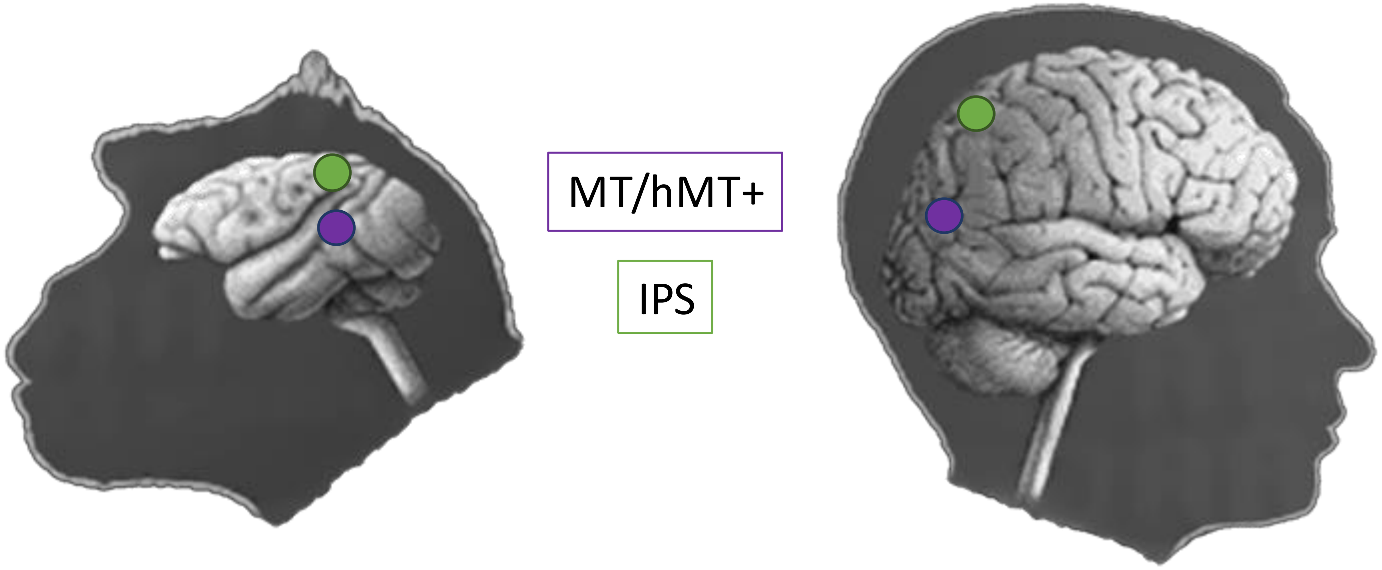

# in most visual areas

*E.g.: Hubel & Wiesel, 1970; DeAngelis et al., 1998; Janssen et al., 1999; Uka et al., 2000; Taira et al., 2000; Hinkle & Connor, 2001; Tsao et al., 2003; Durand et al., 2009; Likova and Tyler, 2007; Rokers et al., 2009; Sanaka & DeAngelis, 2014; Czuba et al., 2014; Kaestner et al., 2019*

# Integration of binocular disparities

*Temporal gradients*

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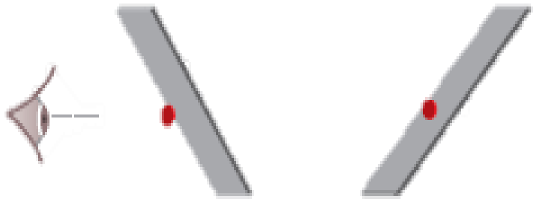
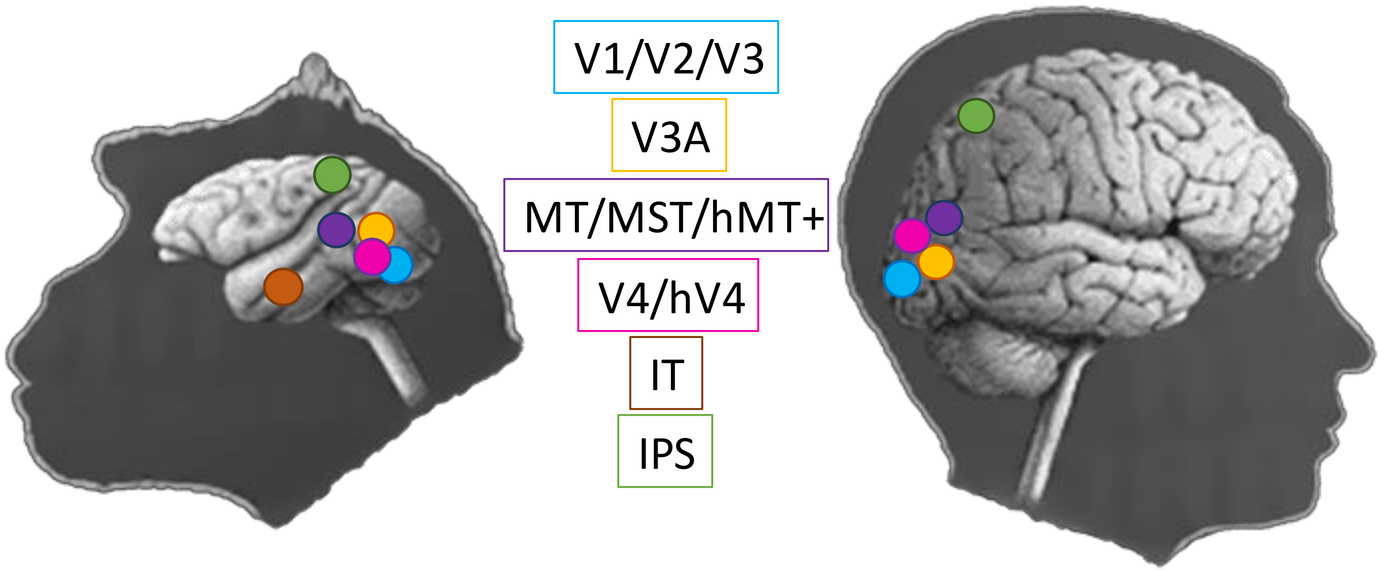
# Integration of binocular disparities

*Spatial gradients*



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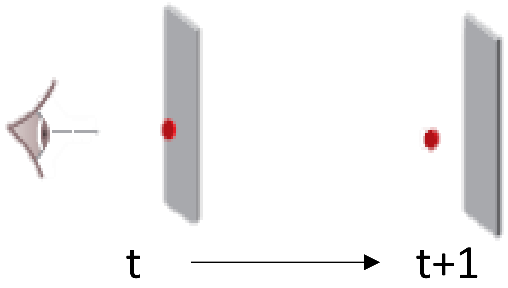


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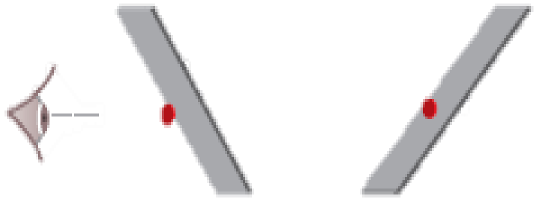

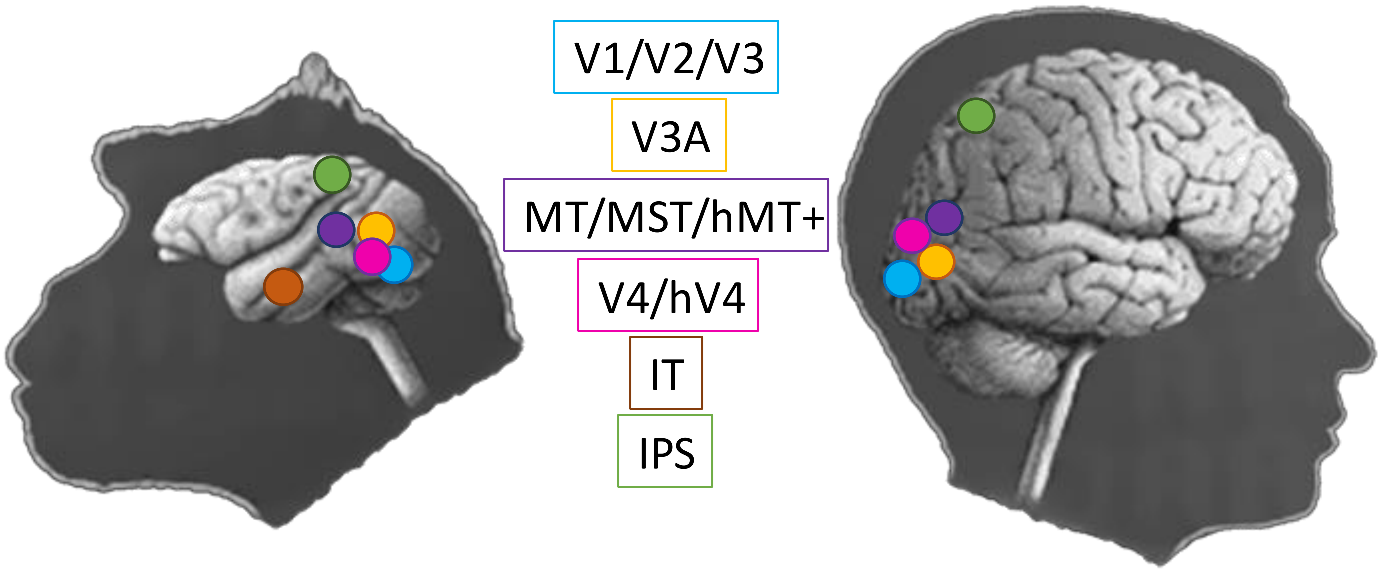


in most visual areas

*Orban, 2011*

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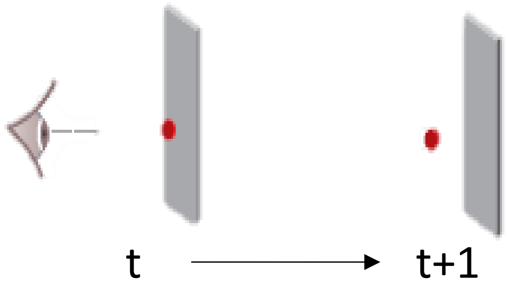
# Aims of the thesis

*Temporal gradients*

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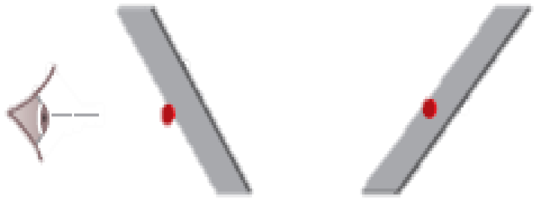


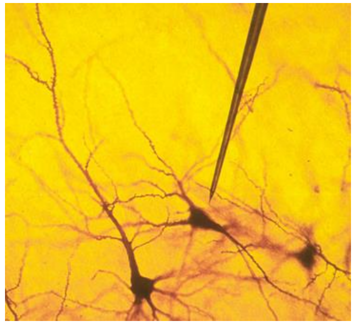
- Temporal integration of binocular disparities
  - →Barely studied: Main focus on 2D motion but some differences might exist

- Spatial integration of binocular disparities
  - →Influence of natural statistics
  - →Link with perception?

# Monkey fMRI

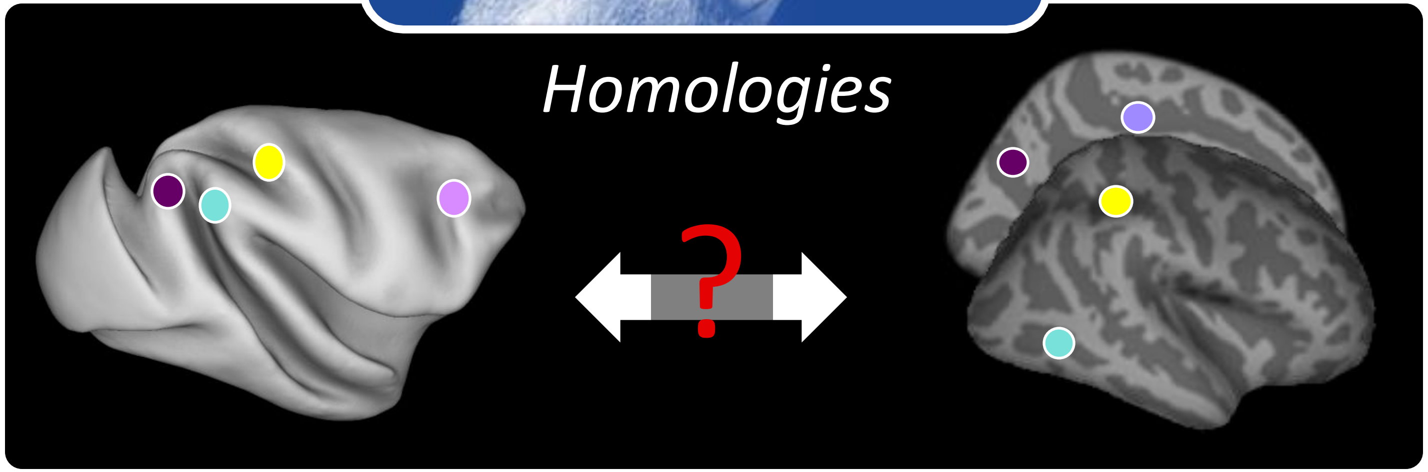
Methodological developments

# Monkey fMRI



*electrophysiology*

*fMRI*



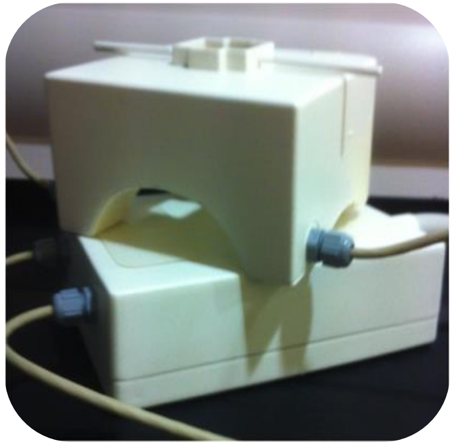

*Vanduffel et al., 2001*

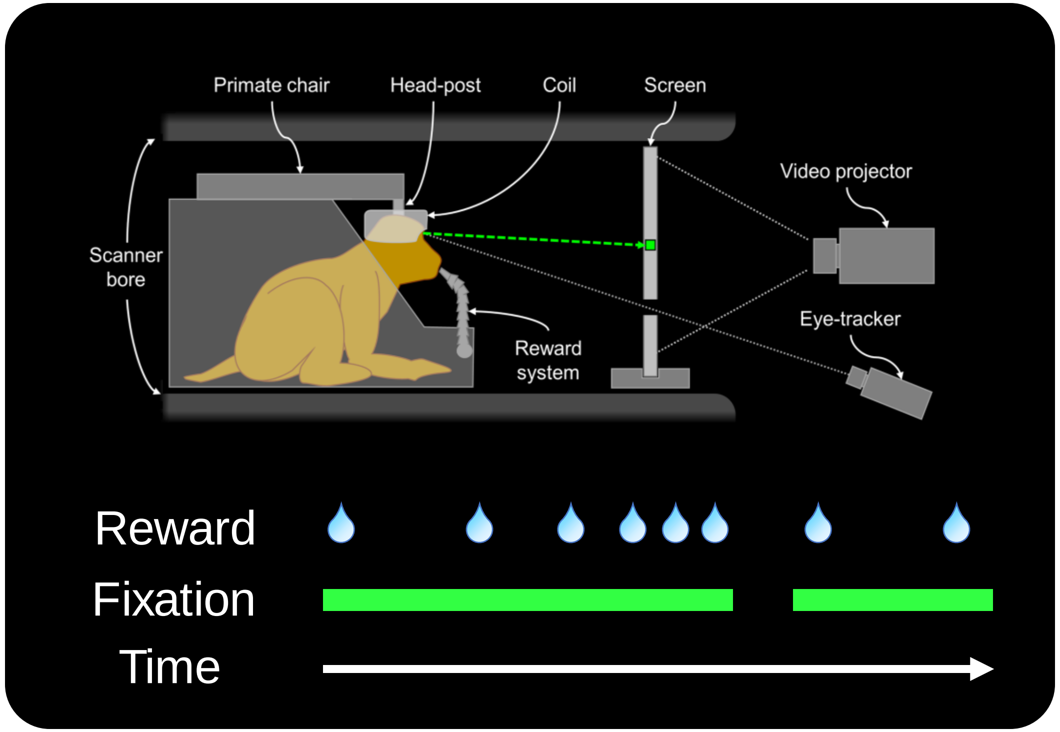
# Monkey fMRI: Development

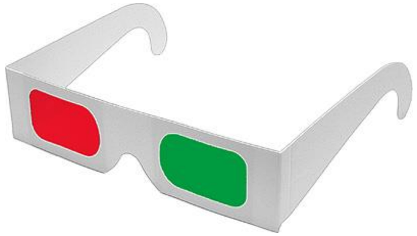
Macaque conditioning

Experimental setup

Pre-processing and data analysis





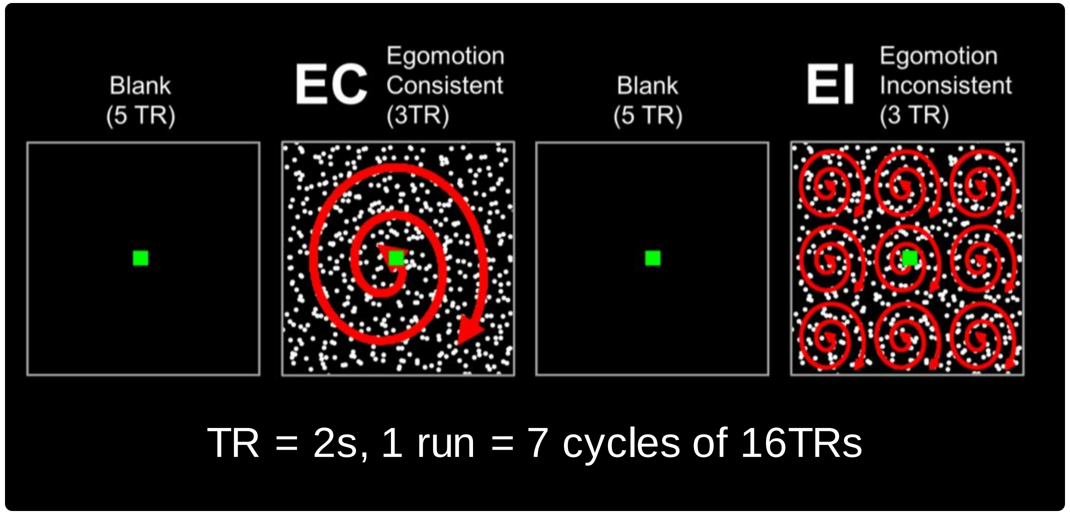



# The very first study: Optic flow processing

ORIGINAL ARTICLE

**Processing of Egomotion-Consistent Optic Flow in the Rhesus Macaque Cortex**

Benoit R. Cottereau[1,2], Andrew T. Smith[3], Samy Rima[1,2], Denis Fize[4], Yseult Héjja-Brichard[1,2], Luc Renaud[5,6], Camille Lejards[1,2], Nathalie Vayssière[1,2], Yves Trotter[1,2] and Jean-Baptiste Durand[1,2]



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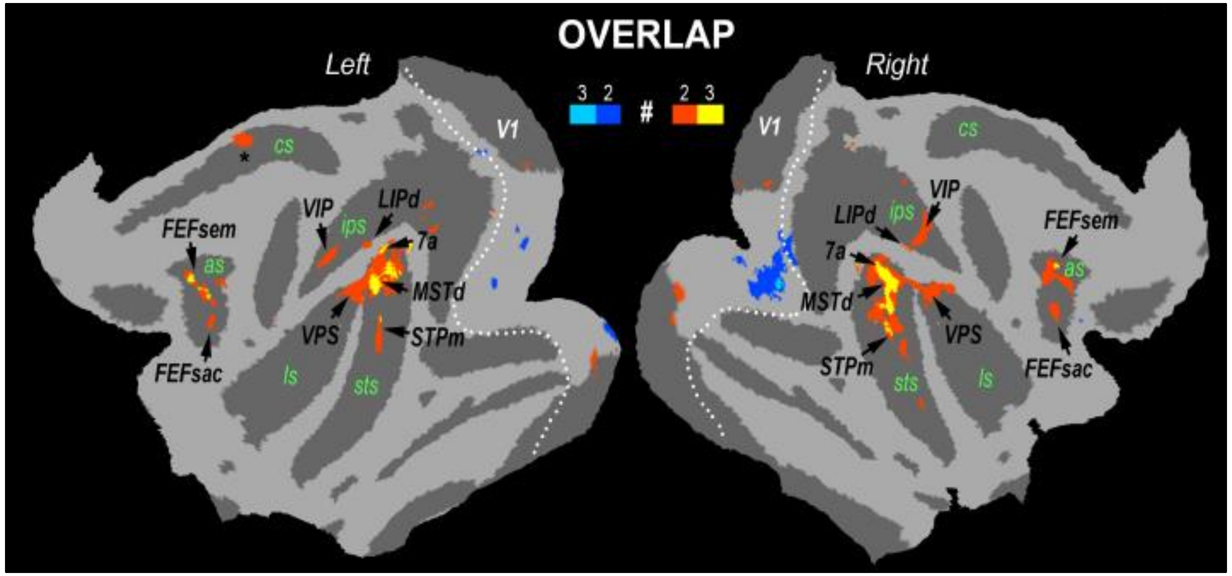

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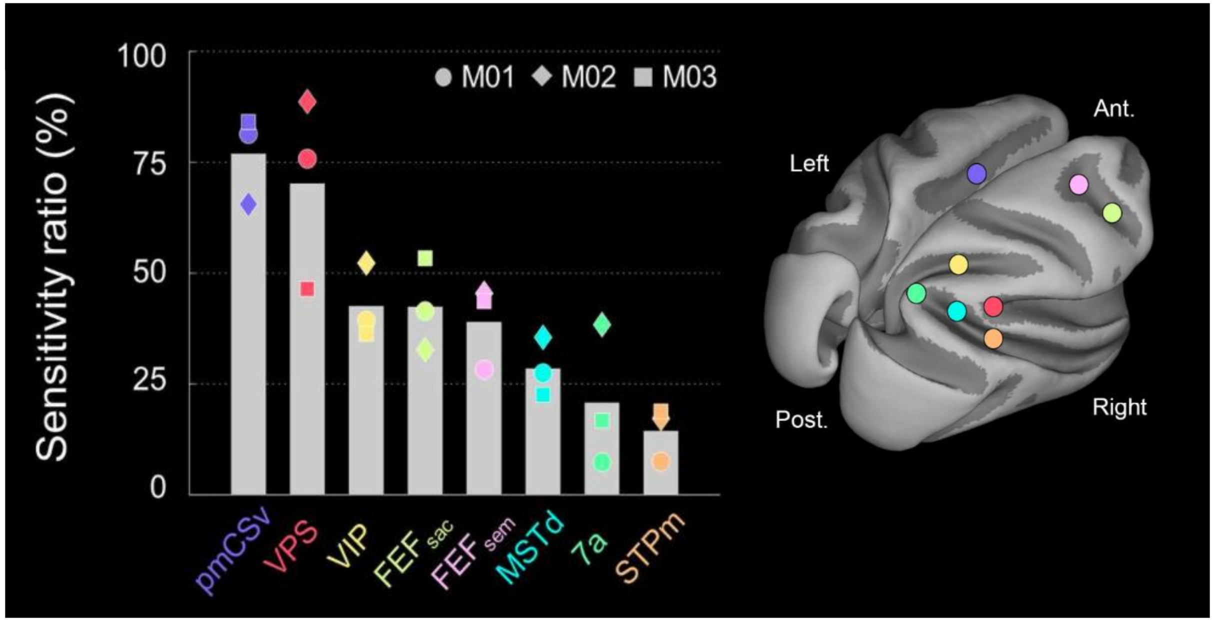

