Stability and plasticity in visual cortex at the resolution of MRI

Professor Brian Wandell
Center for Cognitive and Neurobiological Imaging (CNI)
Neurosciences Institute
Stanford University

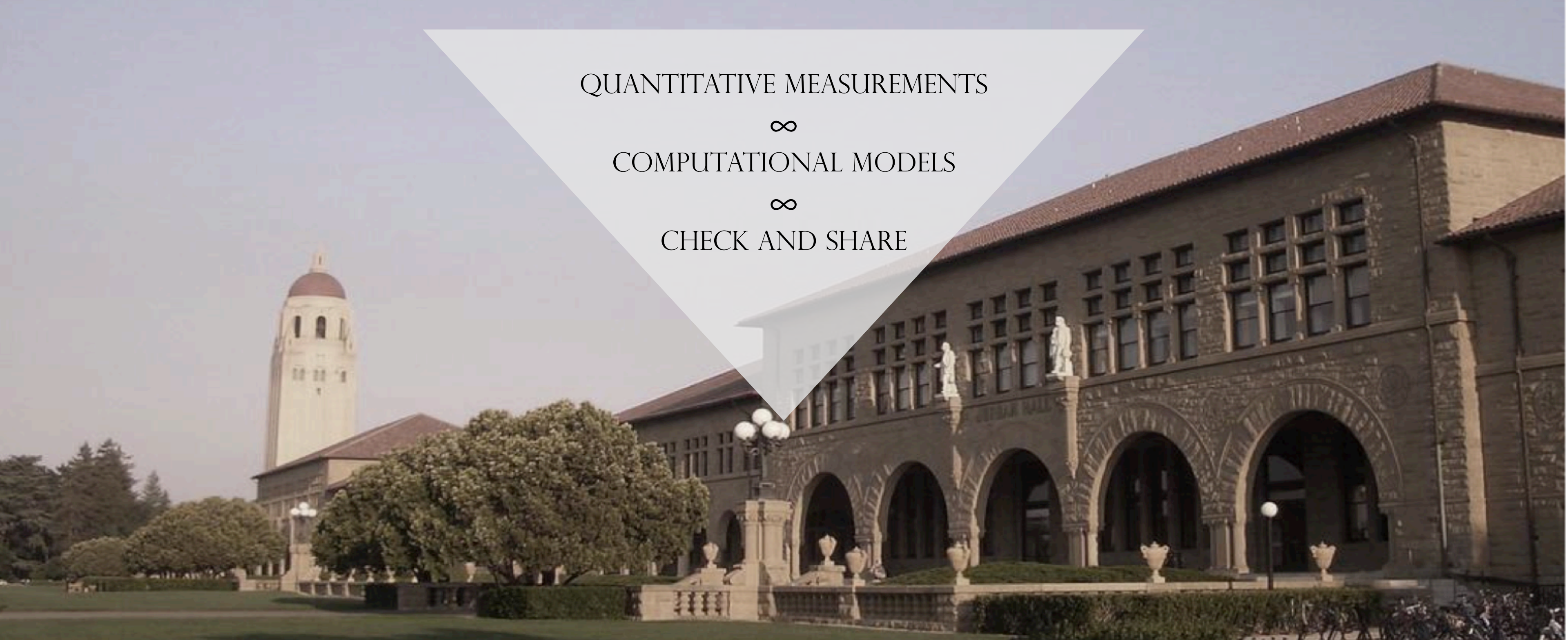
QUANTITATIVE MEASUREMENTS

∞

COMPUTATIONAL MODELS

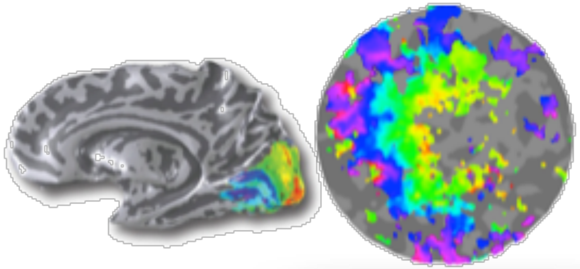
∞

CHECK AND SHARE

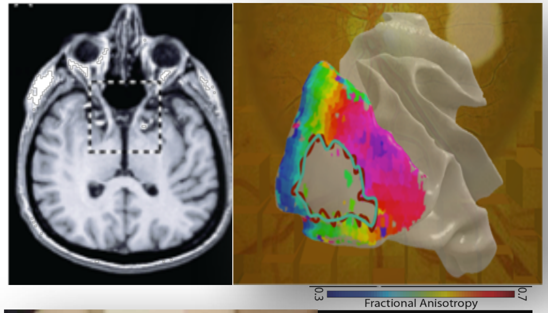


Plasticity and stability in human visual cortex

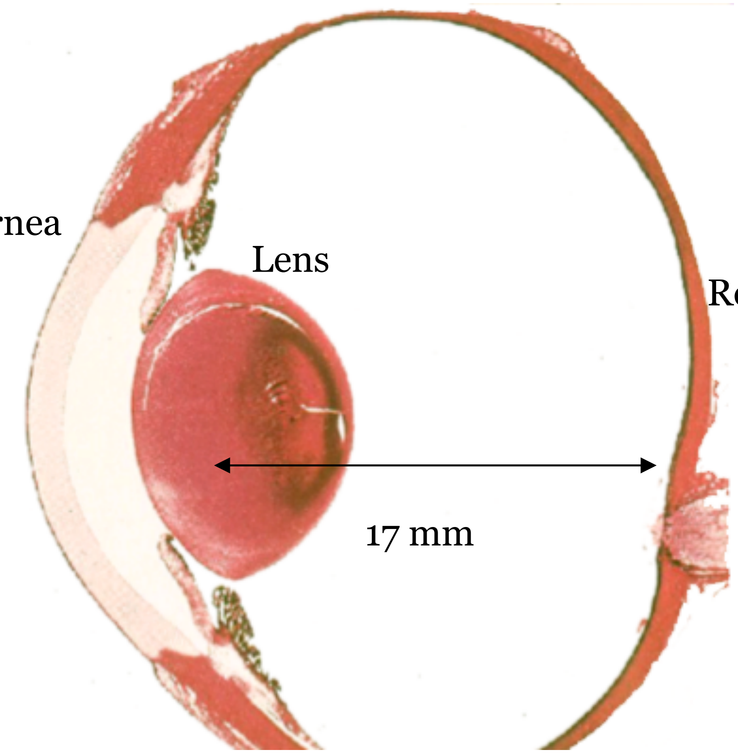
- Experiments measuring stability and plasticity measurements in the **visual pathways**
- Retinal (or optics) dysfunction is a natural experiment for human cortical plasticity



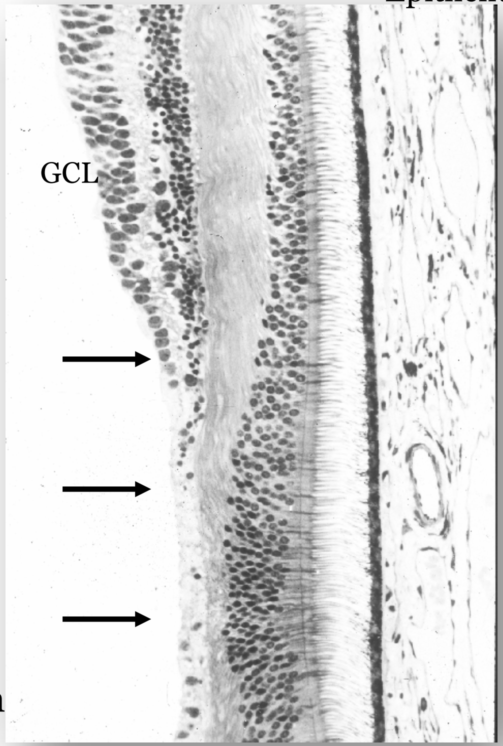
  - Brief methods background
  - V1 maps in (congenital) rod monochromats
  - Achiasmic subjects
  - Retinal lesions (macaque and human JMD)
  - Miracle cures: (restored optics, MM)
  - White matter consequences of retinal disease



Optics, retinal disease, wiring defects are natural plasticity experiments

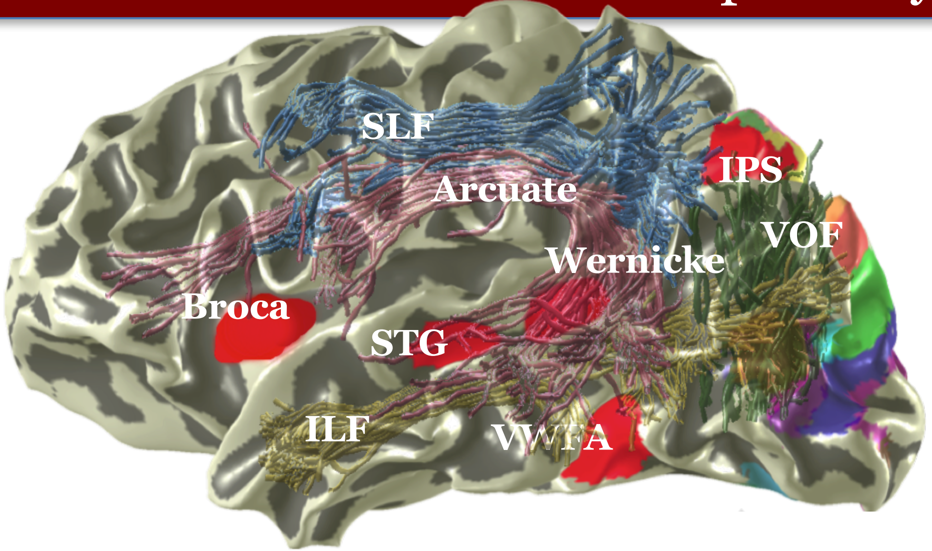


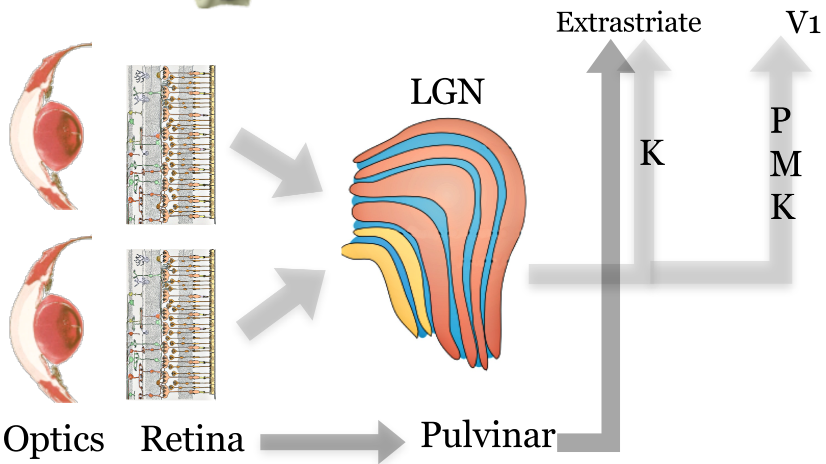
F-number ~ 2.4-11
Pupil diameter ~ 2-8mm