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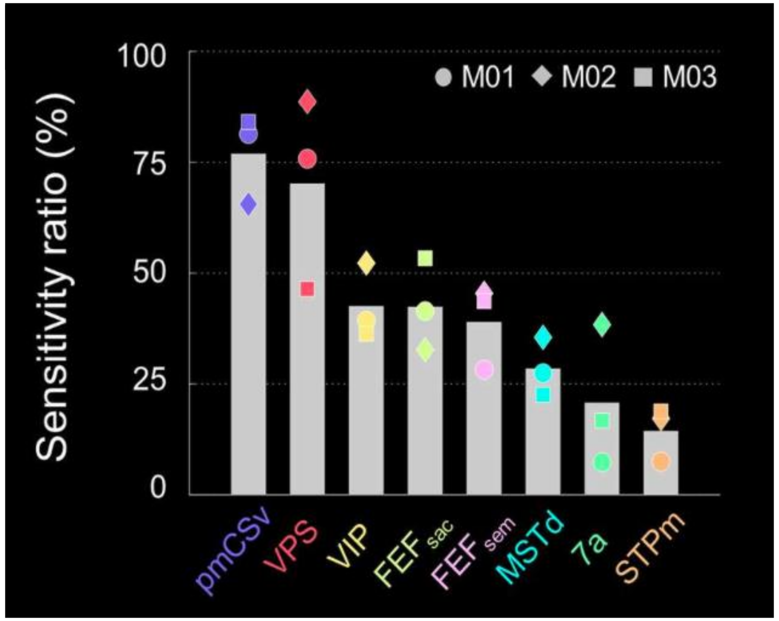
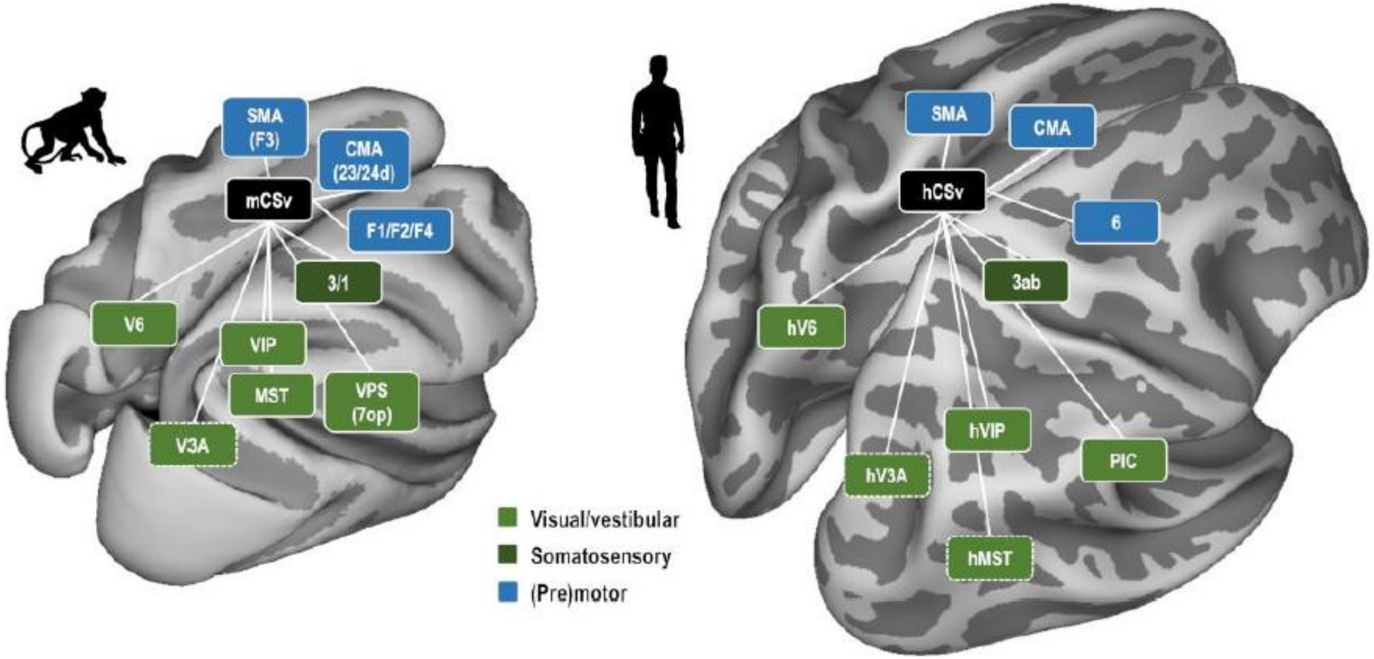
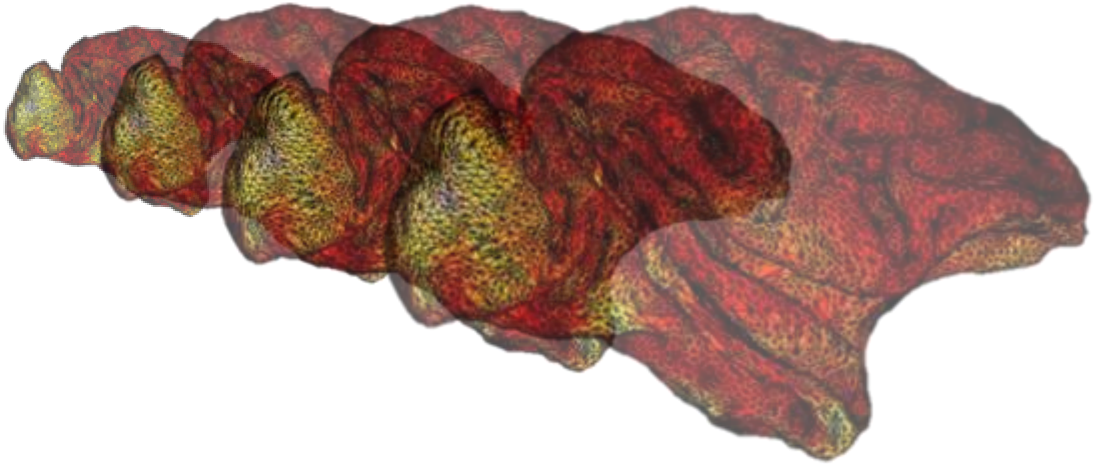



Connectivity analyses




*De Castro et al., in revision*



# Stereomotion

**Stereomotion processing in the non-human primate brain**

*Héjja-Brichard, Y., Rima, S., Rapha, E., Durand, J.-B., Cottereau, B.R. (2020)*

# 2D vs 3D motion

- 2D motion has been widely studied in MT/hMT+

  *Huk & Heeger, 2002; Maunsell & Newton, 1987*

- Much less is known about 3D motion processing

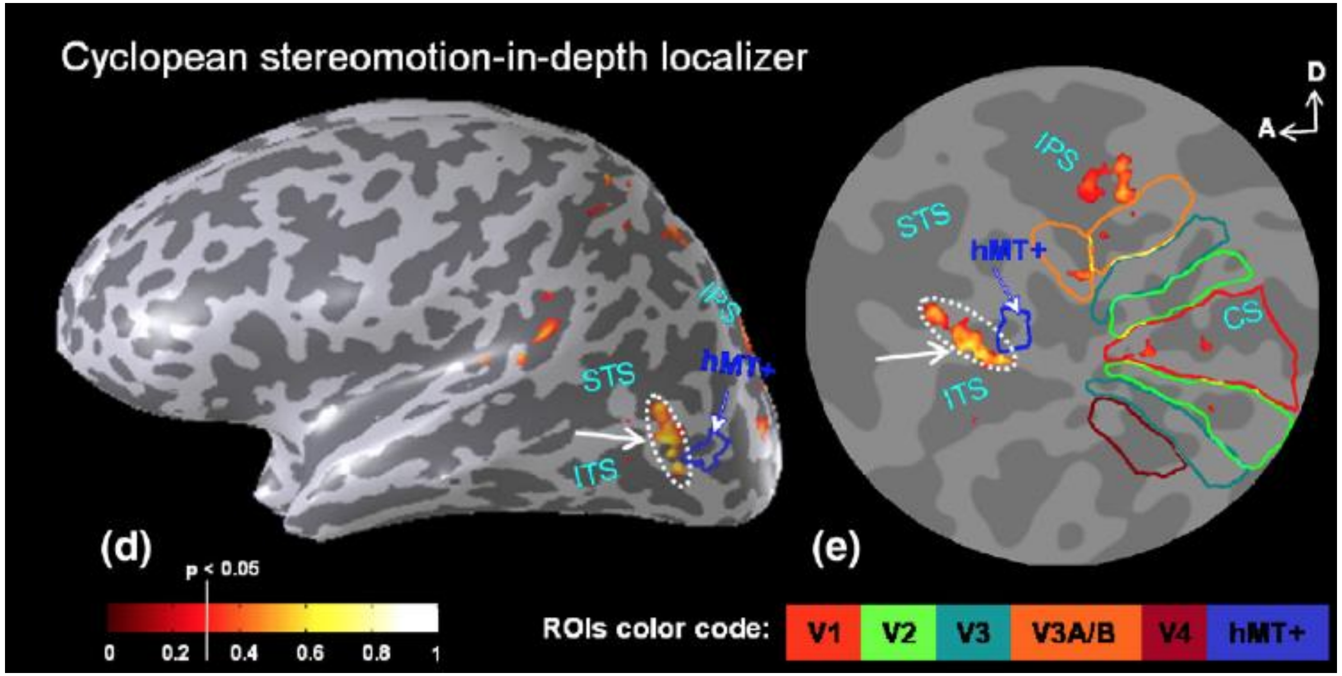
  Most studies focused on MT/hMT+

  *Rokers et al., 2009 (ROI-based analysis)*

  *Sanaka & DeAngelis, 2014; Czuba et al., 2014*

=> Limited understanding of 3D motion despite its ecological relevance

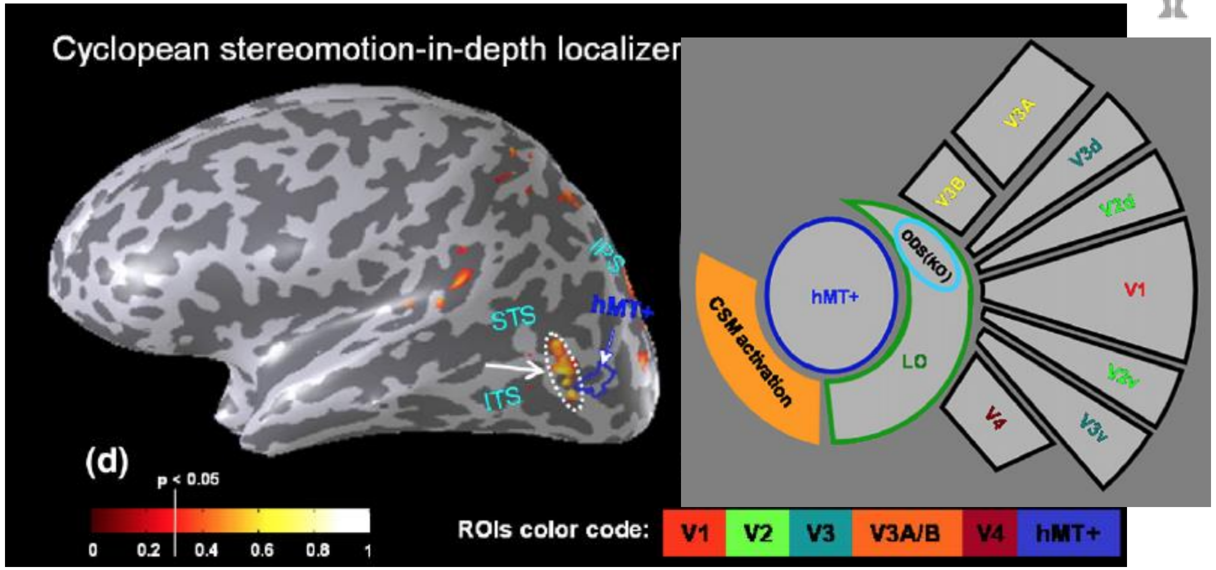
# Stereomotion: CDOT processing




*Likova & Tyler, 2007*

# Stereomotion: CDOT processing

→ CSM area in macaque?

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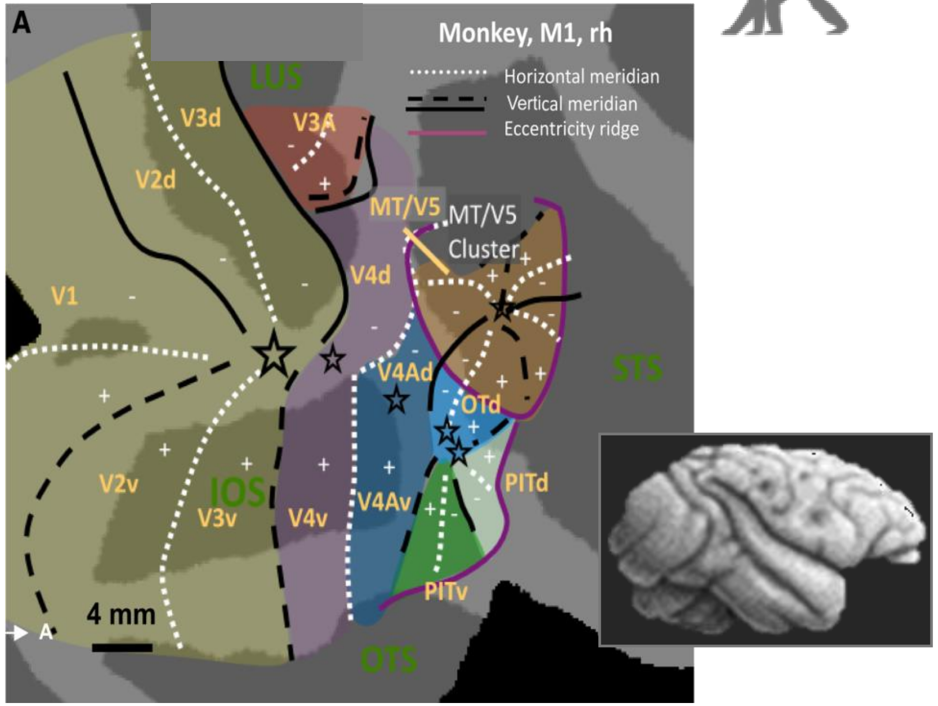


*Kolster et al., 2014*

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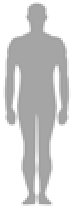

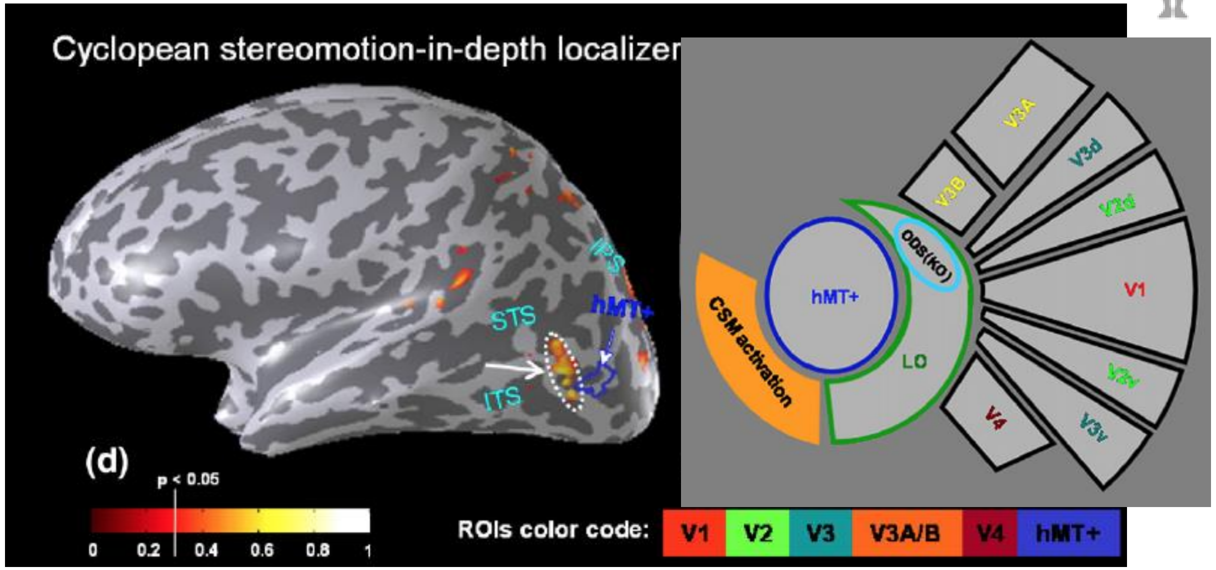


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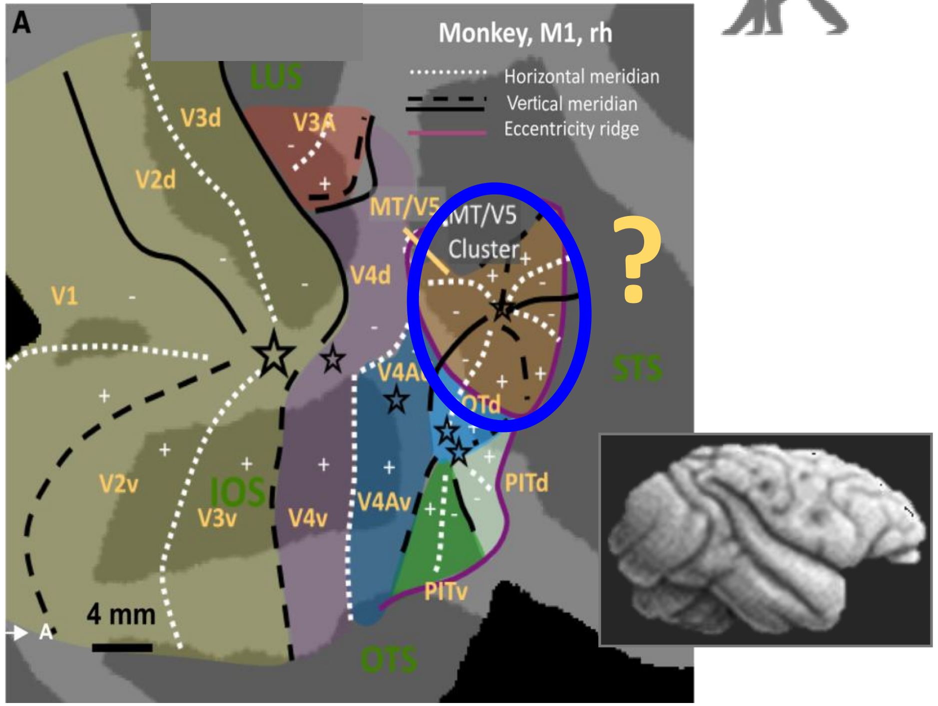
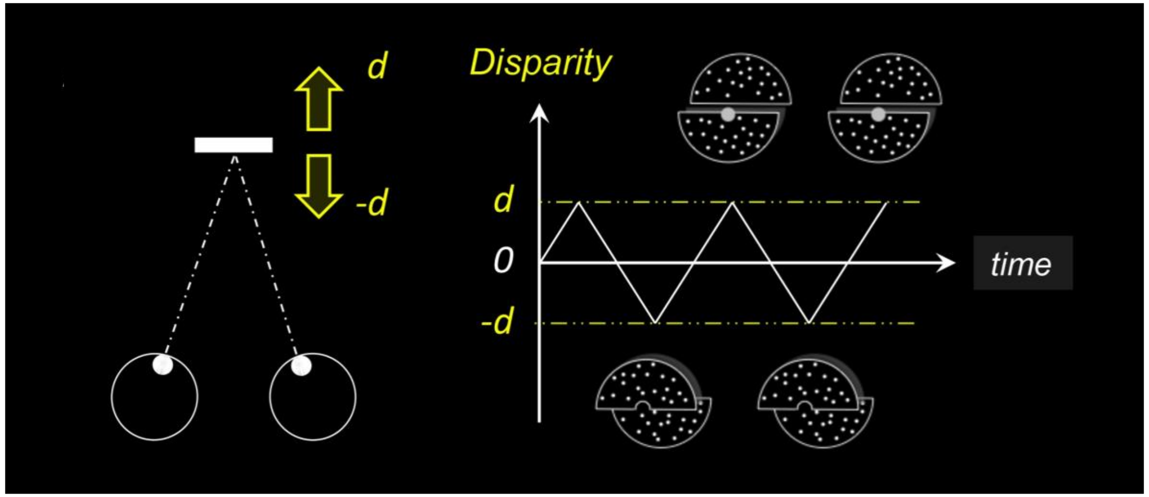
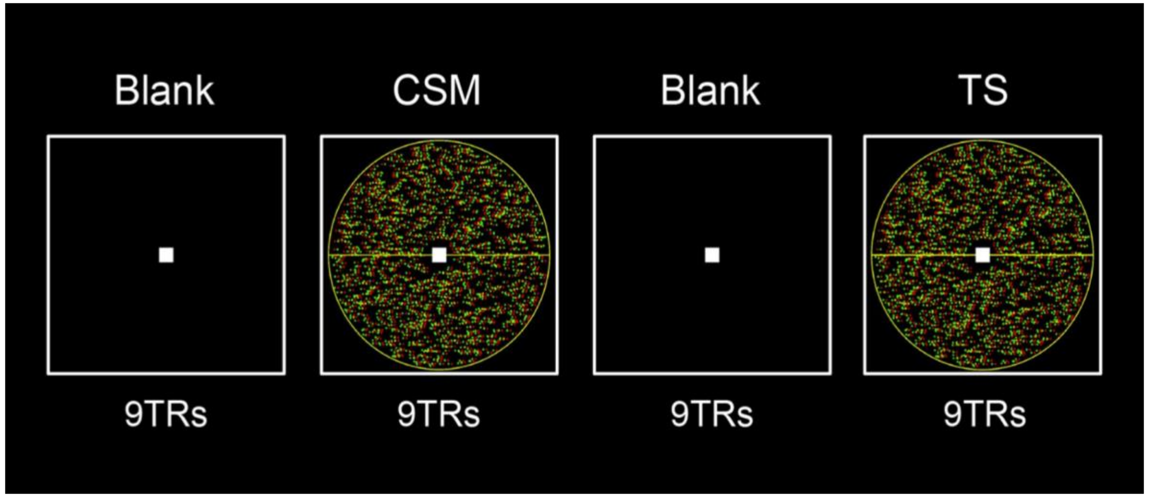



*Kolster et al., 2014*

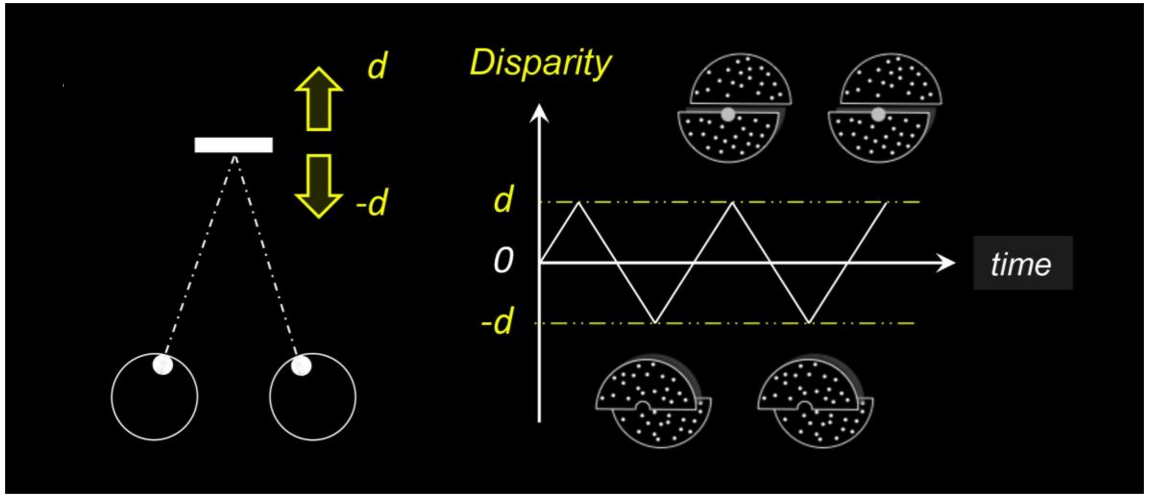
# Experimental paradigm

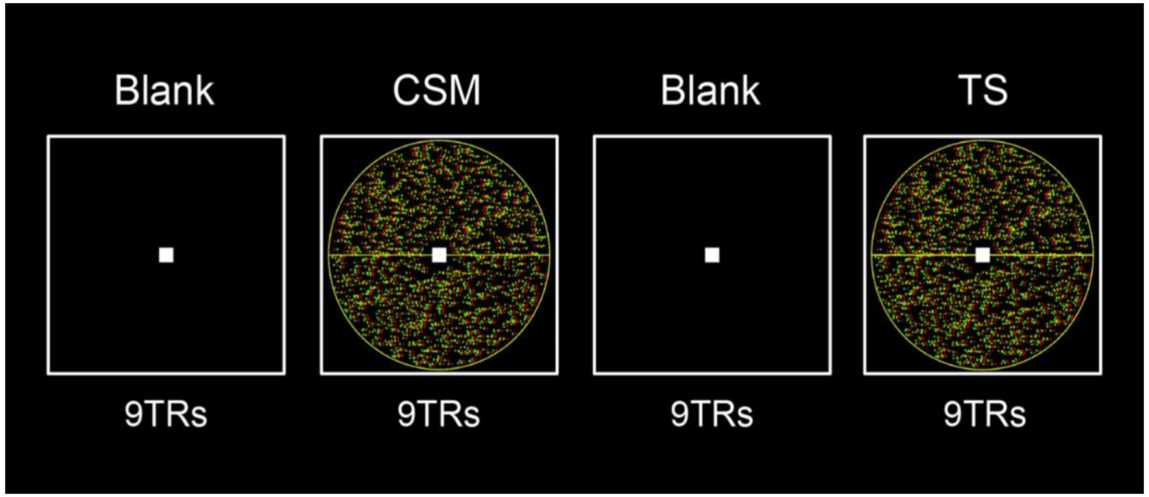


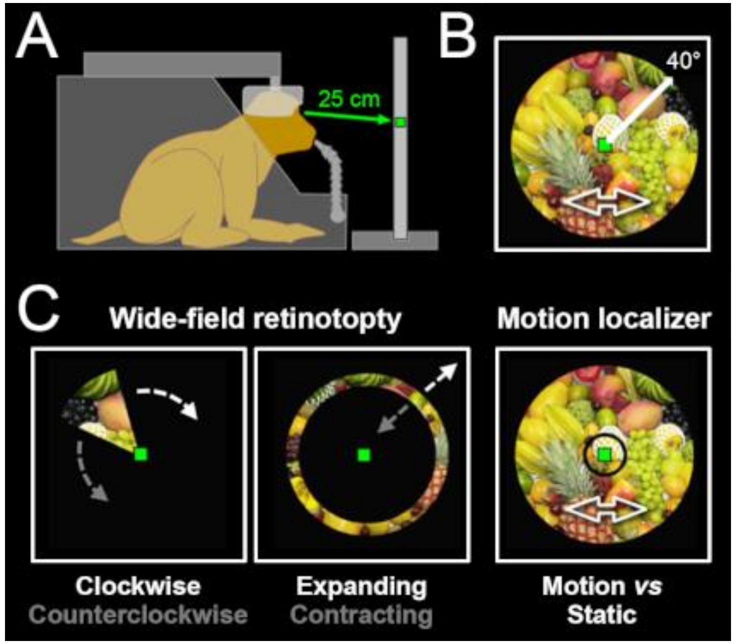




2 macaques
43 and 47 runs
BOLD signal

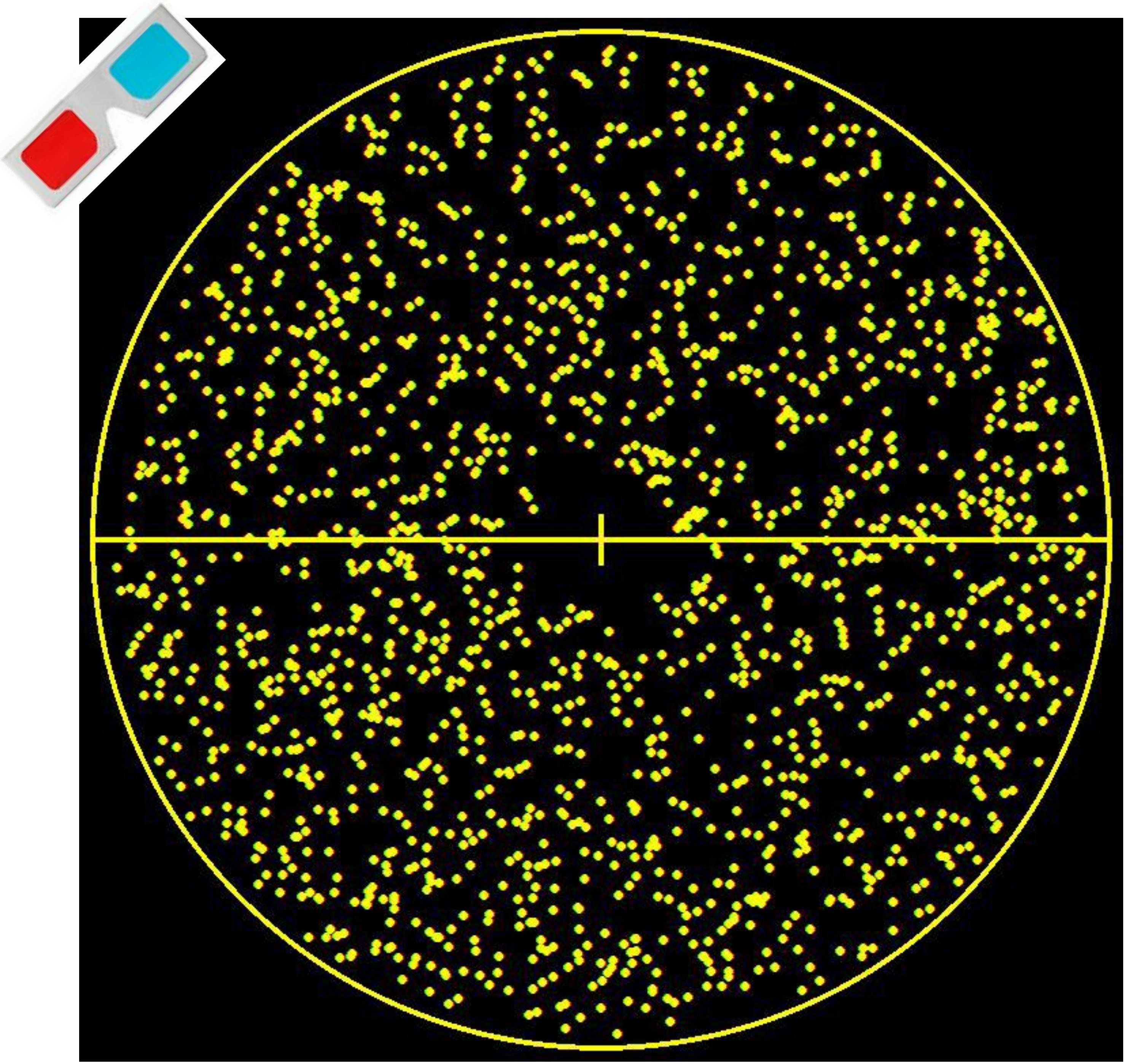
# Experimental paradigm



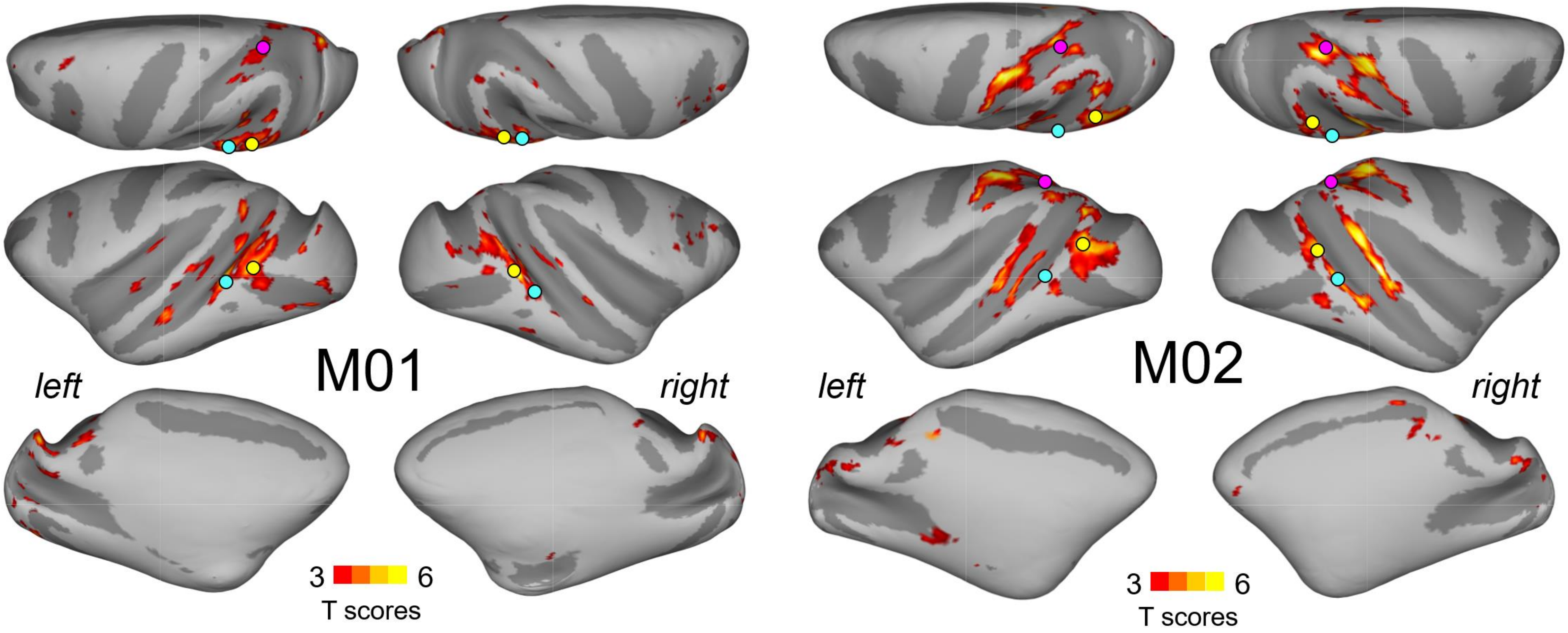




*Rima et al. (minor revisions)*



# Projection on the individual surfaces




**Caret software*

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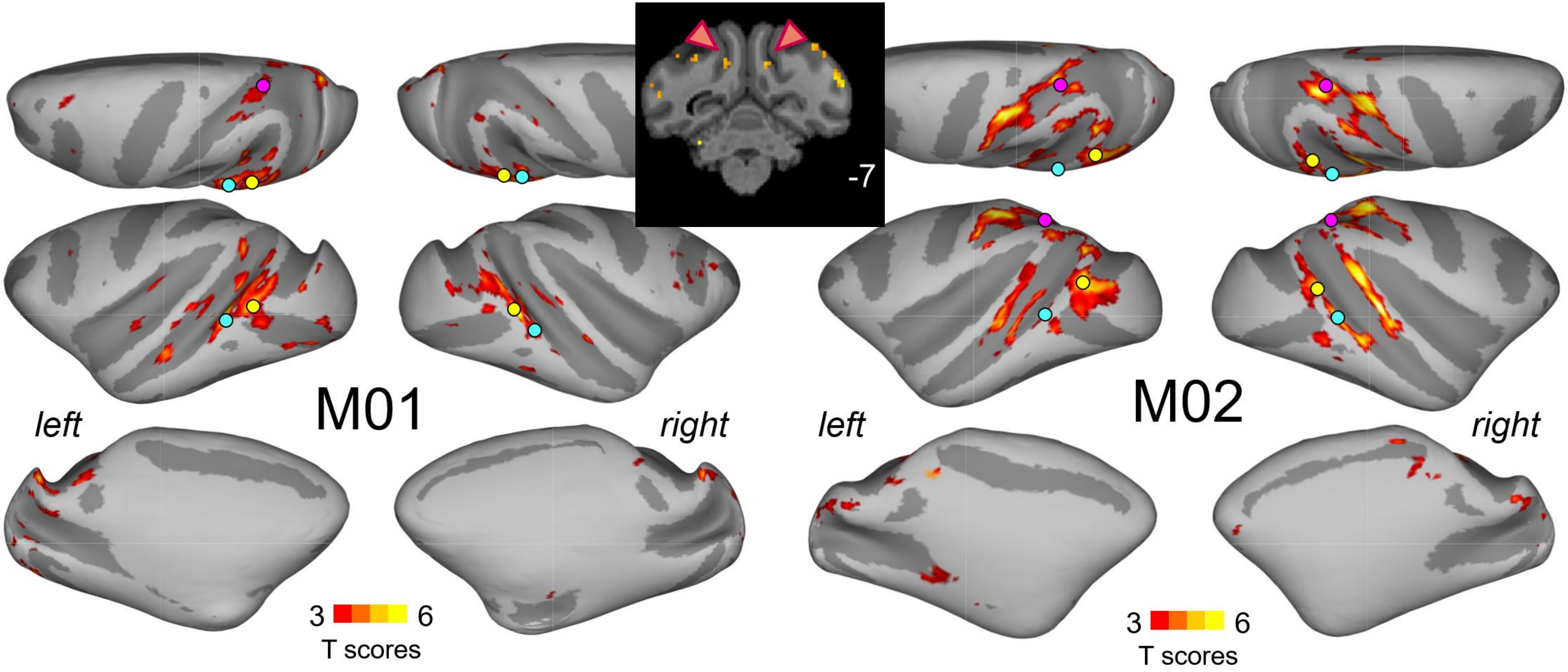
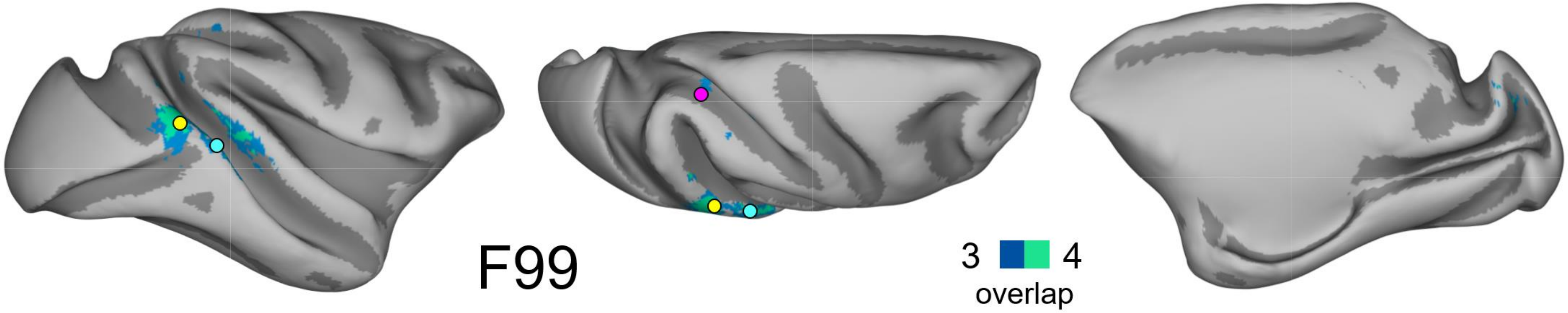