5 x 5 cm x 0.4 mm
5 x 10^6 cones
10^8 rods
10^6 optic nerve fibers

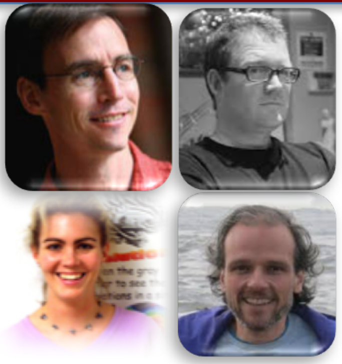
A reminder about the visual pathways



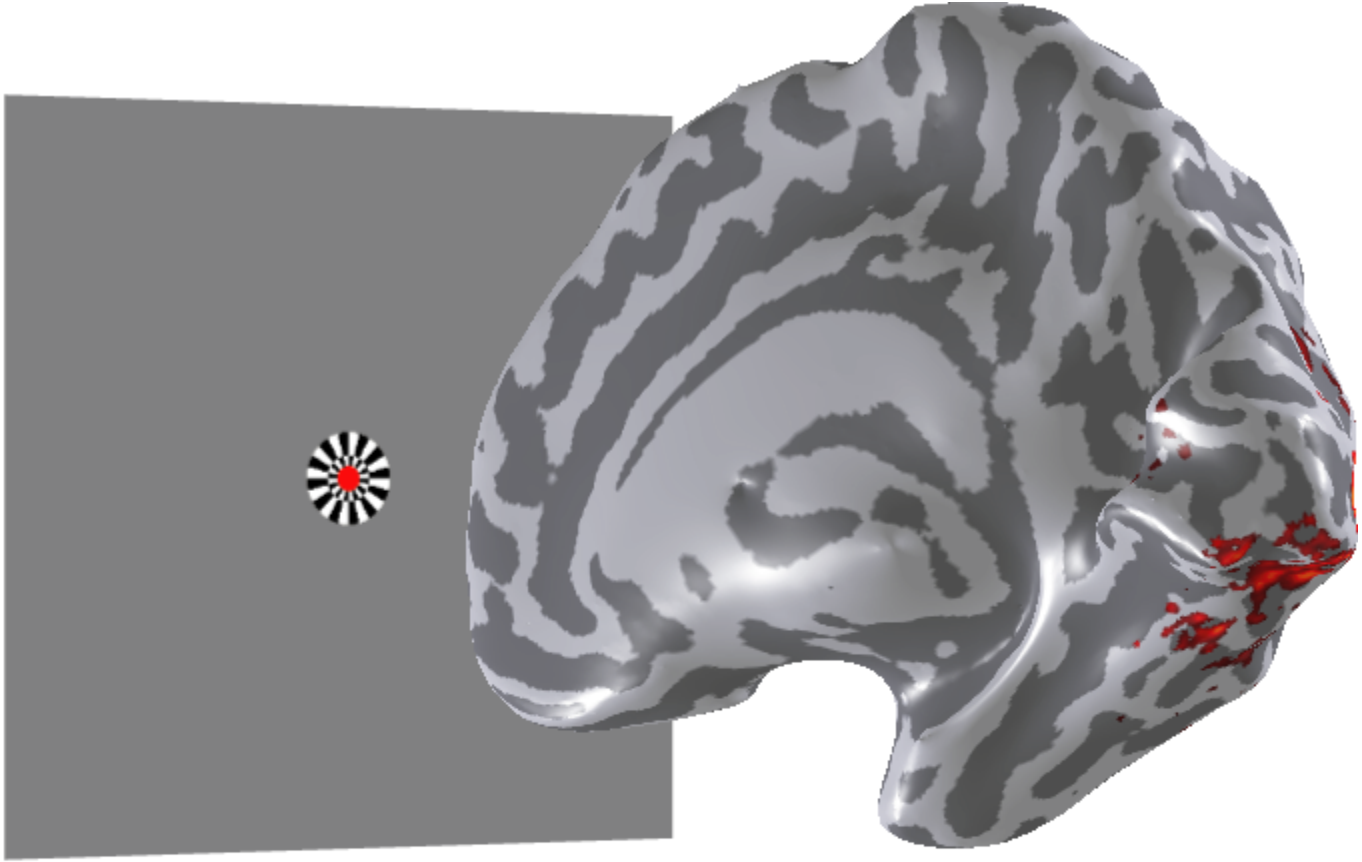


Human eccentricity mapping using fMRI

(Engel et al., 1994,1997; Sereno, 1995; DeYoe 1995)

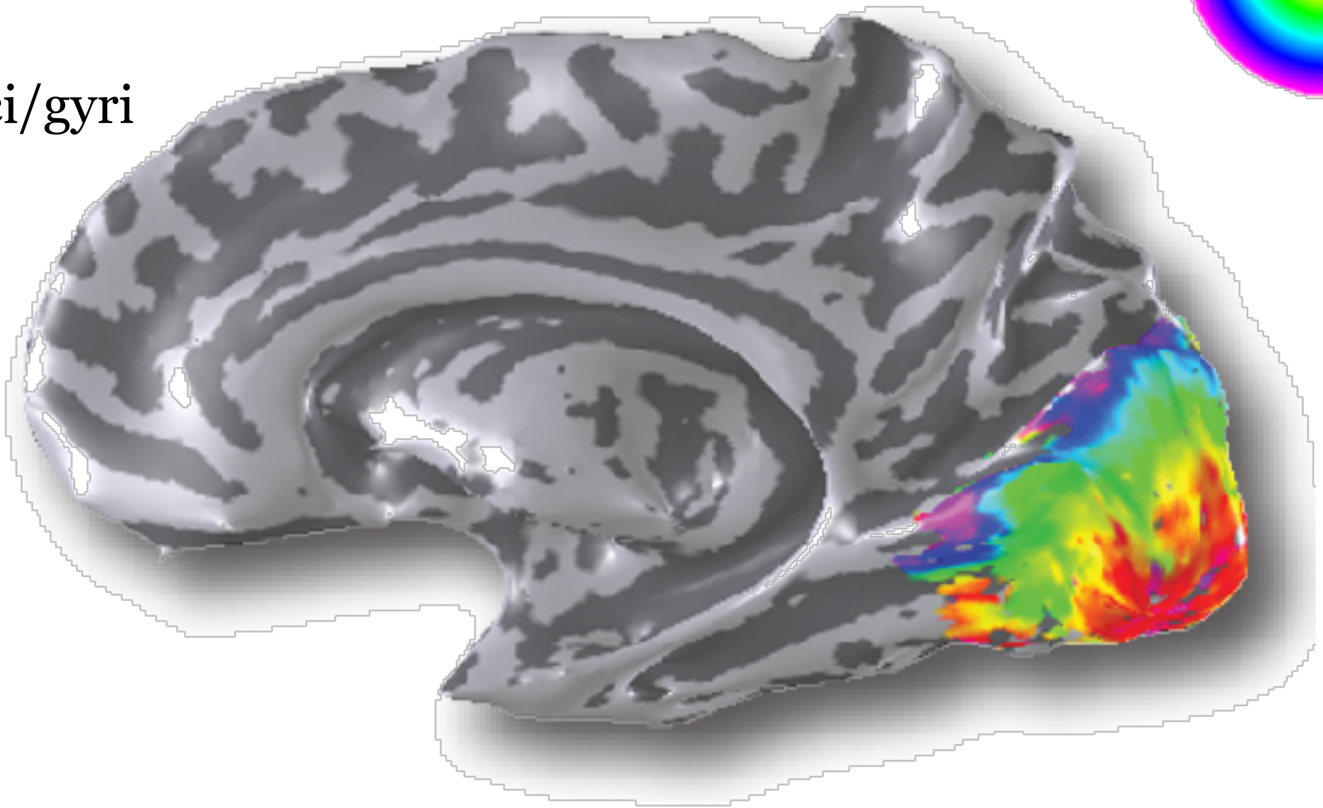


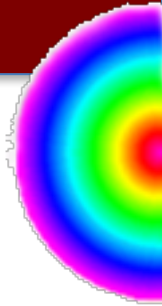
FUNCTIONAL MAGNETIC RESONANCE IMAGING, Figure 1.2 © 2004 Sinauer Associates, Inc.