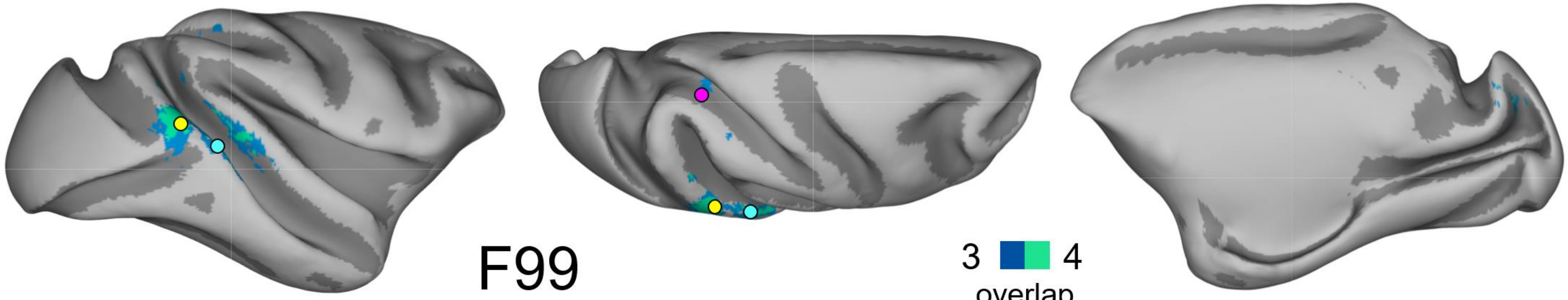

*Caret software

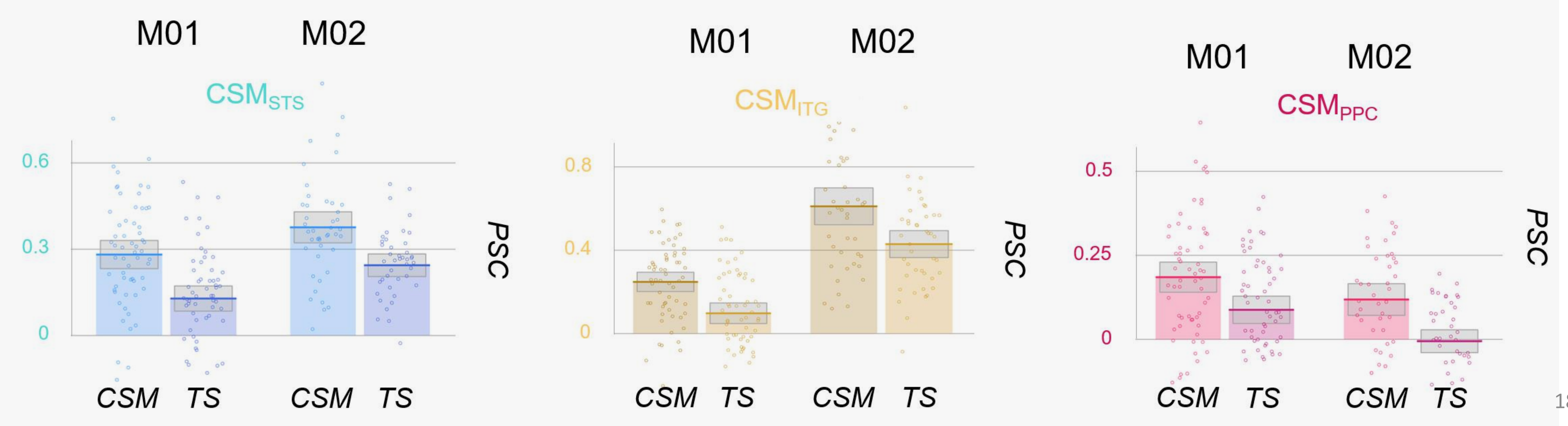
# Projection overlap

Projection on the F99 template

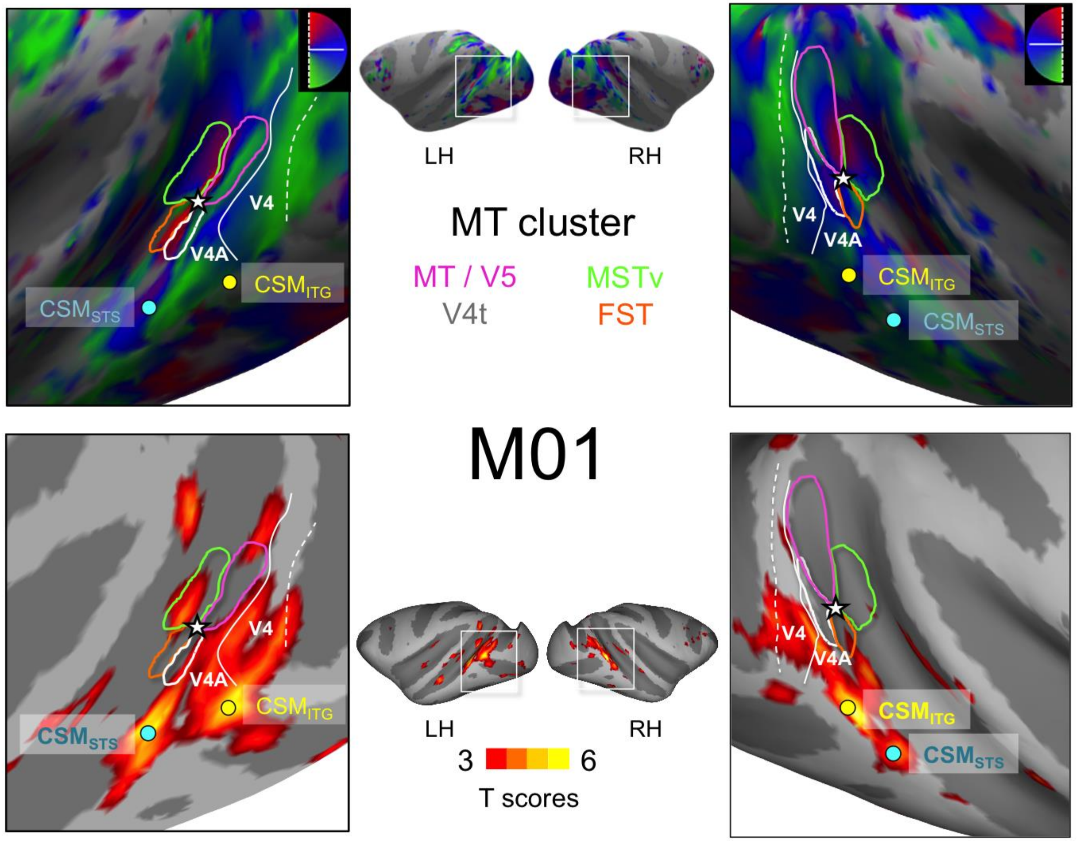


# ROI analyses in the volume

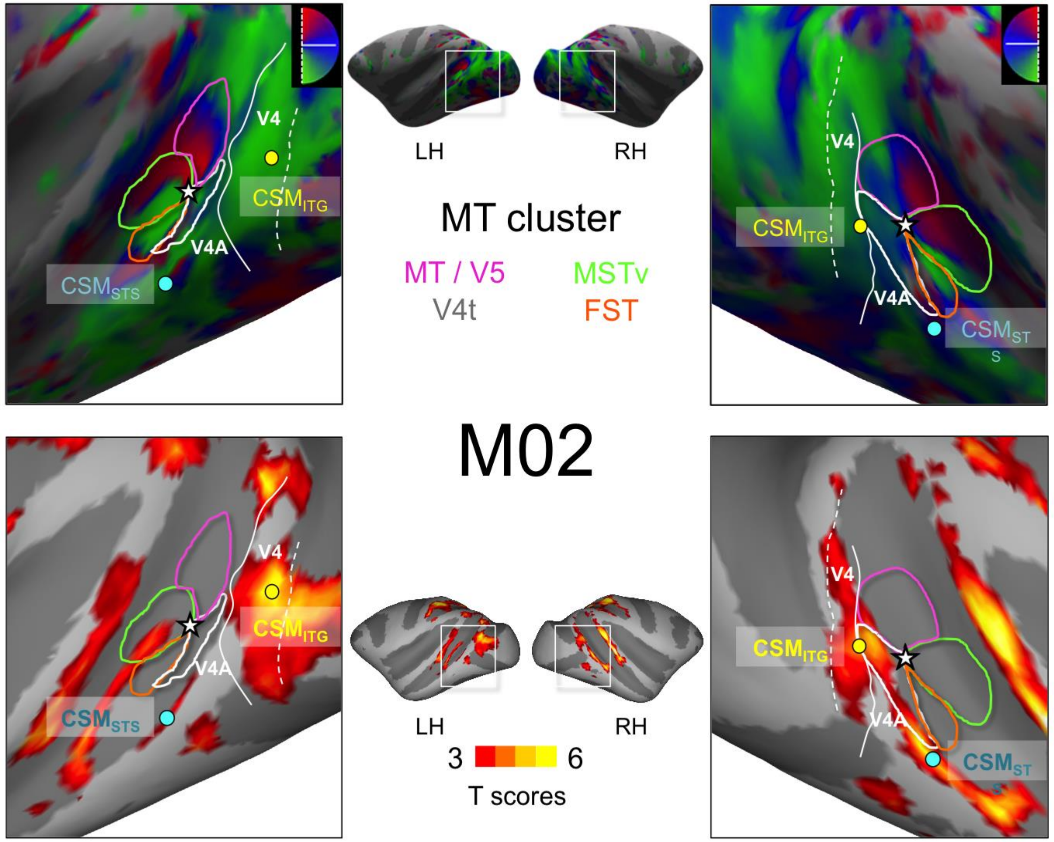


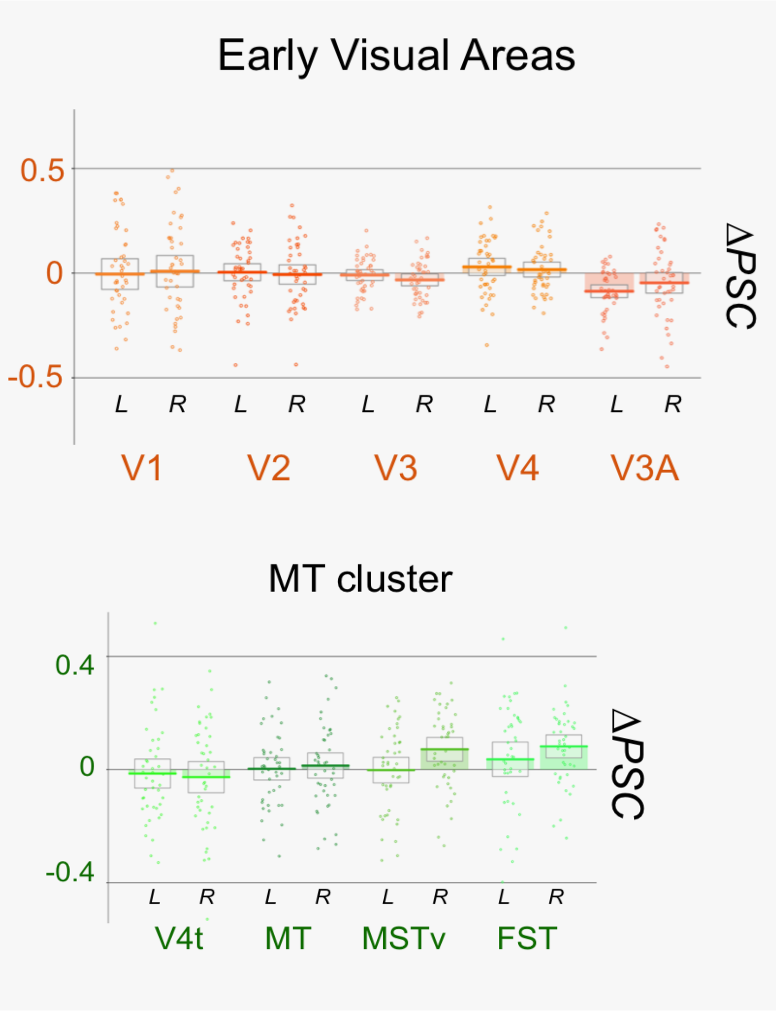



# ROI-based analyses

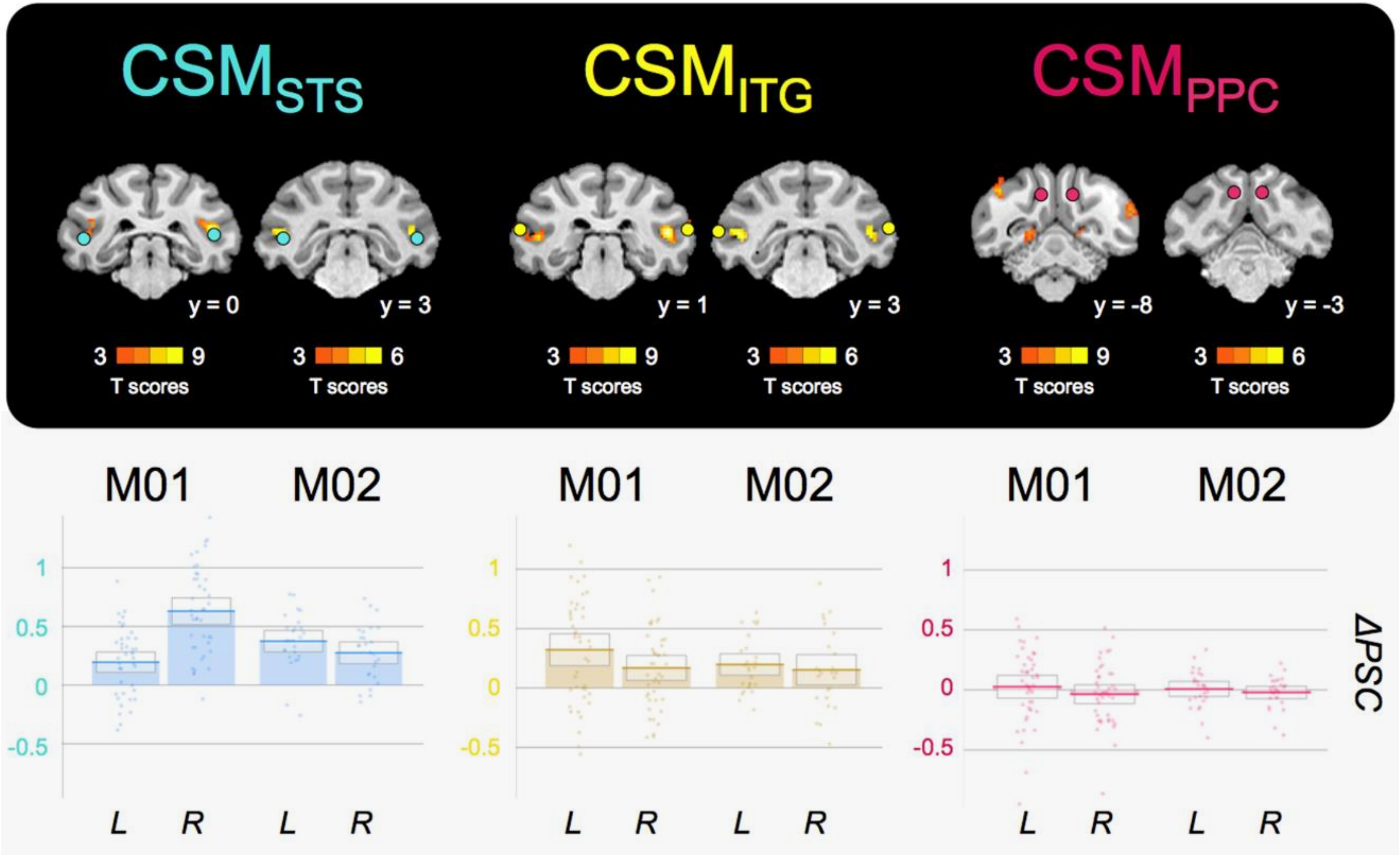



# ROI-based analyses



# Monocular motion sensitivity



# Temporal integration?

- Three areas with significant activations for CSM: $CSM_{STS}$, $CSM_{ITG}$, $CSM_{PPC}$
- Tendency observed in the MT cluster (FST, MSTv)
- One area was found to respond exclusively to stereomotion

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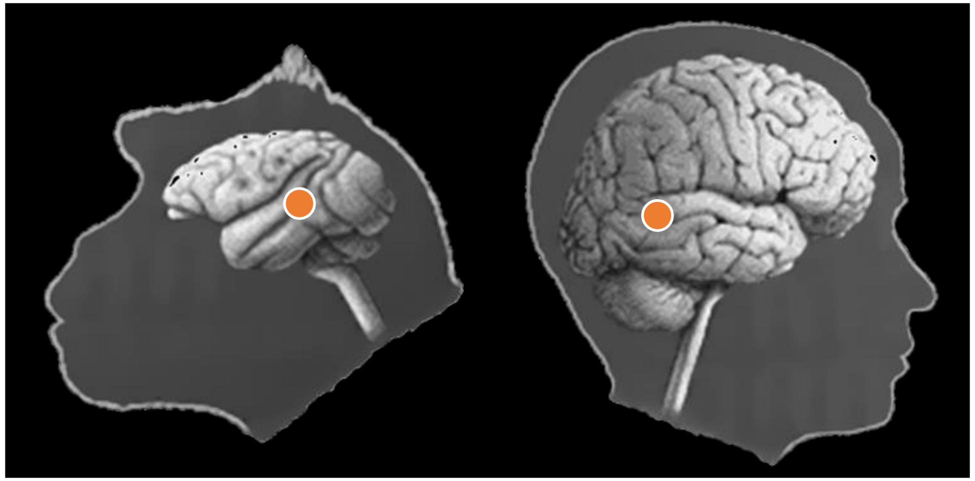
CSM$_{STS}$



CSM

*Likova & Tyler 2007*

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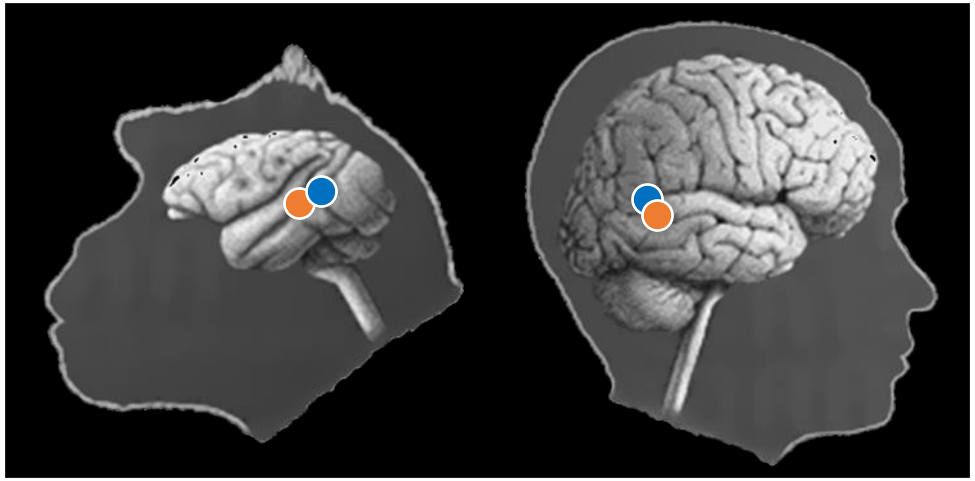
CSMSTS

CSMITG



CSM

LO?

*Likova & Tyler 2007*

*Rokers et al., 2009*

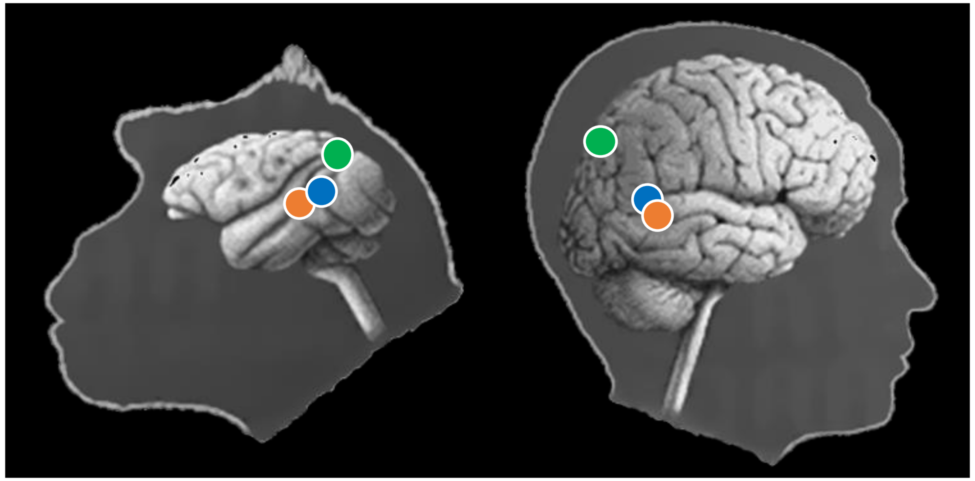
# Temporal integration?

- Three areas with significant activations for CSM: CSMSTS, CSMITG, CSMPPC
- Tendency observed in the MT cluster (FST, MSTv)
- One area was found to respond exclusively to stereomotion

CSMSTS

CSMITG

CSMPPC



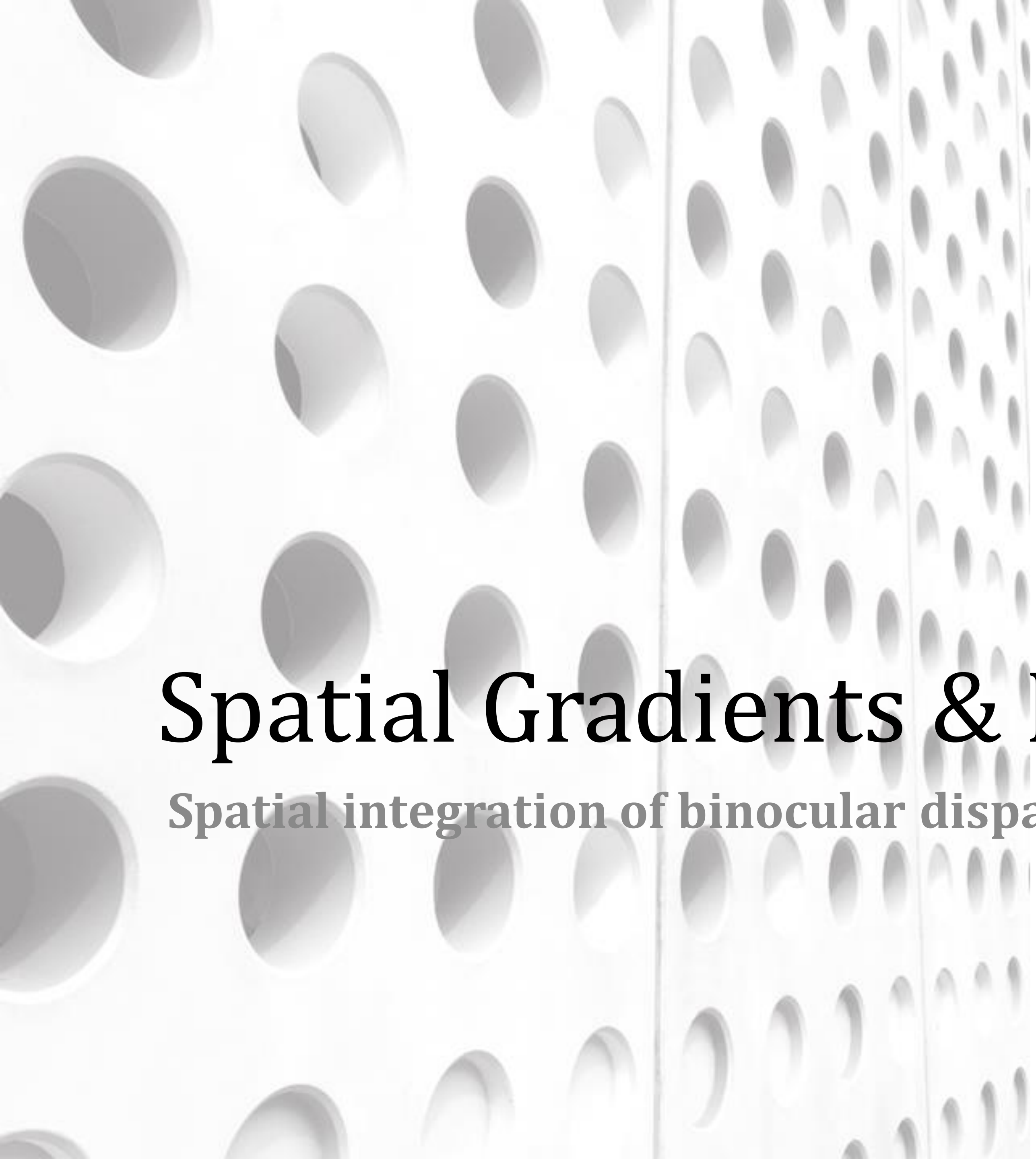
CSM

LO?

*Likova & Tyler 2007*

*Rokers et al., 2009*

*Kaestner et al. 2019*



# Spatial Gradients & Natural Statistics

**Spatial integration of binocular disparities and orientation biases**

# Spatial gradients processing

- The brain network responding to spatial gradients is well known in macaques

*Janssen et al., 1999, 2000, 2001; Taira et al., 2000; Tsutsui et al., 2002; Hinkle & Connor, 2002; Nguyenkin & DeAngelis, 2003*

- And so is the involvement of some human areas (V3A, V3B/KO, hMT+, LOC)

*Chandrasekaran et al., 2007; Murphy, Ban, Welchman, 2013; Ban & Welchman, 2015*

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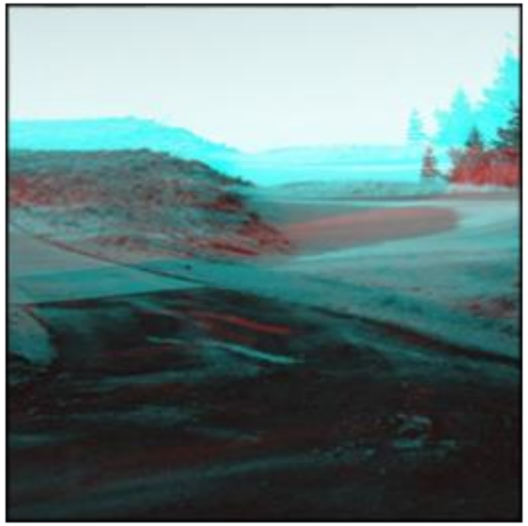
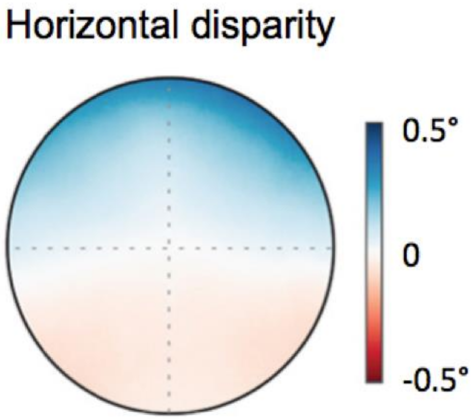
*Chandrasekaran et al., 2007; Murphy, Ban, Welchman, 2013; Ban & Welchman, 2015*

**What about an influence of natural statistics within those networks?**

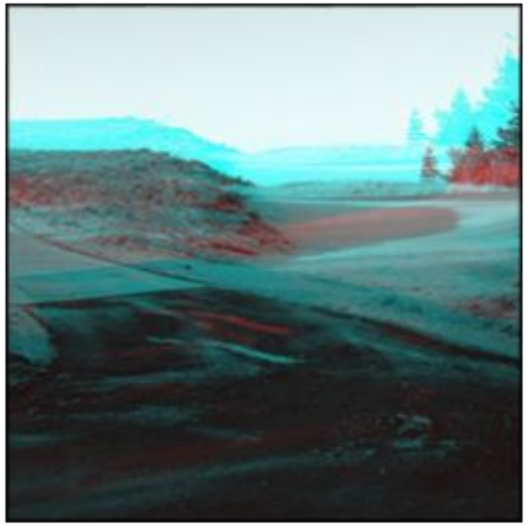
# Spatial gradients and statistical biases