Pseudo-color representation of visual field map

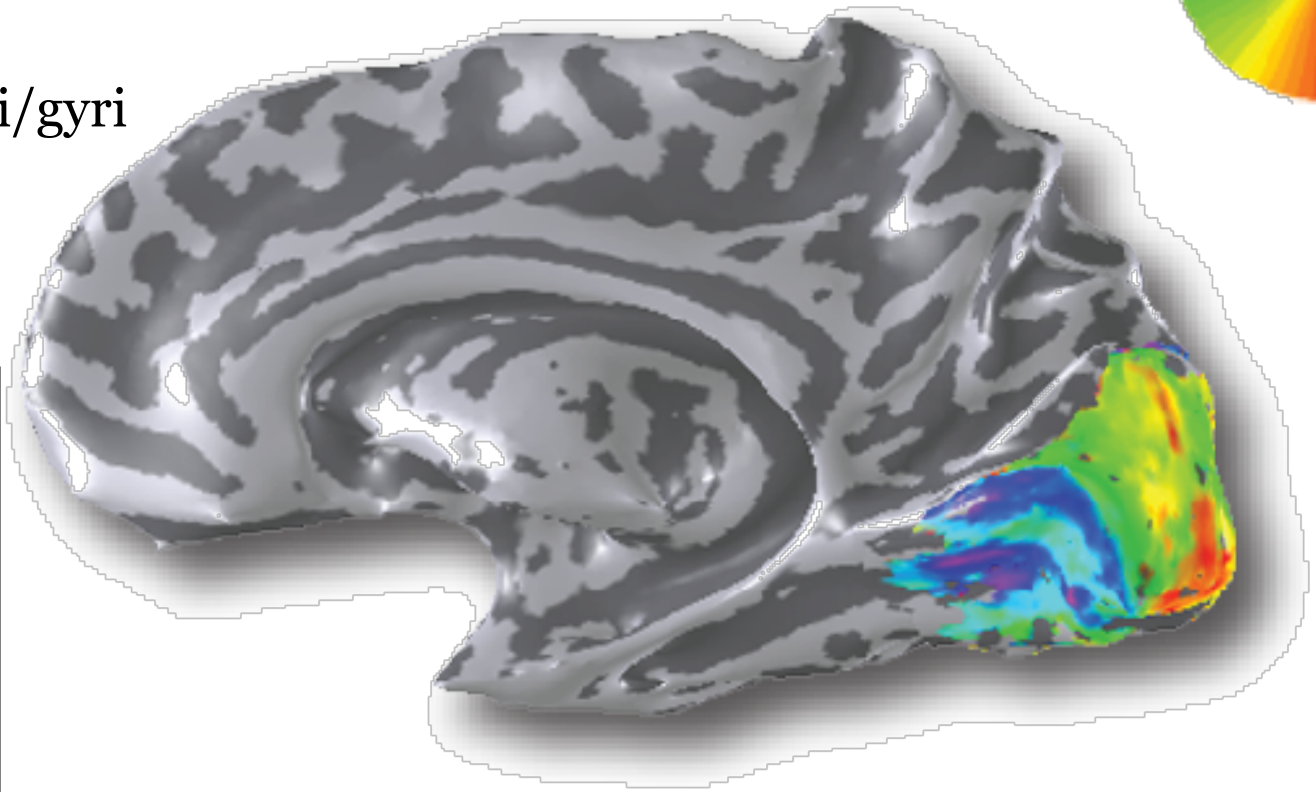
- Inflated and smoothed cortical surface
- Gray/white are sulci/gyri



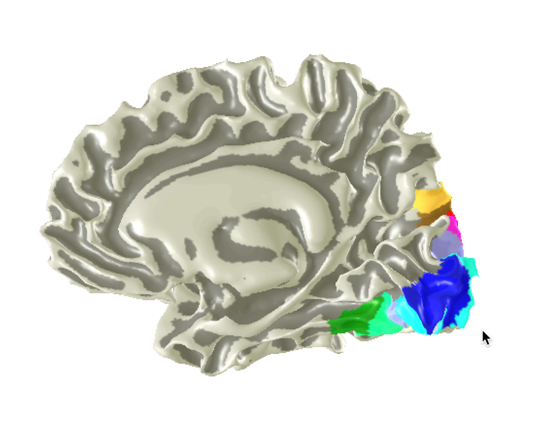


Angular measurements sharply delineate visual field map boundaries

- Inflated and smoothed cortical surface
- Gray/white are sulci/gyri



Visual field map reviews

- Maps tile the occipital lobe
- Extend into IPS and VOT
- Response properties differ
- Identification from gross anatomy

366 Neuron 56, October 25, 2007

Cell PRESS

Neuron
Review

Visual Field Maps in Human Cortex

Brian A. Wandell,[1,*] Serge O. Dumoulin,[1] and Alyssa A. Brewer[2]
[1]Psychology Department, Stanford University, Stanford, CA 94305-2130, USA
[2]Department of Cognitive Sciences, University of California, Irvine, Irvine, CA 92697, USA
*Correspondence: wandell@stanford.edu
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Much of the visual cortex is organized into visual field maps: nearby neurons have receptive fields at nearby locations in the image. Mammalian species generally have multiple visual field maps with each species having similar, but not identical, maps. The introduction of functional magnetic resonance imaging made it possible to identify visual field maps in human cortex, including several near (1) medial occipital (V1,V2,V3), (2) lateral occipital (LO-1,LO-2, hMT+), (3) ventral occipital (hV4, VO-1, VO-2), (4) dorsal occipital (V3A, V3B), and (5) posterior parietal cortex (IPS-0 to IPS-4). Evidence is accumulating for additional maps, including some in the frontal lobe. Cortical maps are arranged into clusters in which several maps have parallel eccentricity representations, while the angular representations within a cluster alternate in visual field sign. Visual field maps have been linked to functional and perceptual properties of the visual system at various spatial scales, ranging from the level of individual maps to map clusters to dorsal-ventral streams. We survey recent measurements of human visual field maps, describe hypotheses about the function and relationships between maps, and consider methods to improve map measurements and characterize the response properties of neurons comprising these maps.