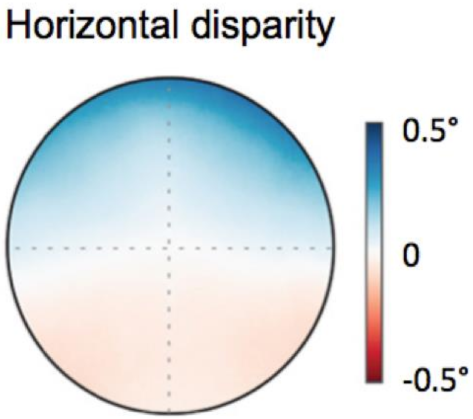


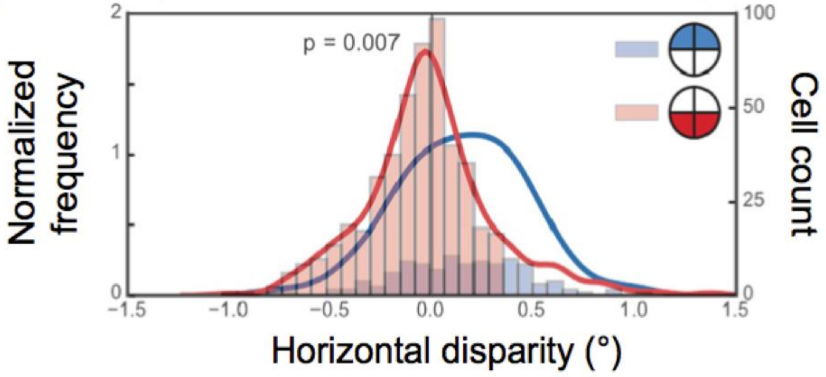



*Sprague et al., 2015*

# Spatial gradients and statistical biases

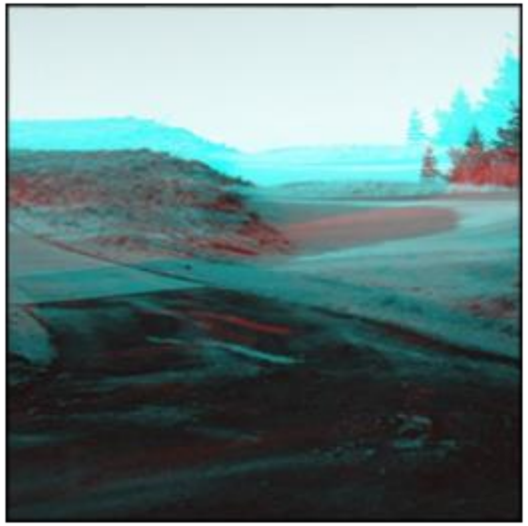


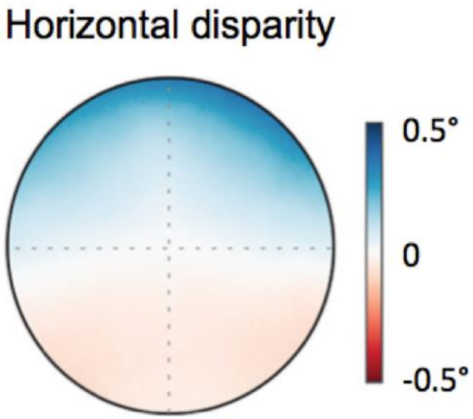


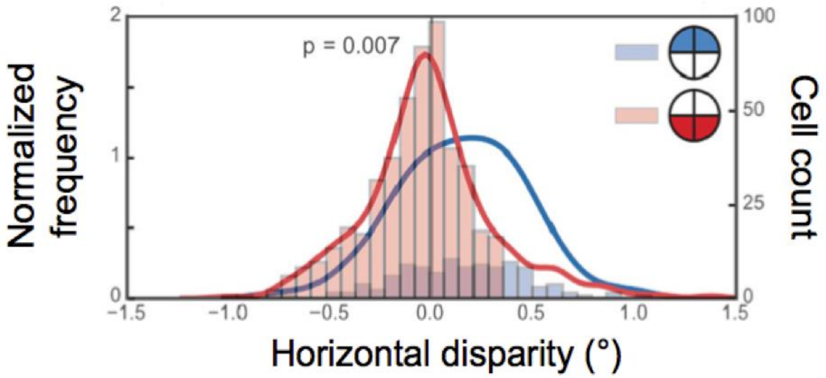



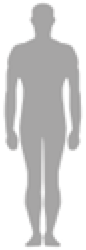

*Sprague et al., 2015*

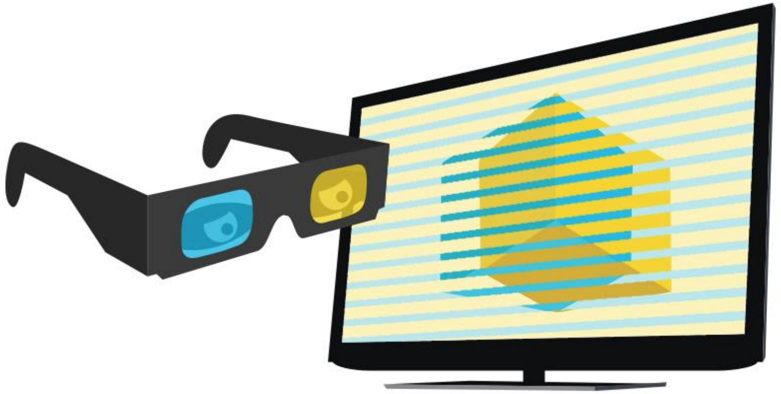
# Spatial gradients and statistical biases





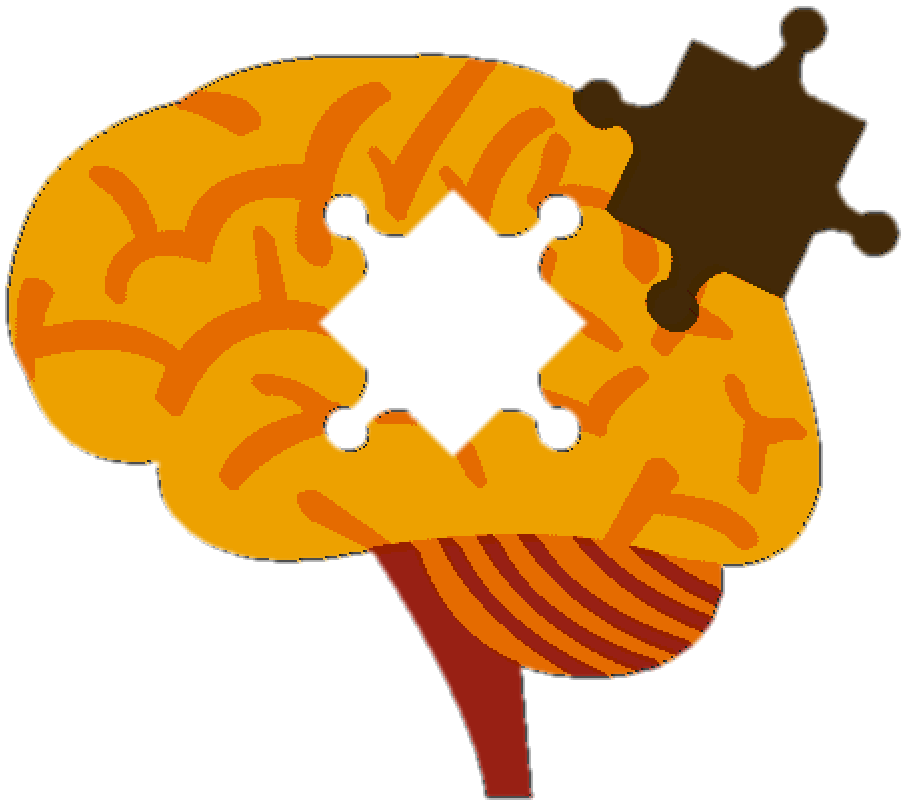



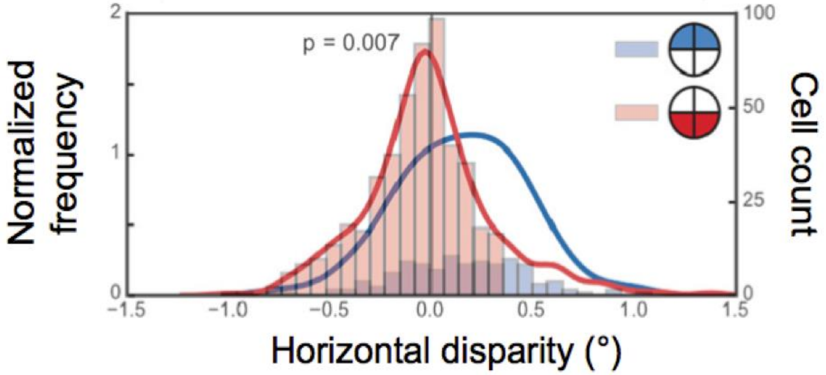



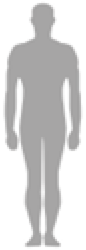


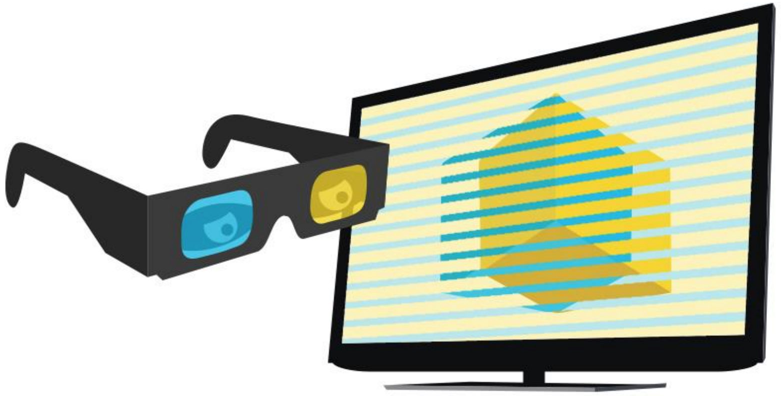
*Sprague et al., 2015*

# Spatial gradients and statistical biases

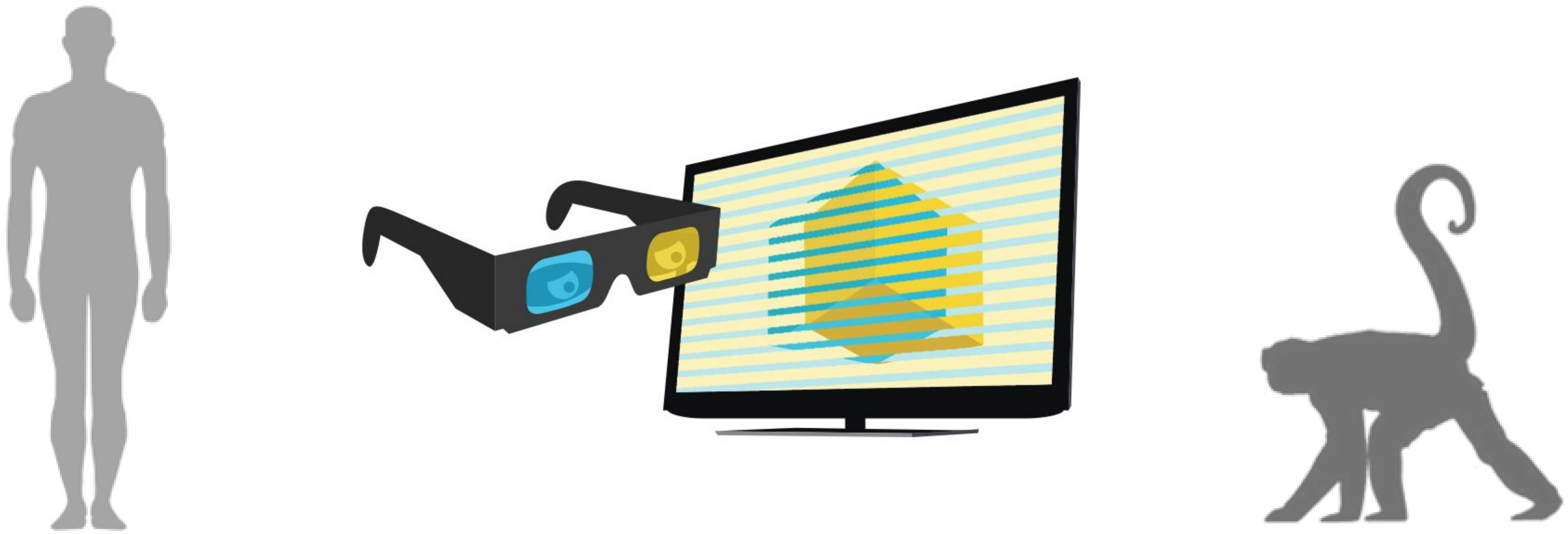






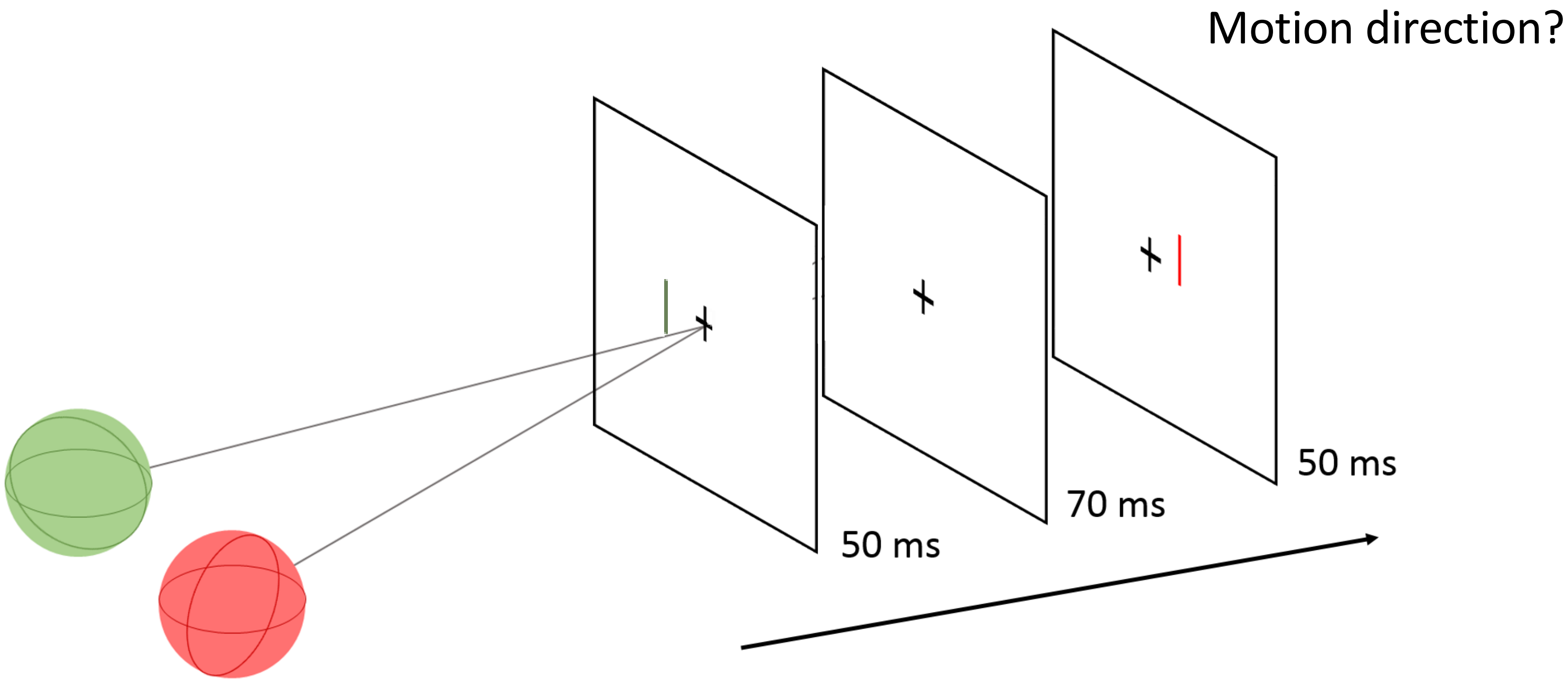
# Visual perception and natural statistics



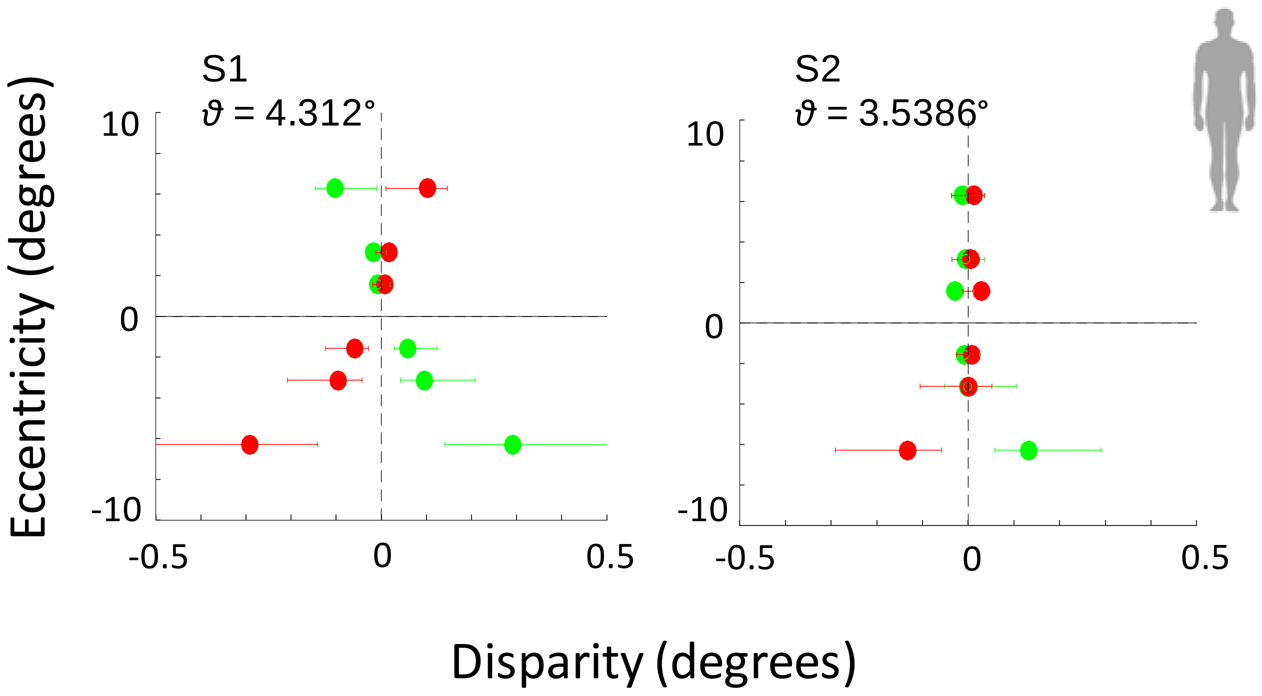
**Are statistical biases reflected at the level of visual perception in macaque?**

# Measuring corresponding points

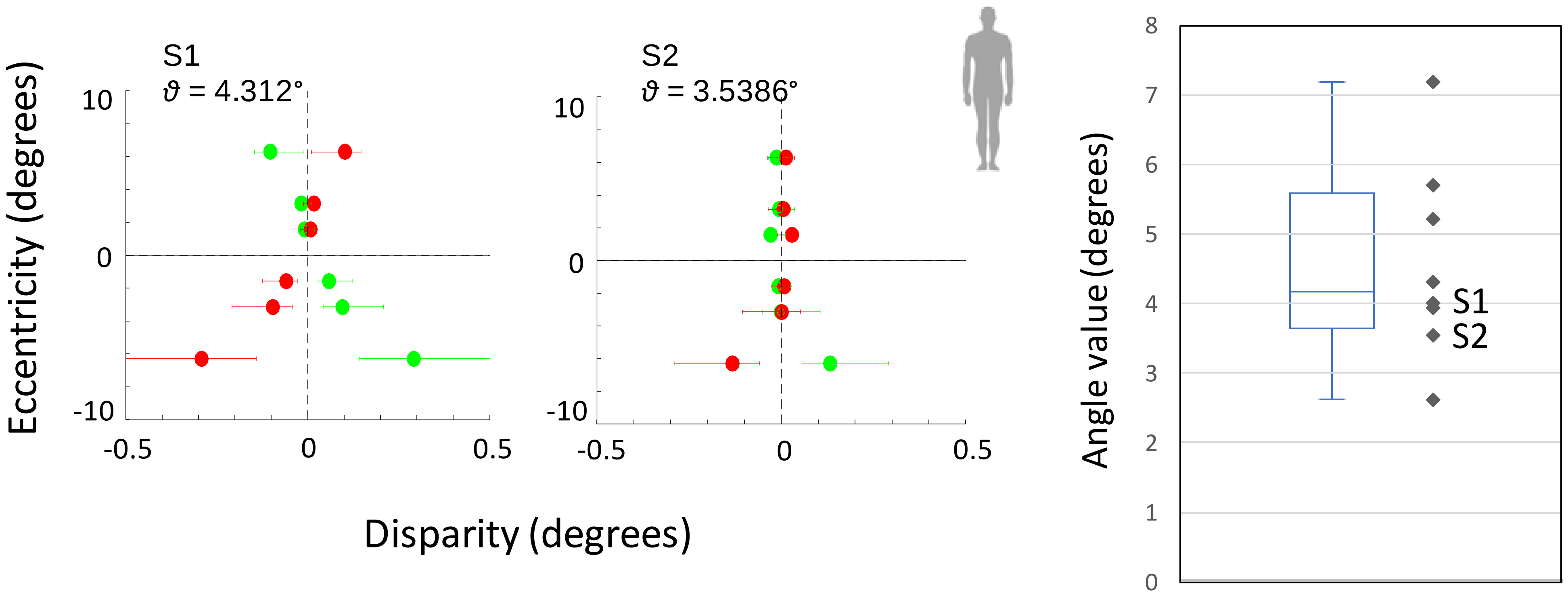
Experimental procedure adapted from Cooper E. et al., 2011