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Review

Imaging retinotopic maps in the human brain

Brian A. Wandell *, Jonathan Winawer
Psychology Department, Stanford University, Stanford, CA 94305, United States

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ABSTRACT

A quarter-century ago visual neuroscientists had little information about the number and organization of retinotopic maps in human visual cortex. The advent of functional magnetic resonance imaging (MRI), a non-invasive, spatially-resolved technique for measuring brain activity, provided a wealth of data about human retinotopic maps. Just as there are differences amongst non-human primate maps, the human maps have their own unique properties. Many human maps can be measured reliably in individual sub-

Population receptive fields: Across maps and within maps

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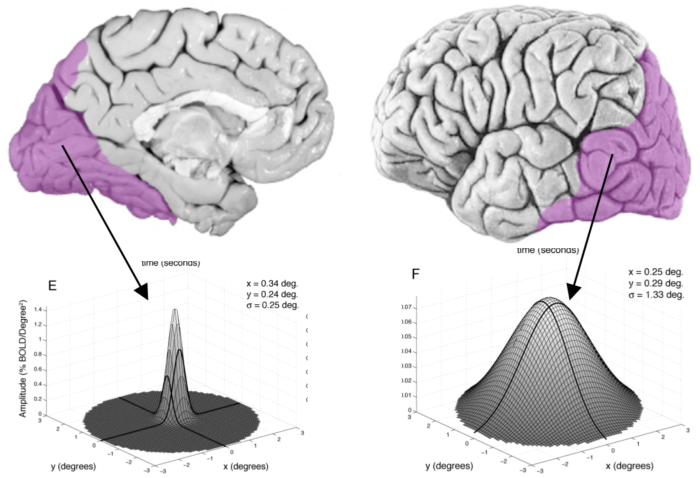
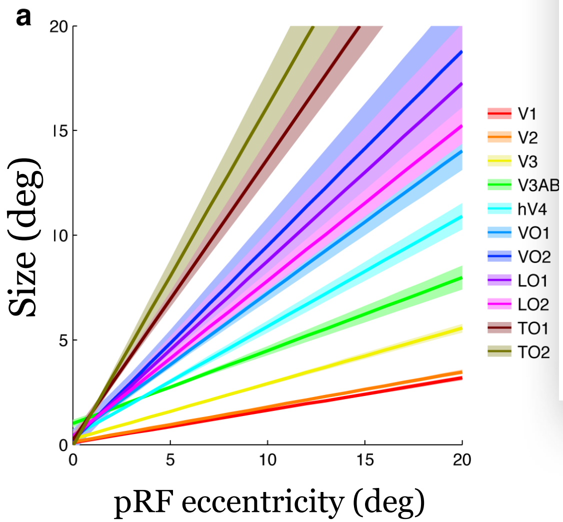
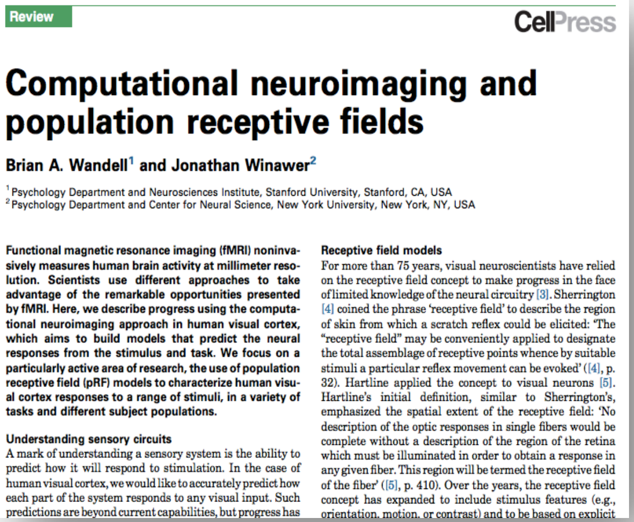
June 2015, Vol. 19, No. 6 349






Review

CellPress

Computational neuroimaging and population receptive fields

Brian A. Wandell[1] and Jonathan Winawer[2]

[1] Psychology Department and Neurosciences Institute, Stanford University, Stanford, CA, USA
[2] Psychology Department and Center for Neural Science, New York University, New York, NY, USA

Functional magnetic resonance imaging (fMRI) noninvasively measures human brain activity at millimeter resolution. Scientists use different approaches to take advantage of the remarkable opportunities presented by fMRI. Here, we describe progress using the computational neuroimaging approach in human visual cortex, which aims to build models that predict the neural responses from the stimulus and task. We focus on a particularly active area of research, the use of population receptive field (pRF) models to characterize human visual cortex responses to a range of stimuli, in a variety of tasks and different subject populations.

Understanding sensory circuits

A mark of understanding a sensory system is the ability to predict how it will respond to stimulation. In the case of human visual cortex, we would like to accurately predict how each part of the system responds to any visual input. Such predictions are beyond current capabilities, but progress has

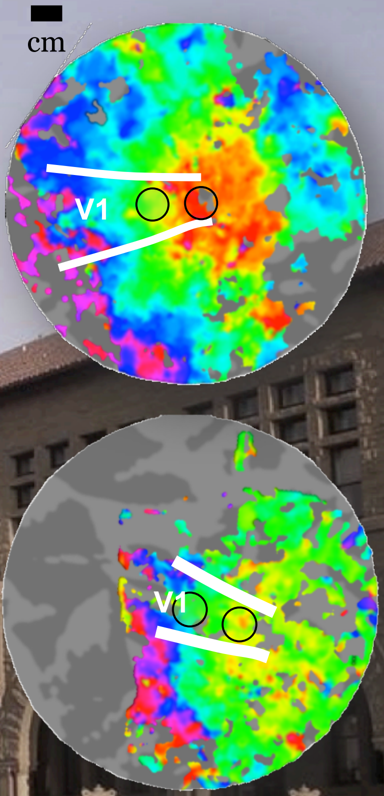
Receptive field models

For more than 75 years, visual neuroscientists have relied on the receptive field concept to make progress in the face of limited knowledge of the neural circuitry [3]. Sherrington [4] coined the phrase 'receptive field' to describe the region of skin from which a scratch reflex could be elicited: 'The "receptive field" may be conveniently applied to designate the total assemblage of receptive points whence by suitable stimuli a particular reflex movement can be evoked' ([4], p. 32). Hartline applied the concept to visual neurons [5]. Hartline's initial definition, similar to Sherrington's, emphasized the spatial extent of the receptive field: 'No description of the optic responses in single fibers would be complete without a description of the region of the retina which must be illuminated in order to obtain a response in any given fiber. This region will be termed the receptive field of the fiber' ([5], p. 410). Over the years, the receptive field concept has expanded to include stimulus features (e.g., orientation, motion, or contrast) and to be based on explicit

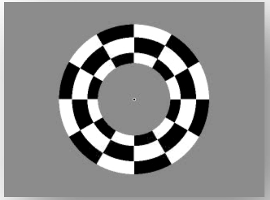
- Attention
- Stability and Plasticity
- Prosopagnosia
- Development and aging
- Autism
- Alzheimer's disease

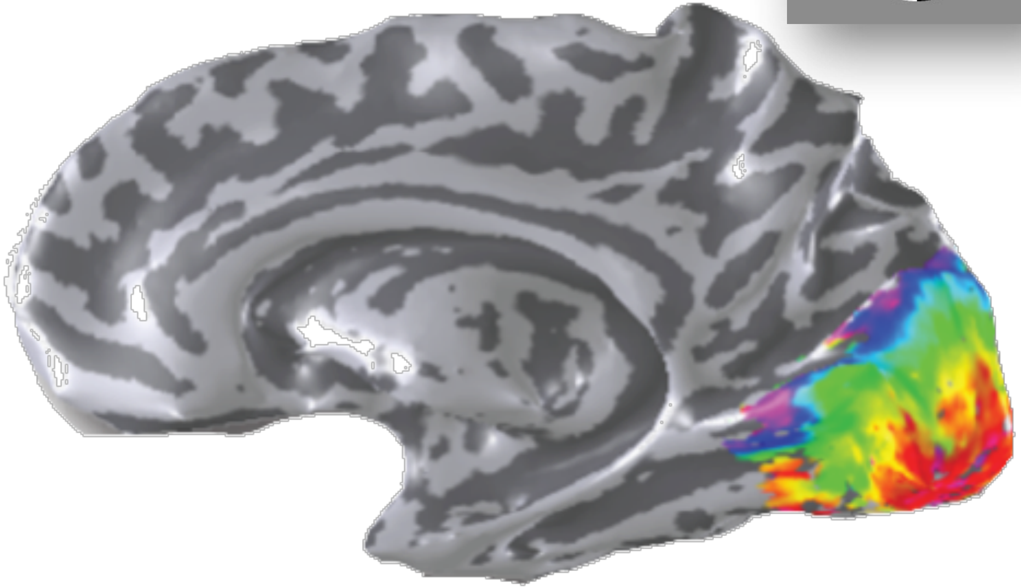
Cortical development with congenital photoreceptor abnormalities

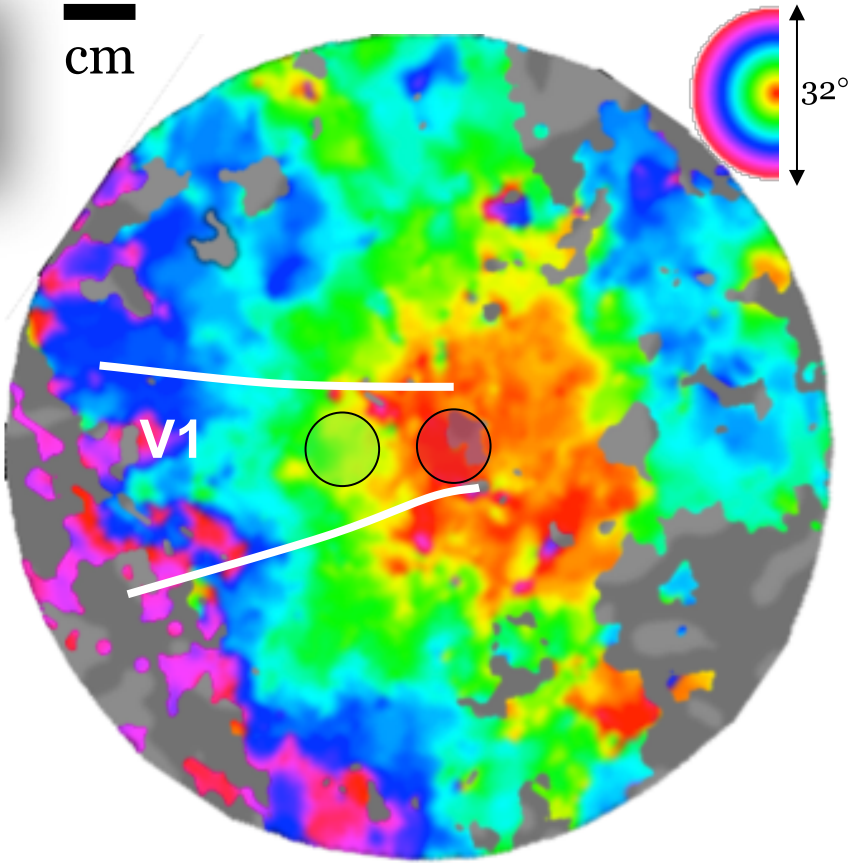
Reorganization of human cortical maps caused by inherited photoreceptor abnormalities (2002).
Baseler, et al. Nature Neuroscience