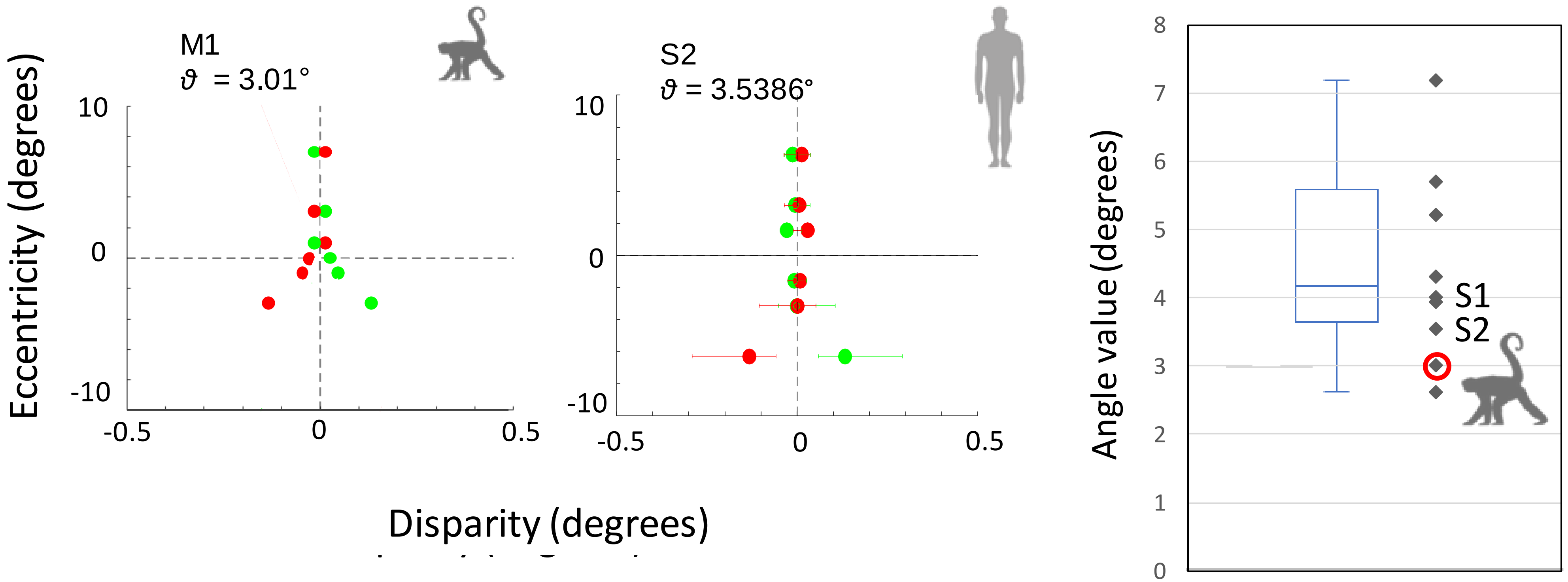
# Corresponding points location



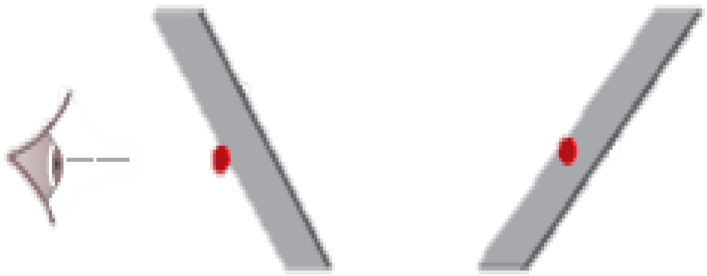
# Corresponding points location



# Corresponding points location

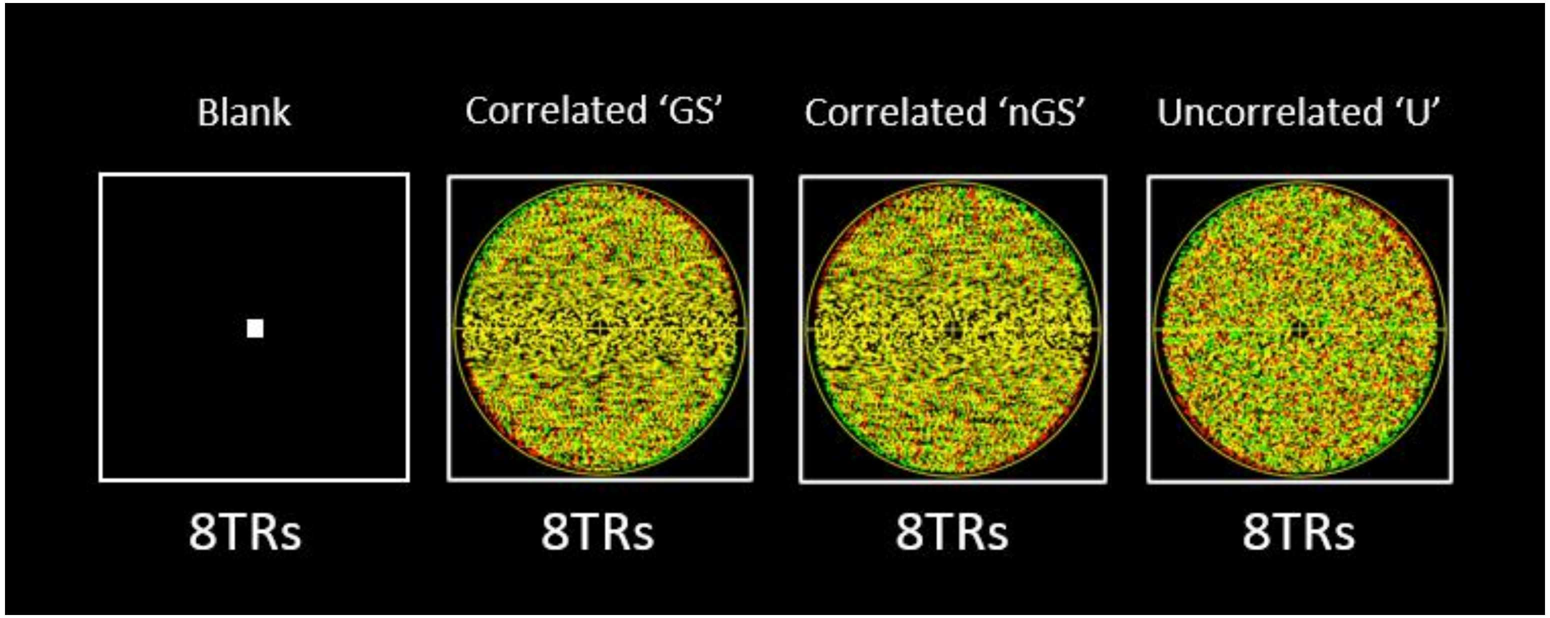


# From perception to cortical networks?

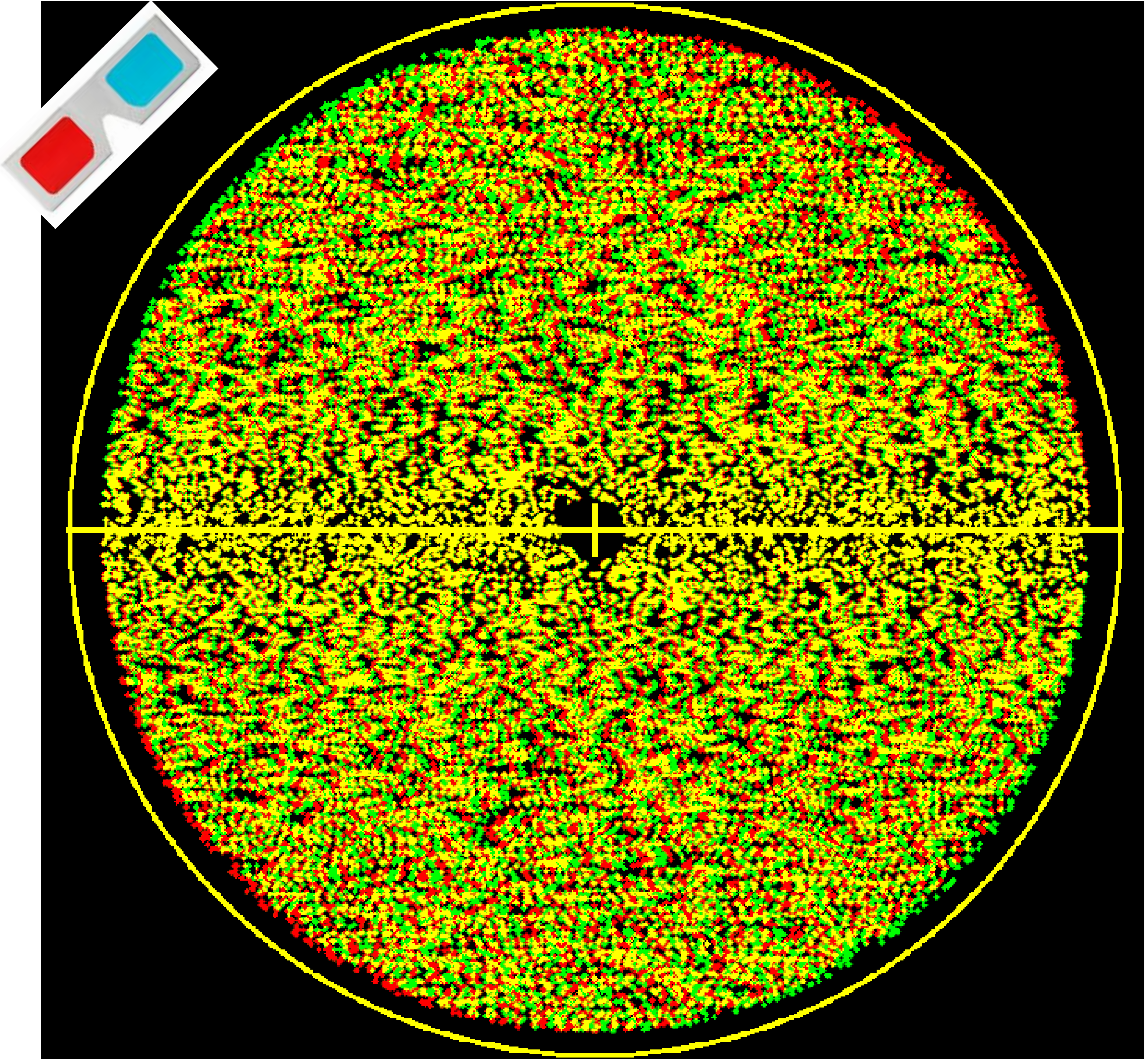


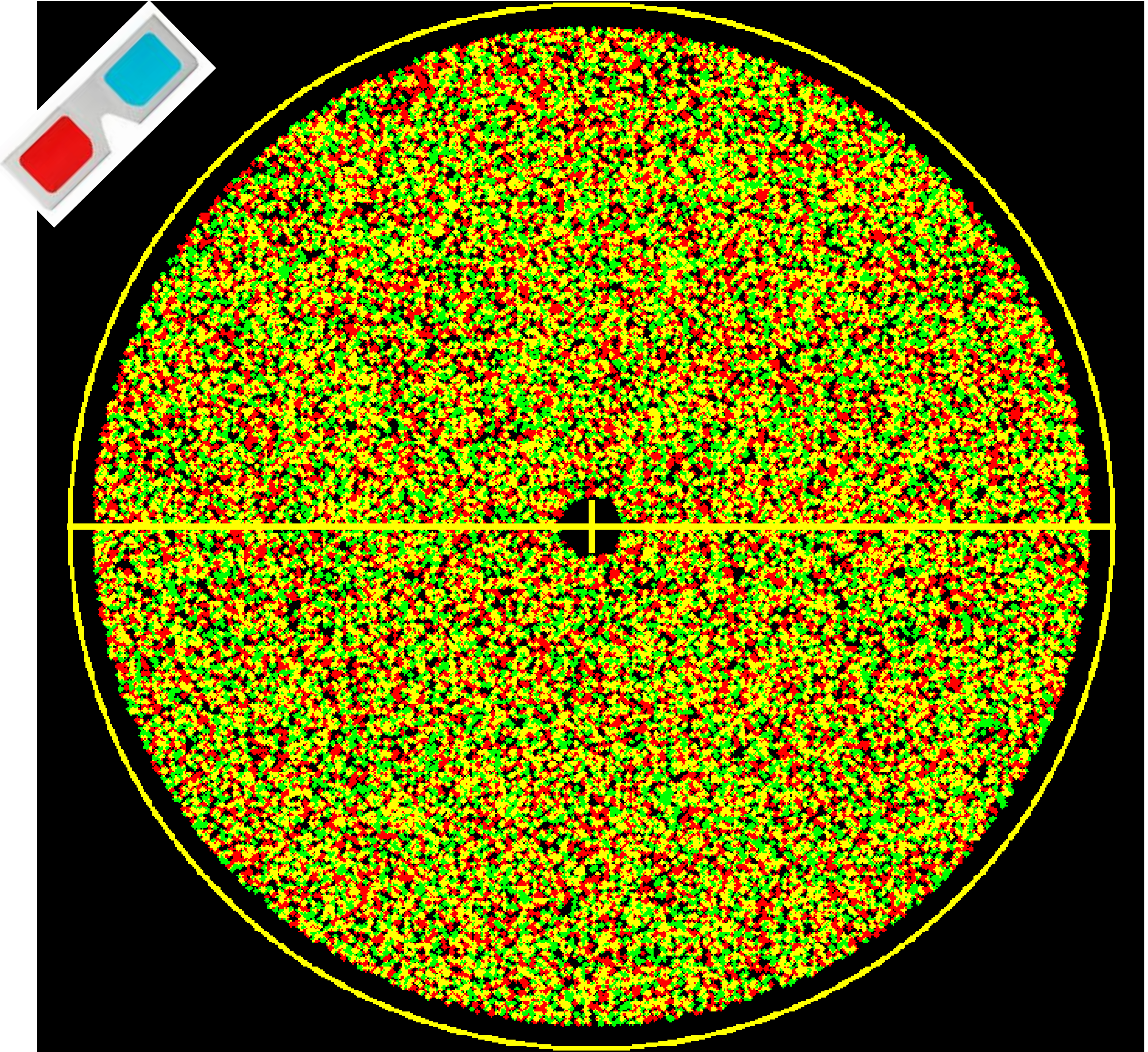
**Is there an influence of natural statistics within the cortical networks known to process binocular disparities ?**

# Experimental paradigm

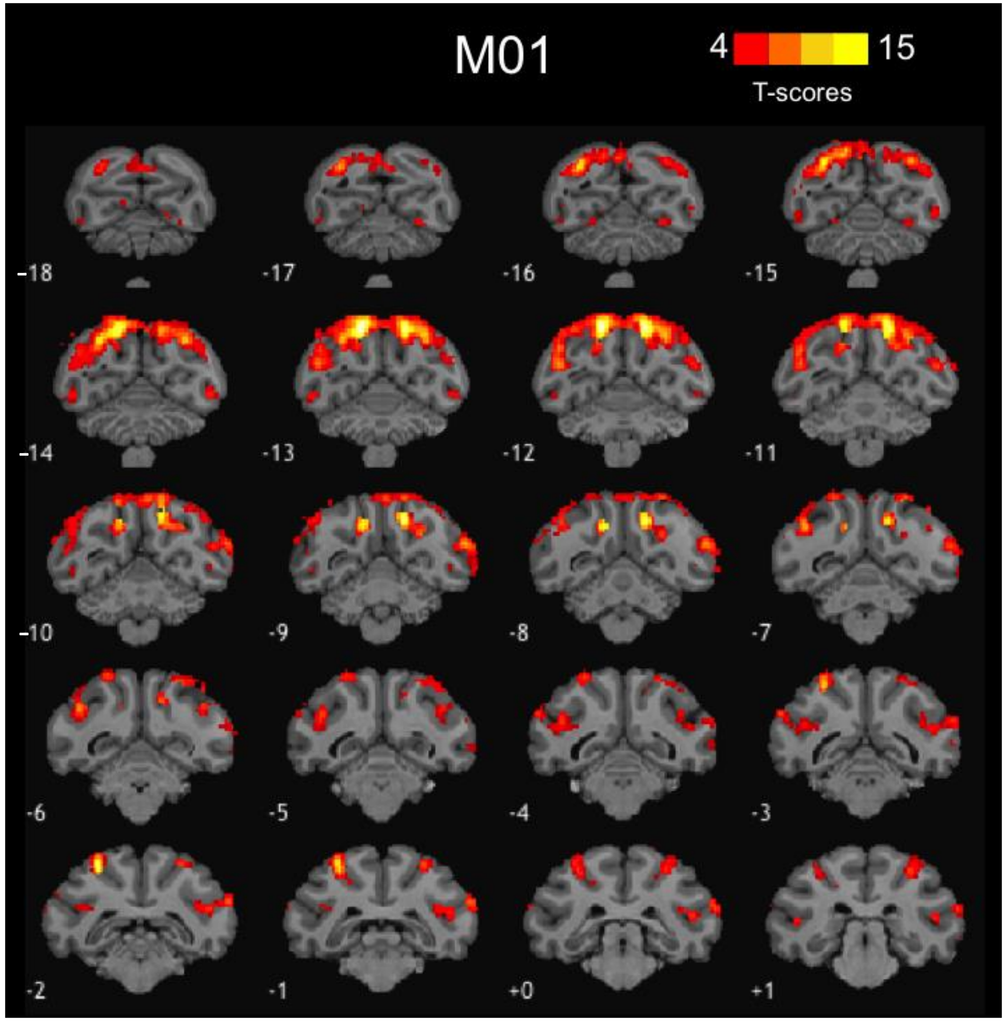


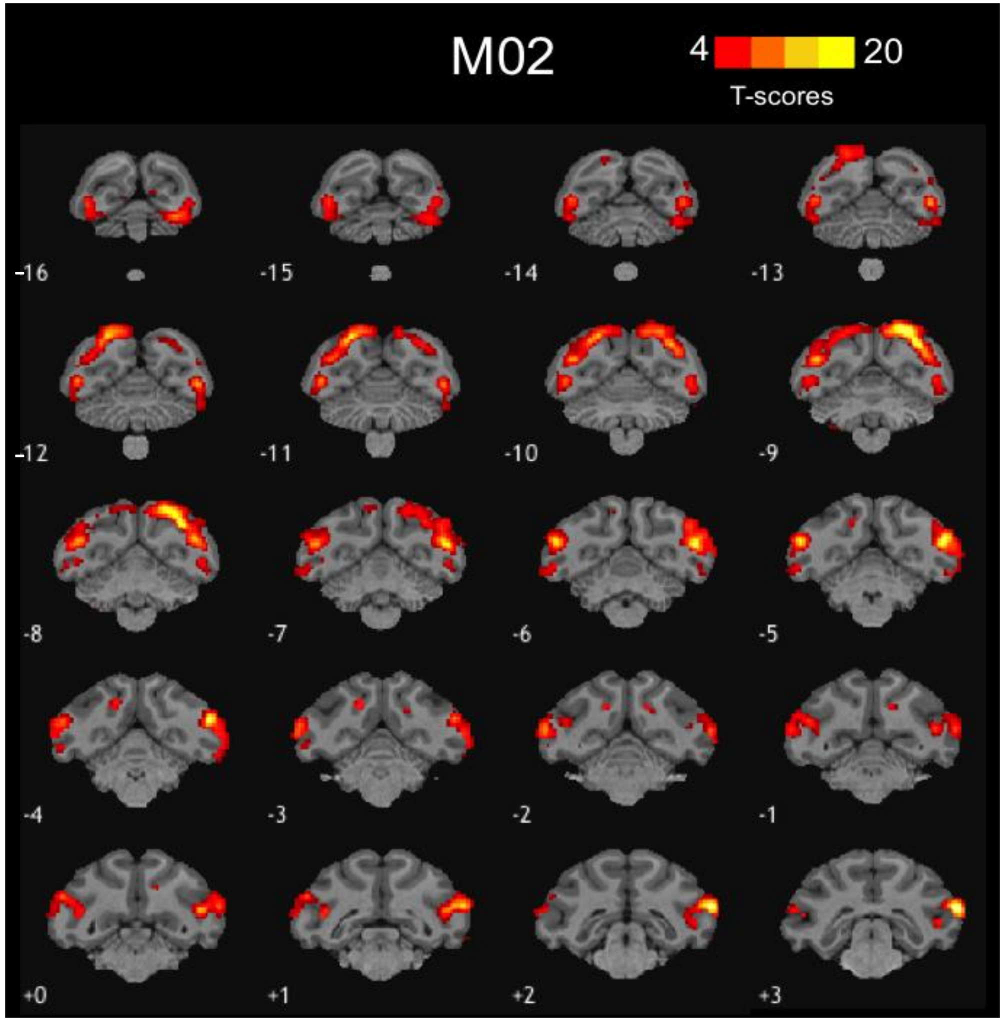

2 macaques
BOLD signal
49 runs (26 ‘S’ and 23 ‘T’)
79 runs (33 ‘S’ and 46 ‘T’)



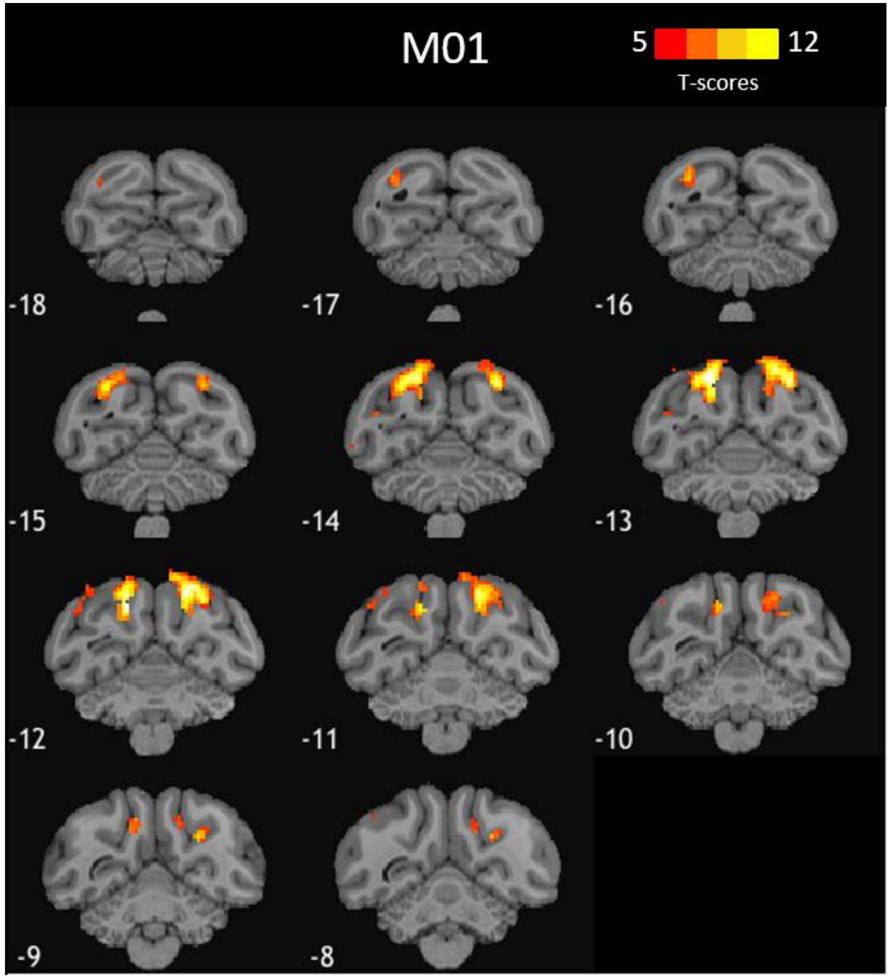


# Correlated vs. Decorrelated



# Orientation biases?



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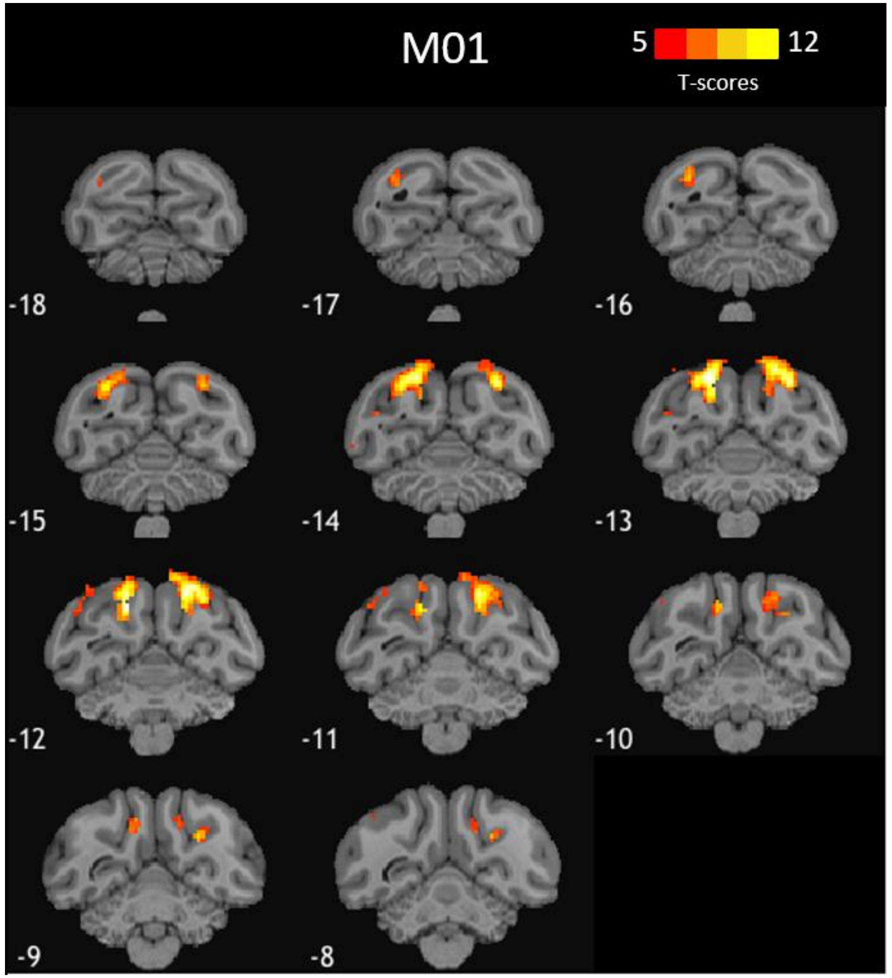
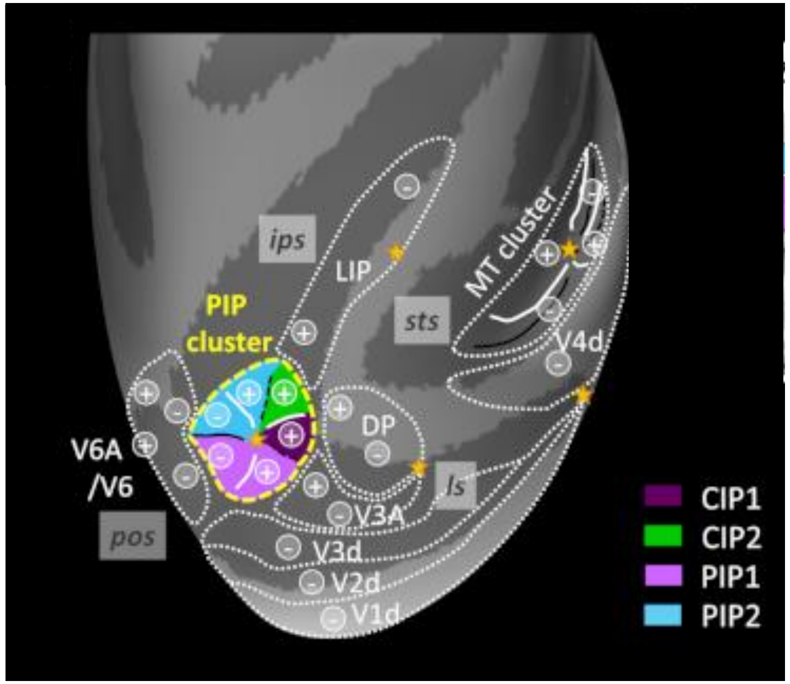
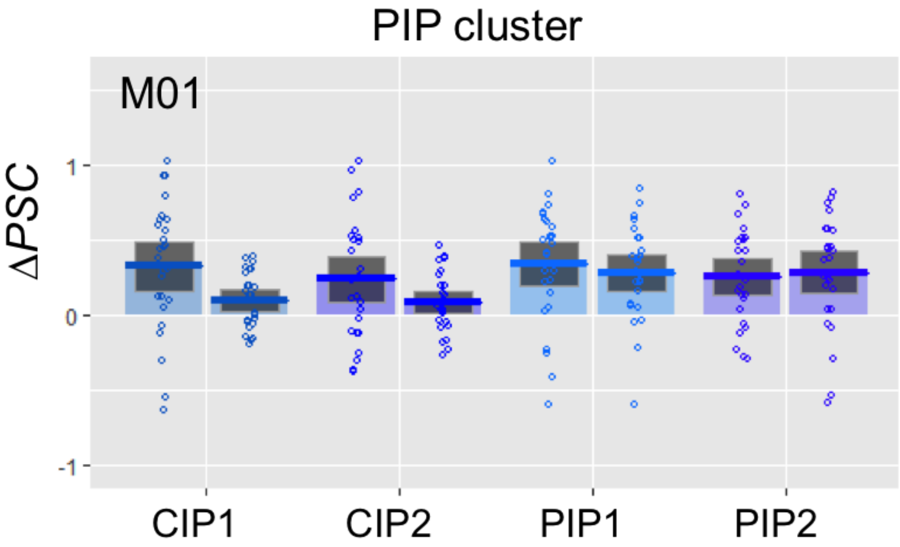
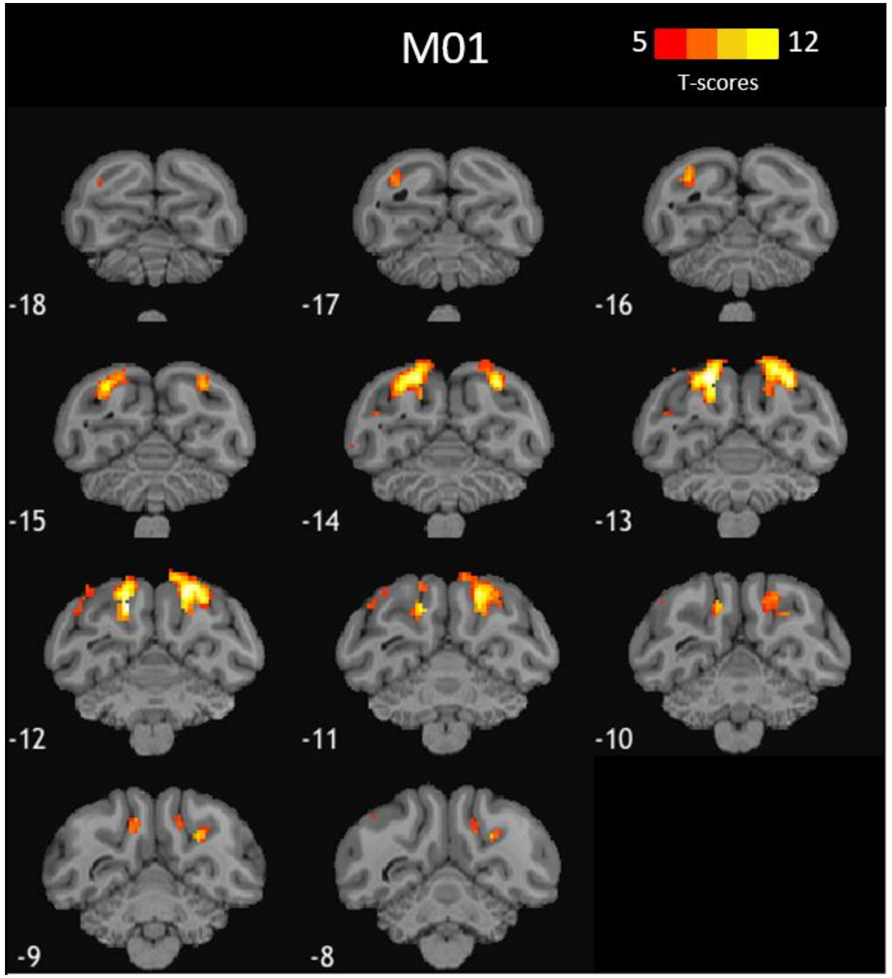


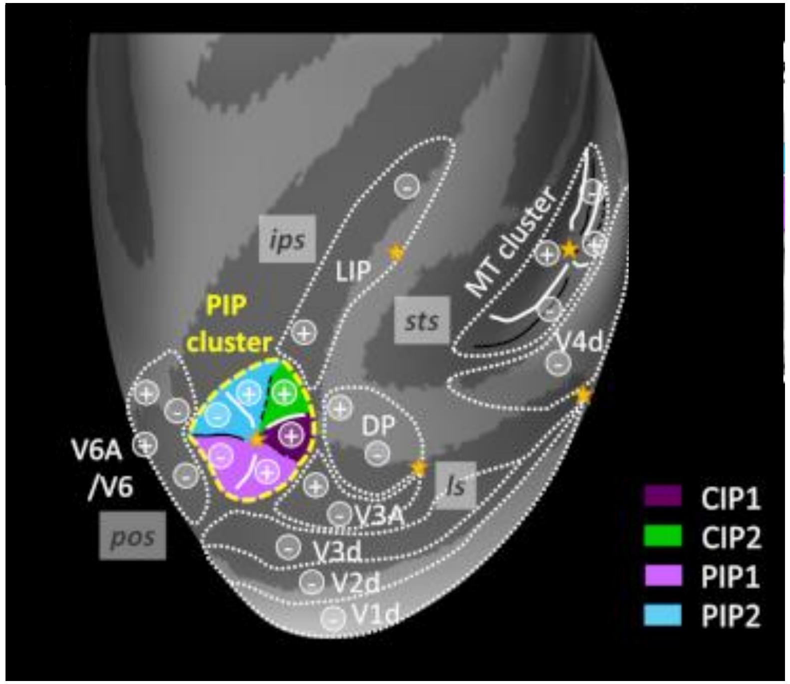




*Rima et al. (minor revisions)*



# Orientation biases?

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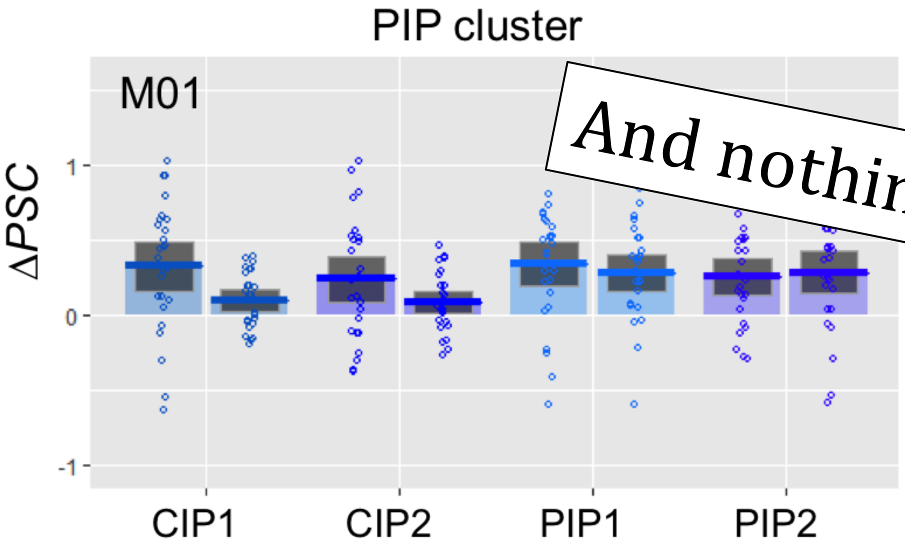



And nothing in M02!

# Spatial integration and natural stats?

- Successful adaptation of the experiment to one macaque subject with a tilt reflecting natural statistics

- A cortical network responding to correlated disparities congruent with the literature

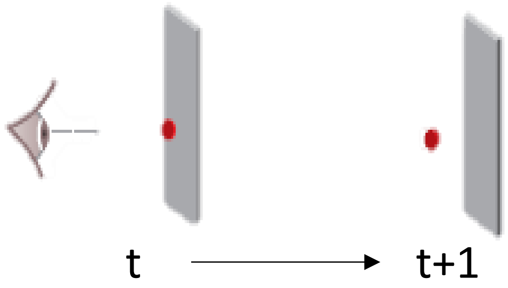
- Inconclusive results regarding the possibility of an encoding bias towards more frequent 3D orientations

# Discussion

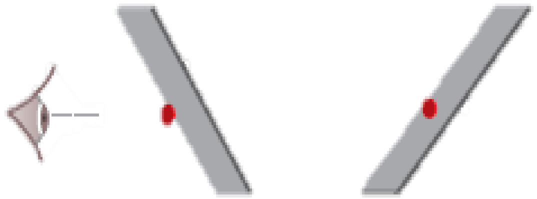
**What did we learn about the integration of binocular disparities?**

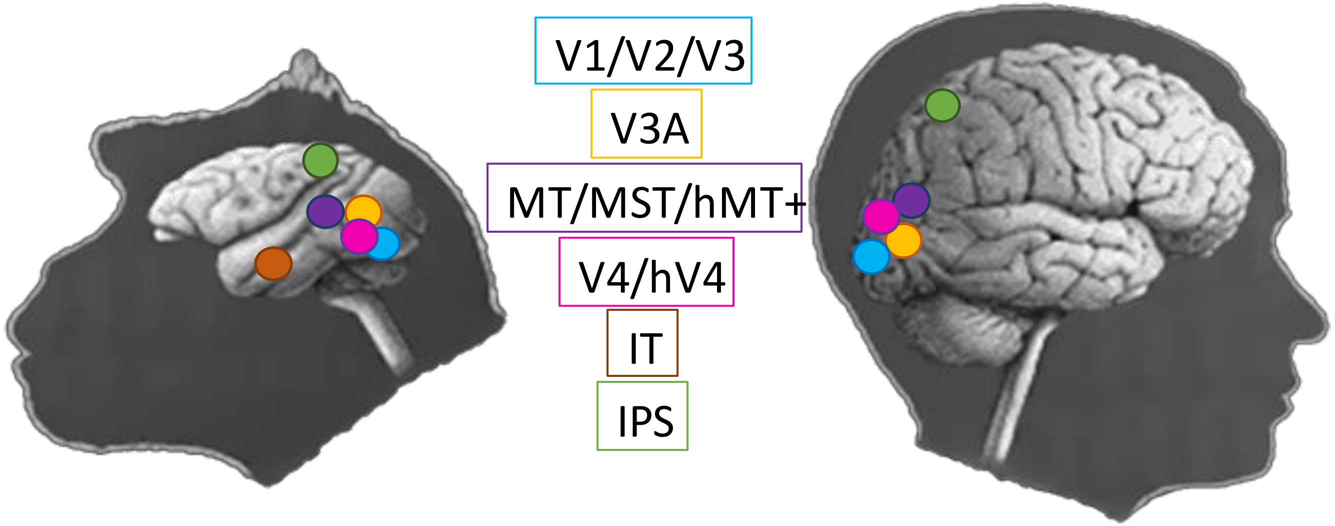
# Integration of binocular disparities

*Temporal gradients*




*Spatial gradients*



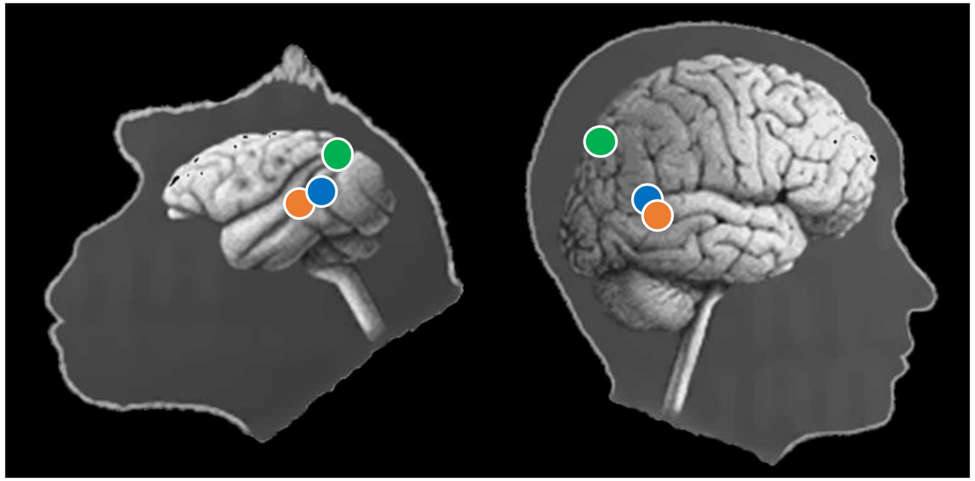


# Summary of the main results

- Temporal integration of binocular disparities
  - The case of cyclopean stereomotion

  →Human and macaque seem to process CSM in a similar manner

  *Likova & Tyler, 2007; Rokers et al., 2009; Kaestner et al.; 2019*



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  *Likova & Tyler, 2007; Rokers et al., 2009; Kaestner et al.; 2019*

- Influence of natural statistics
  - Cortical processing of spatial gradients and 3D orientation biases: Nope! or Nope?
  - Visual perception bias and interspecies comparison

    *Cooper and Pettigrew, 1991; Cooper E. et al., 2011*

# The PIP cluster: An overlap?

## Functional dissociation

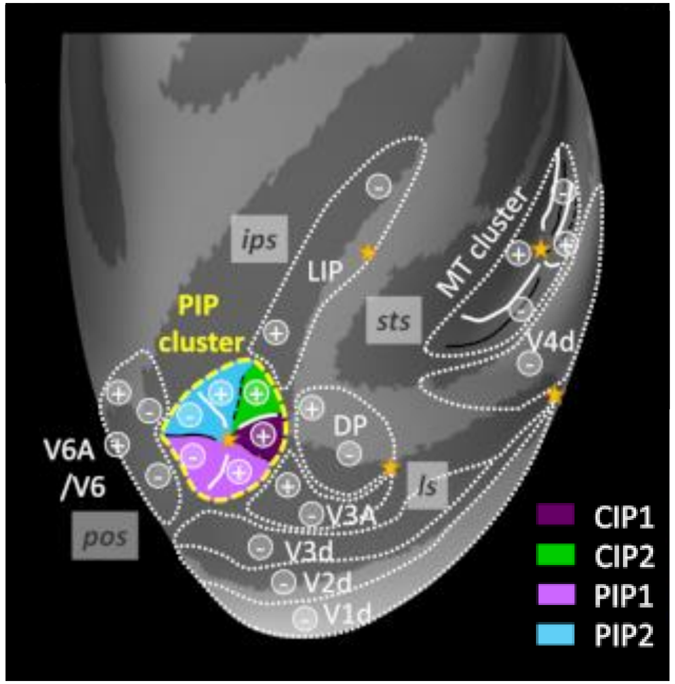
**Stereomotion**

*Héjja-Brichard et al., 2020*

**Disparity gradients**

*Taira et al., 2000; Tsutsui et al., 2002; Durand et al., 2007*

## Retinotopic dissociation




*Rima et al., under review*

# Future directions

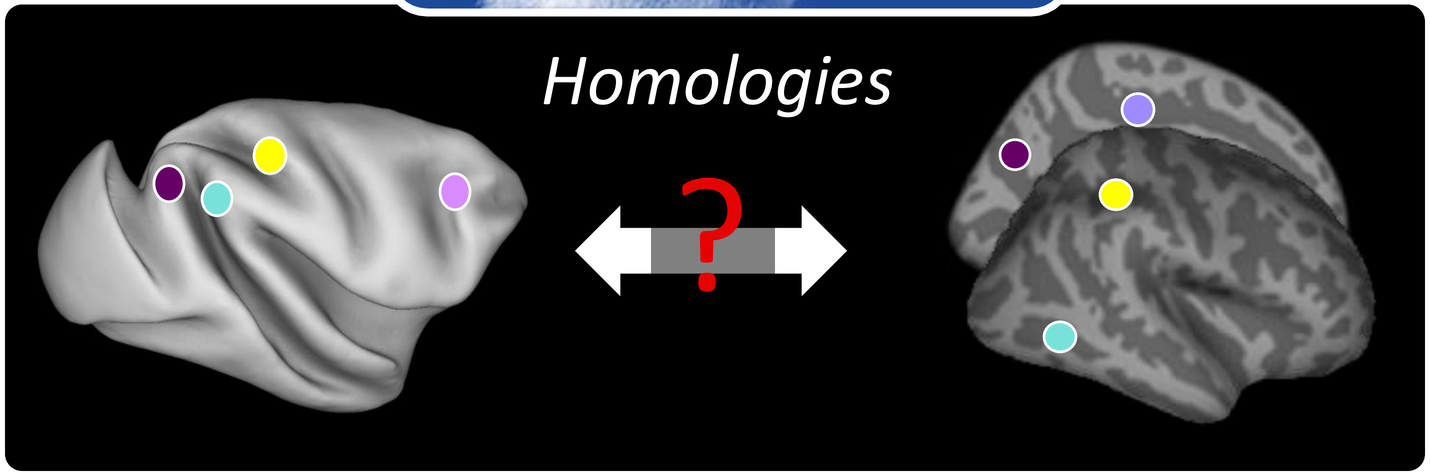
- Stereomotion: other cues and fMRI recording
  - A specific role for the area MT?

  *Sanada & DeAngelis, 2014; Czuba et al., 2014; Joo et al., 2016*

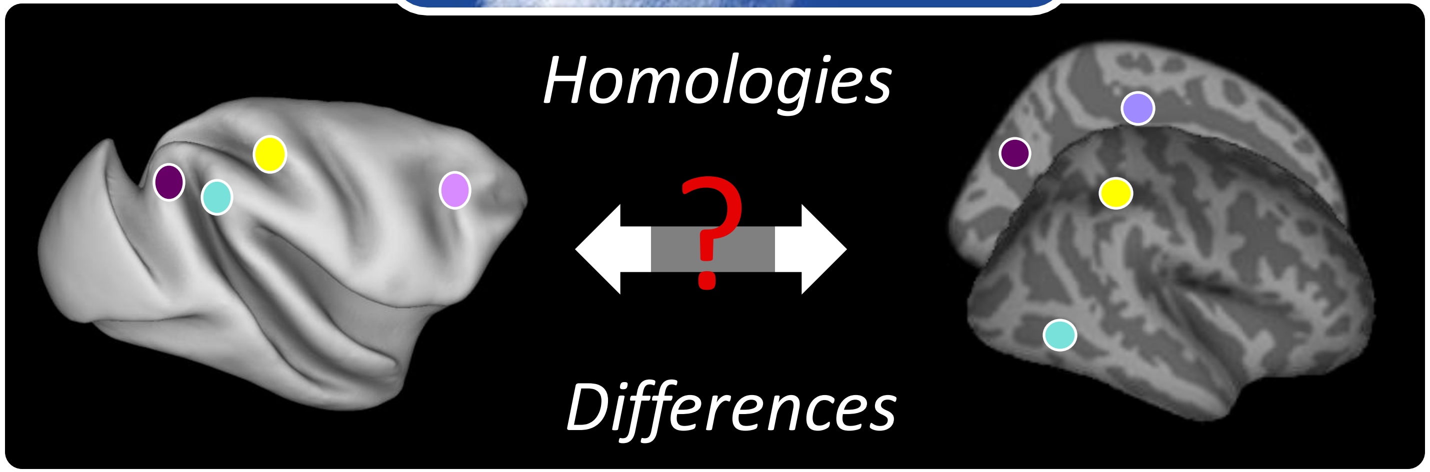
- Better understanding of the link between 3D statistics in natural scenes and visual processing

  *Chauhan, Héjja-Brichard, & Cottereau (under review)*

# Monkey fMRI



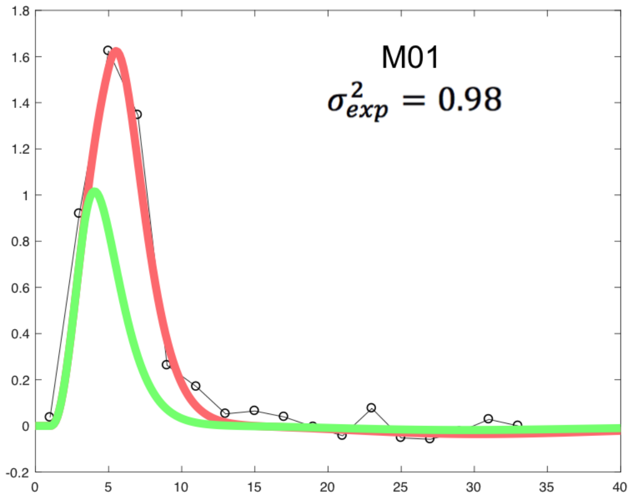

SFR

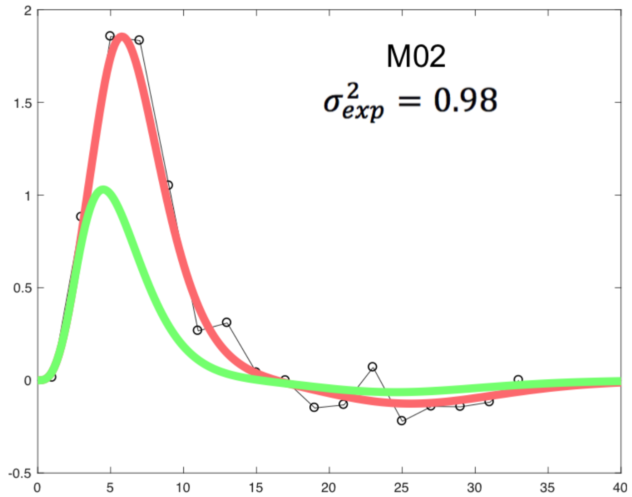

Homologies
?
Differences

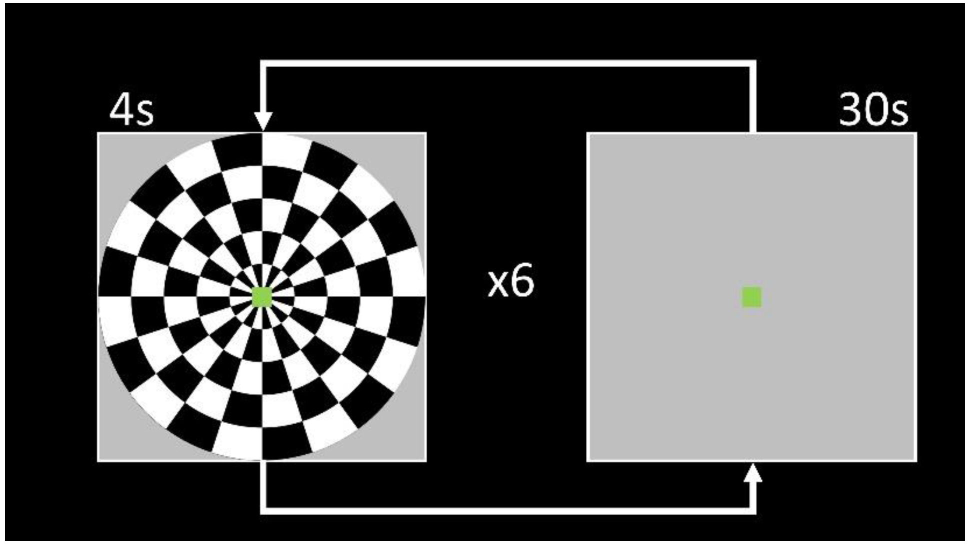
# Thank you for your attention!