Flattened representation of typical cone-driven eccentricity map

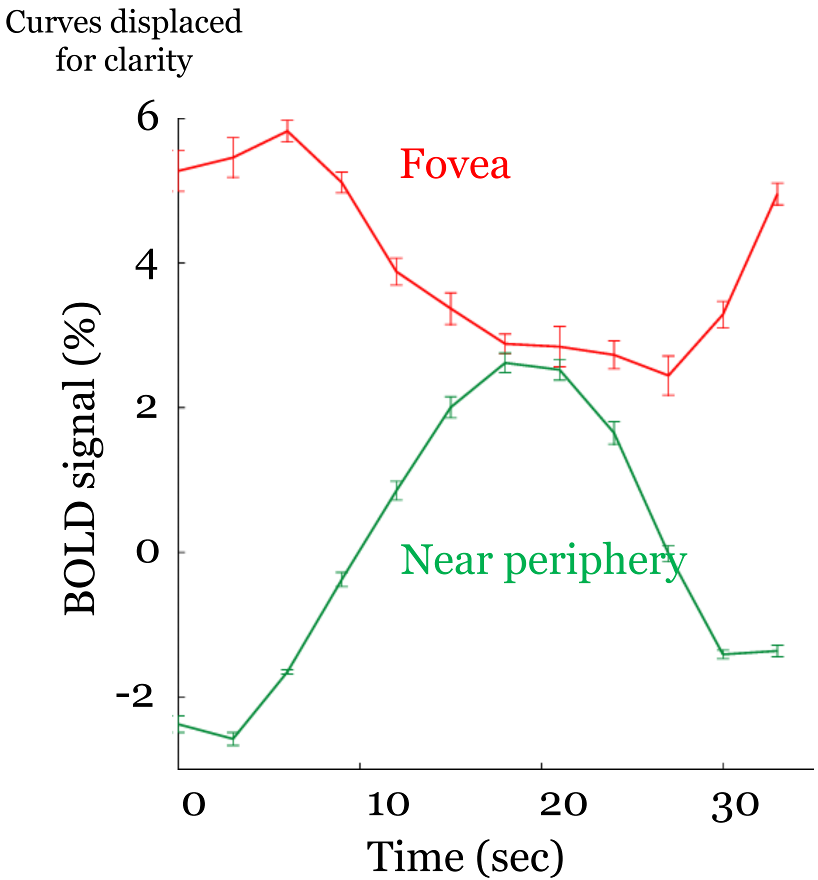


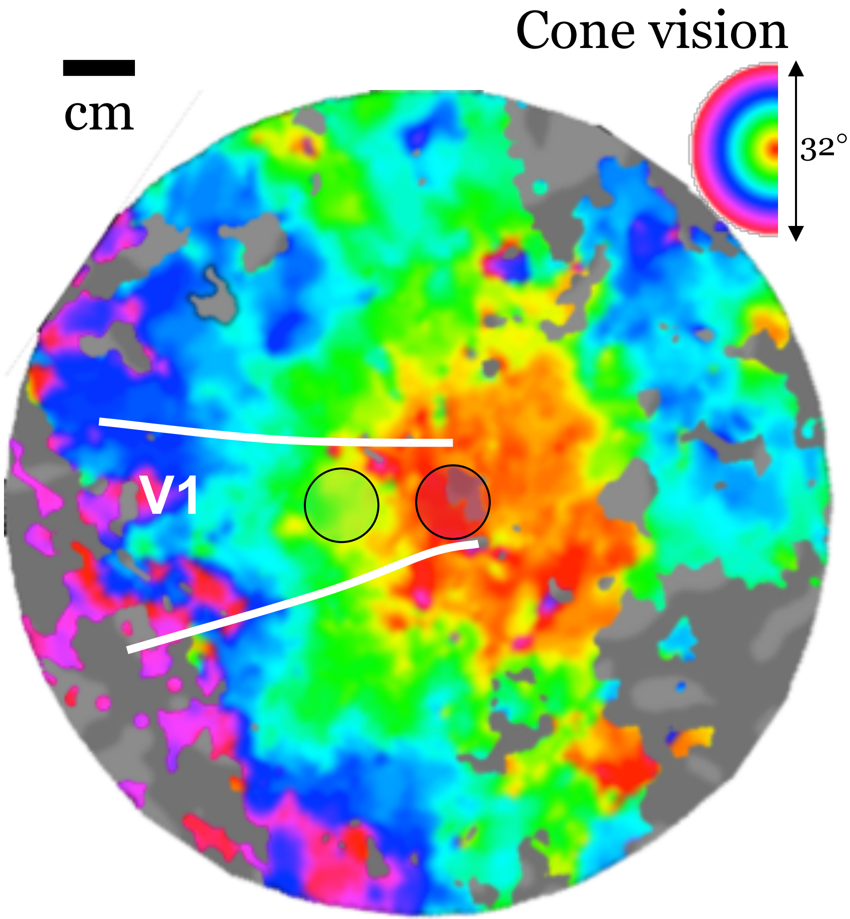




Baseler et al., (2002) Nature Neuroscience

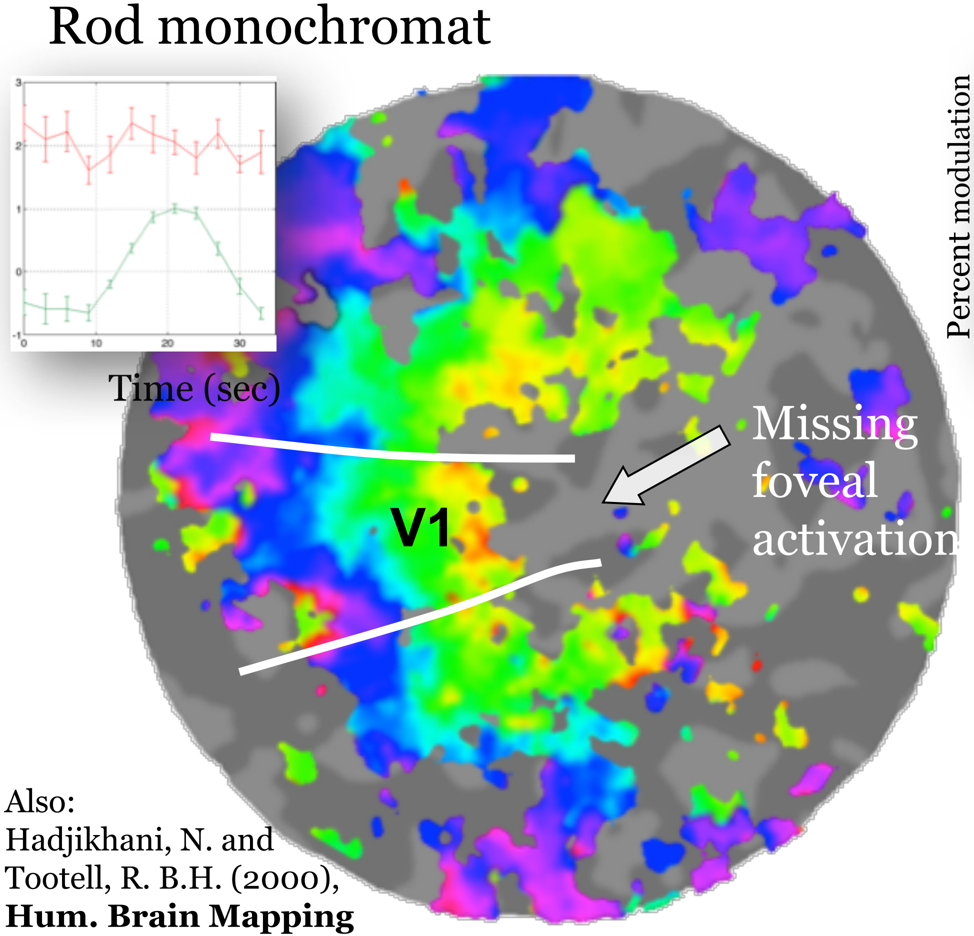
Flattened representation of typical cone-driven eccentricity map