# Appendix

# HRF estimation



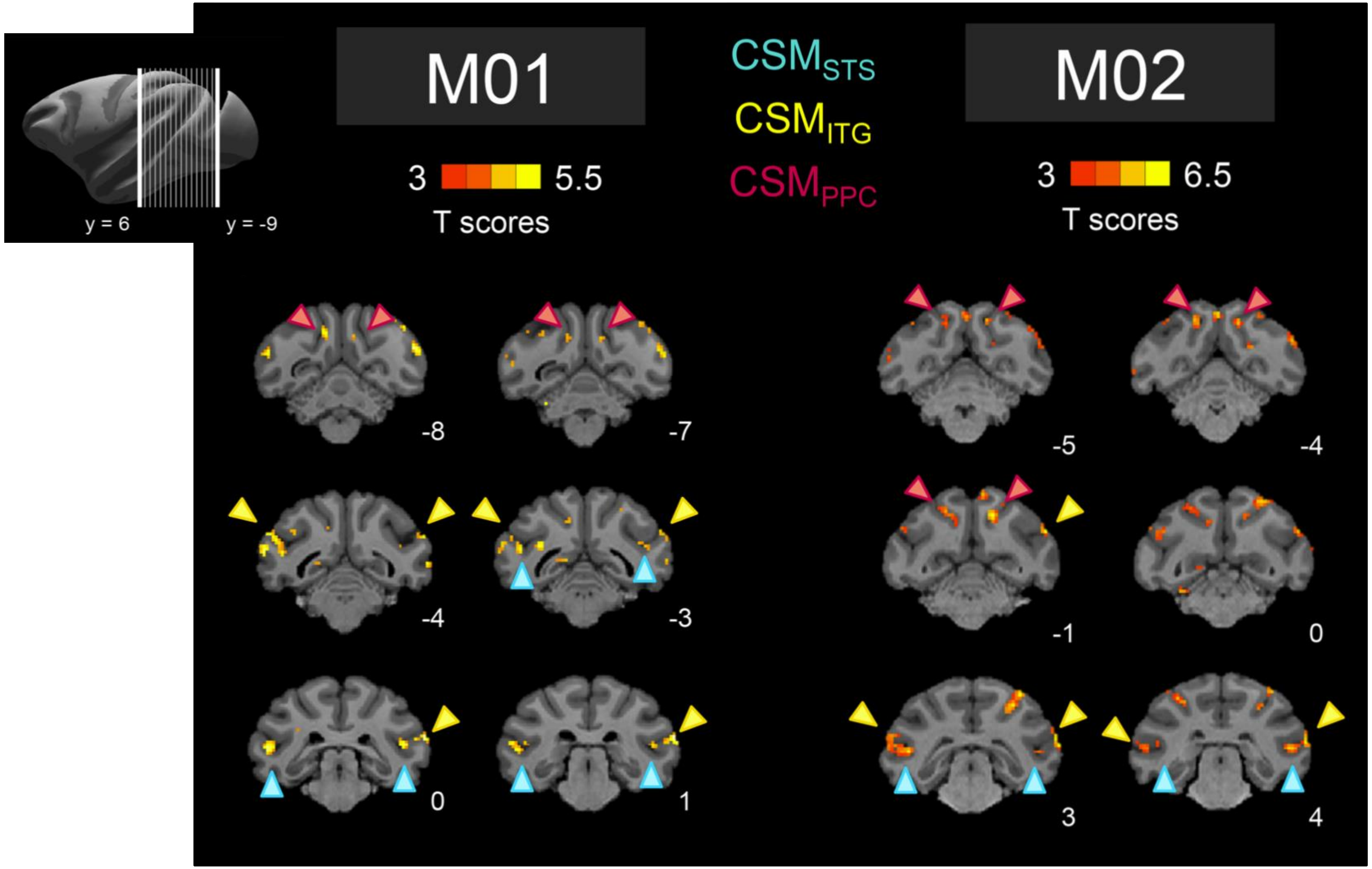



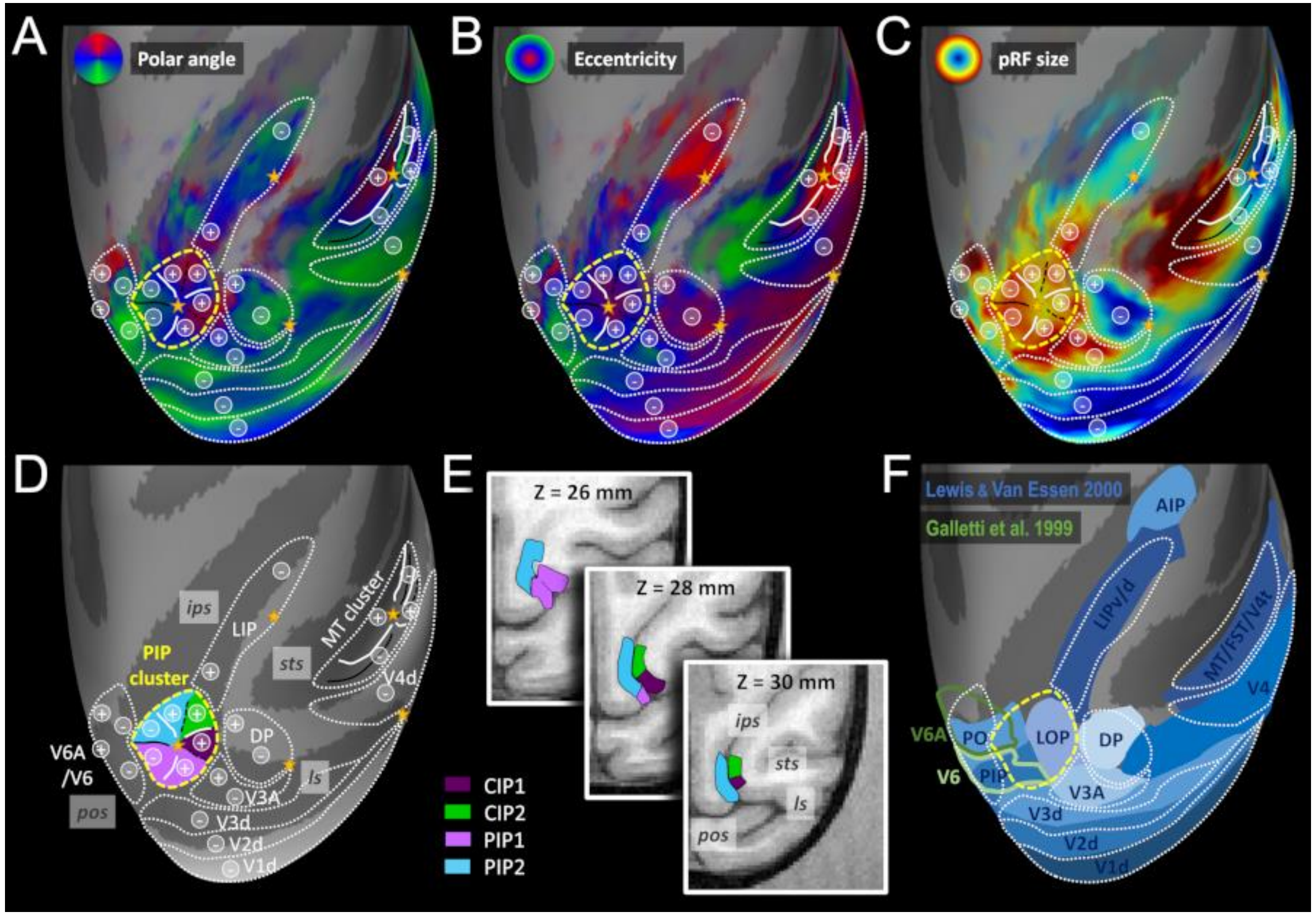

Stimuli: full-field counter phasing (10Hz) checkerboards (40°, 16 sectors) displayed at full contrast, for 4s followed by a 30s blank
One scan = 6 cycles of 34 seconds (total duration: 204s)

| Subject | $\alpha_1$ | $\alpha_2$ | $\beta_1$ | $\beta_2$ | c |
|---|---|---|---|---|---|
| M01 | 2.8572 | 29.9973 | 0.9267 | 2.6957 | 10.0000 |
| M02 | 4.7199 | 24.8772 | 1.2660 | 1.3247 | 6.3917 |

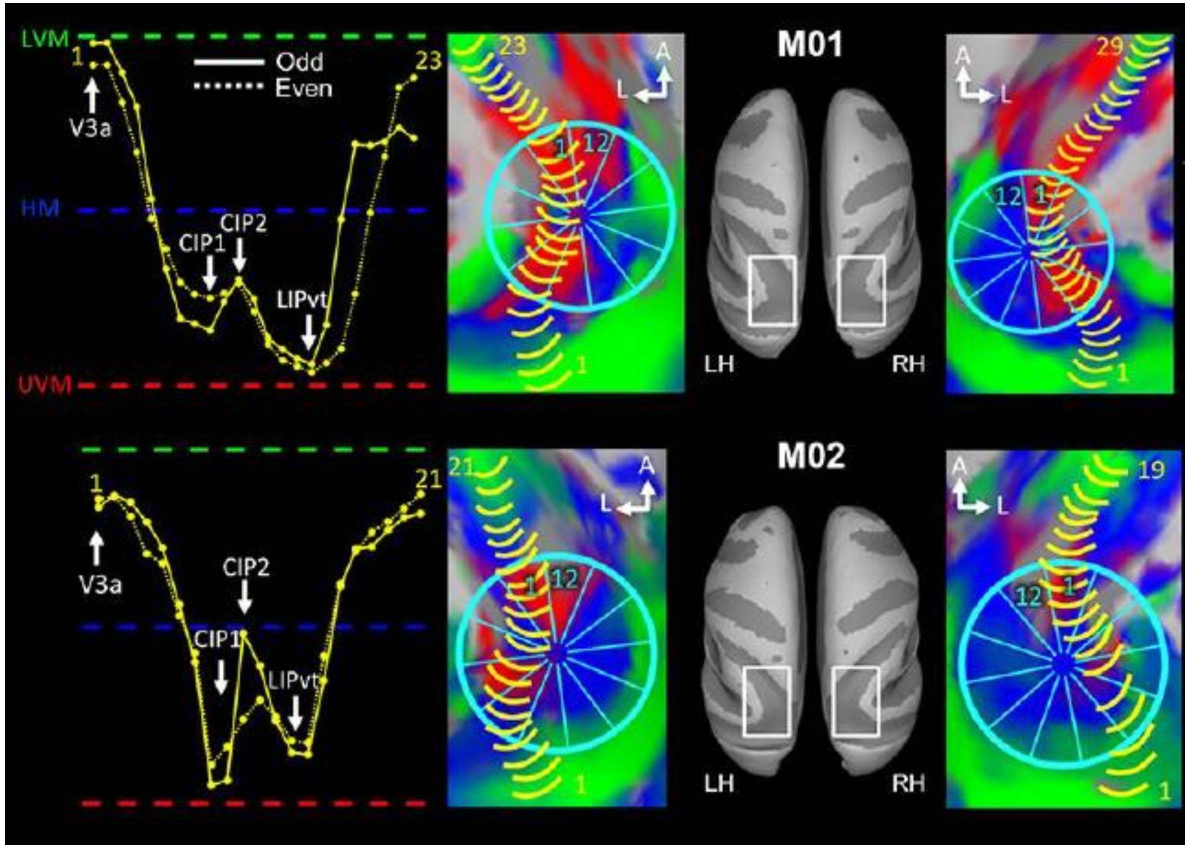
# Results: Projections in the volume



# Retinotopy



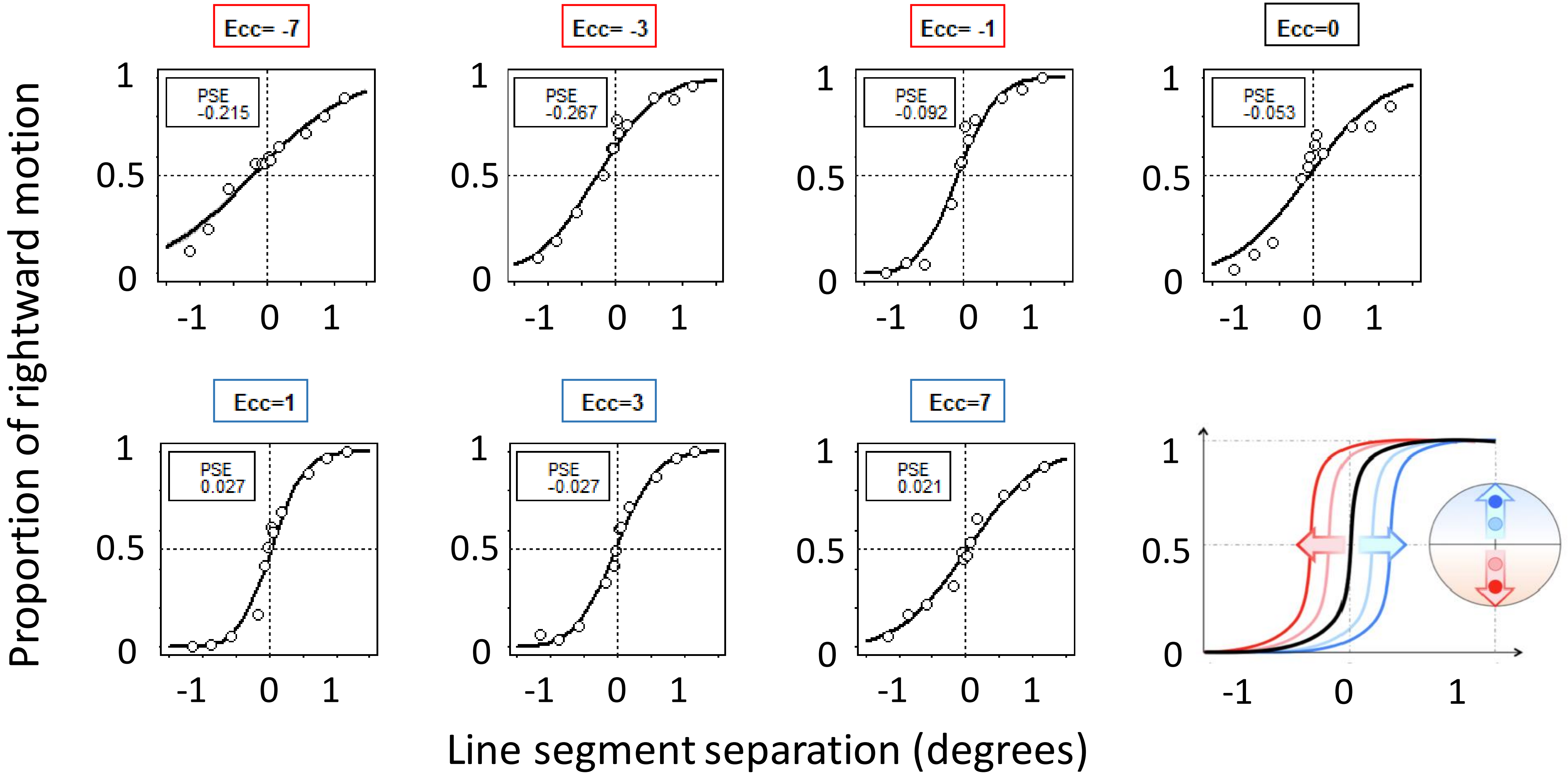

*Rima et al., under review*



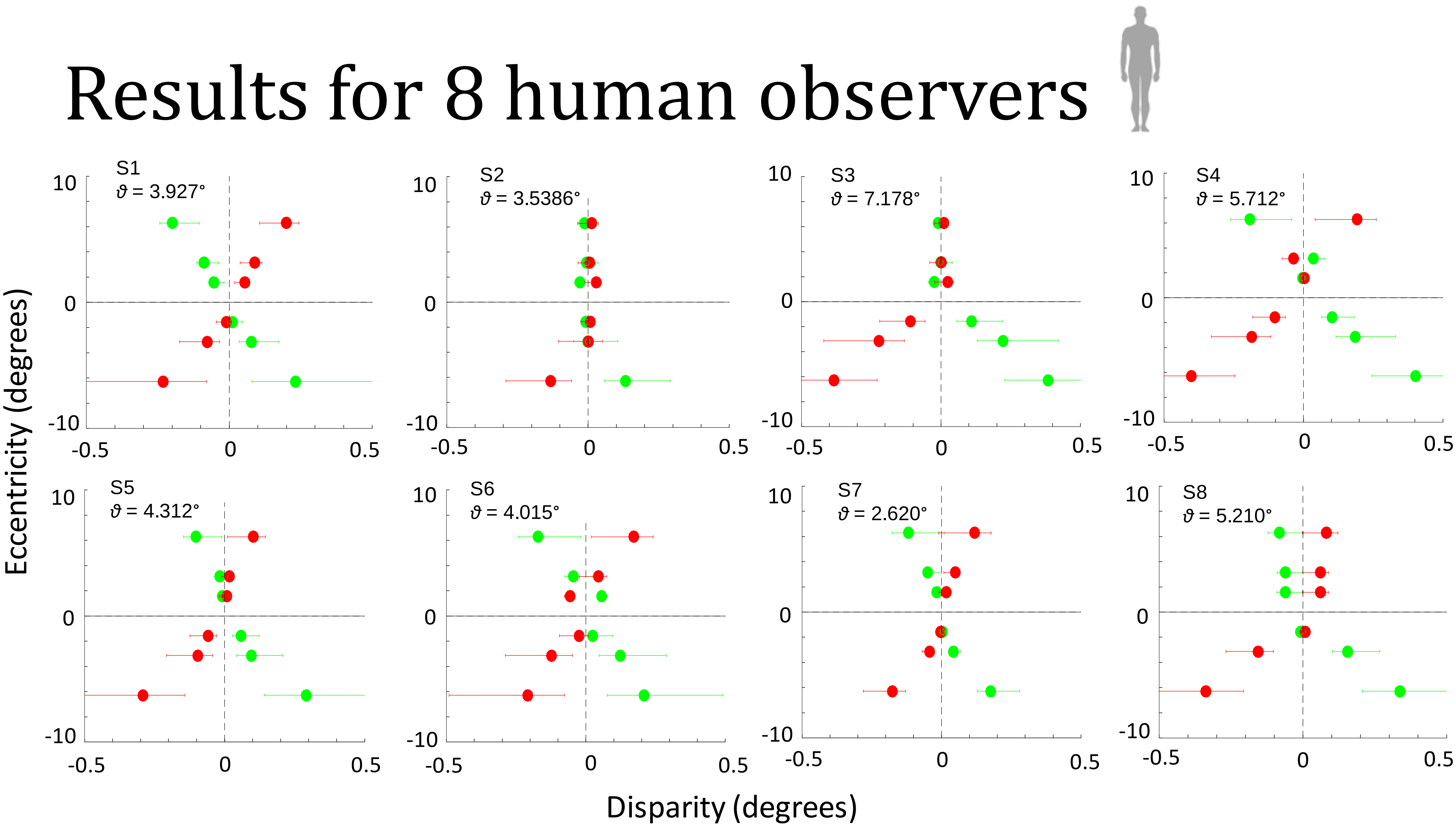

Evolution of polar angle gradients between V3A and LIPvt
→ robust identification of a succession of gradient reversals
→ borders shared by those visuotopic areas.

*Cf. Arcaro et al., 2011*

# Horopter: Results



# Results for 8 human observers



# Horopter: Observers’ characteristics

Optimal shear angle
$\vartheta = 2\ tan^{-1}\ \frac{I}{2h}$

| Subject | IOD (cm) | Eyes height (cm) | Optimal shear angle (degrees) | Shear angle all sessions (degrees) |
|---|---|---|---|---|
| S1 | 6.15 | 153.0 | 2.3028 | 3.927 |
| S2 | 6.30 | 171.5 | 2.1045 | 3.5386 |
| S3 | 6.55 | 166.5 | 2.2537 | 7.1776 |
| S4 | 6.15 | 157.5 | 2.237 | 5.7120 |
| S5 | 6.70 | 169.5 | 2.2645 | 4.3118 |
| S6 | 6.90 | 163.5 | 2.4176 | 4.0147 |
| S7 | 6.03 | 156.0 | 2.2144 | 2.6200 |
| S8 | 6.30 | 169.0 | 2.1356 | 5.2106 |
| M1 | 3.14 | 38 | 4.8973 | 3.01 |

# Selectivity profile along the STS