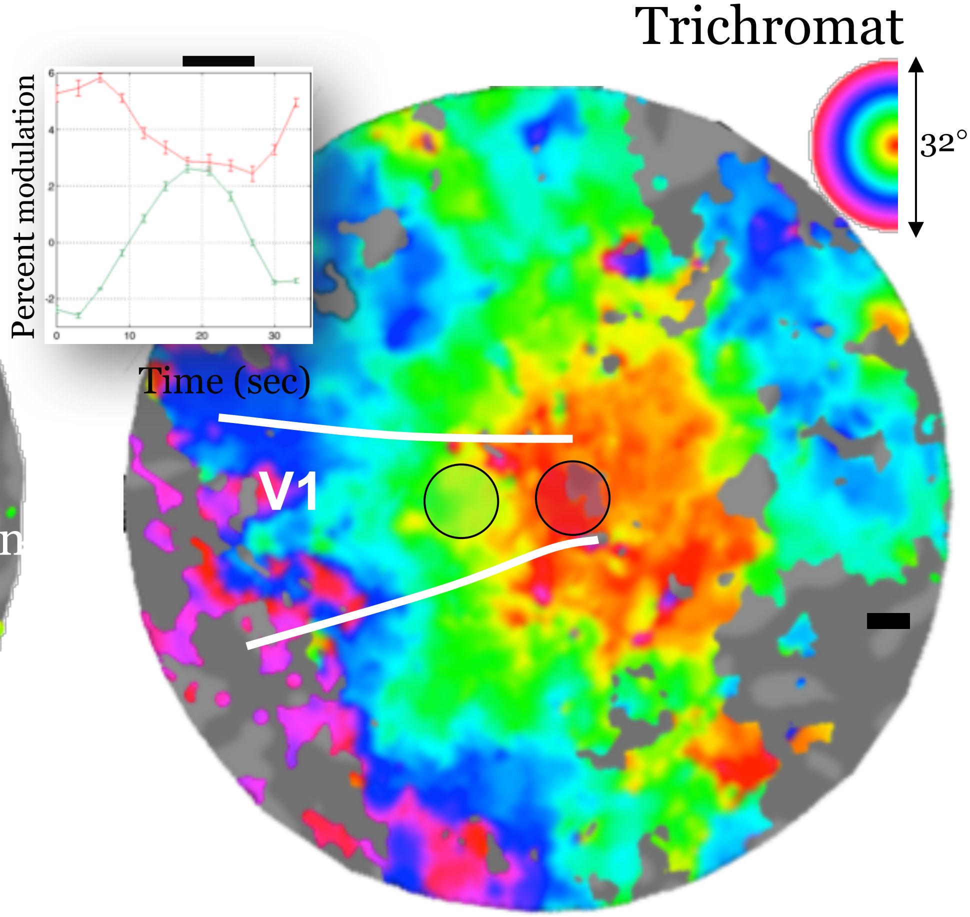




Baseler et al., (2002) Nature Neuroscience

Rod signals in control: No response in central representation

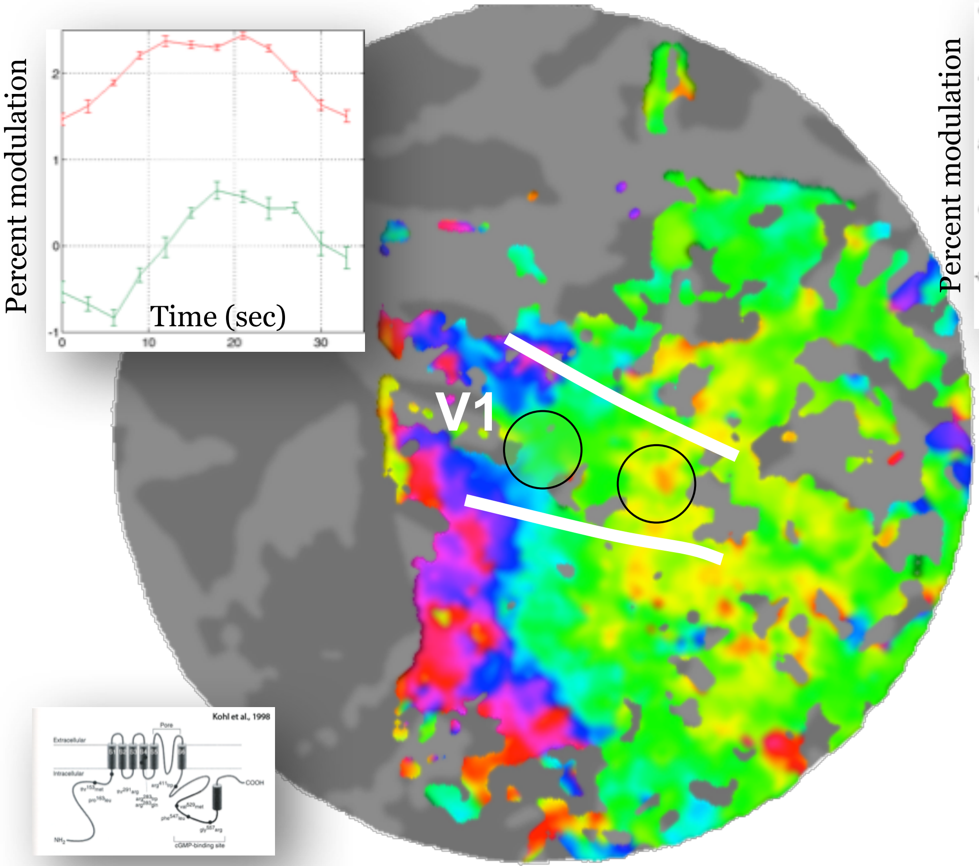




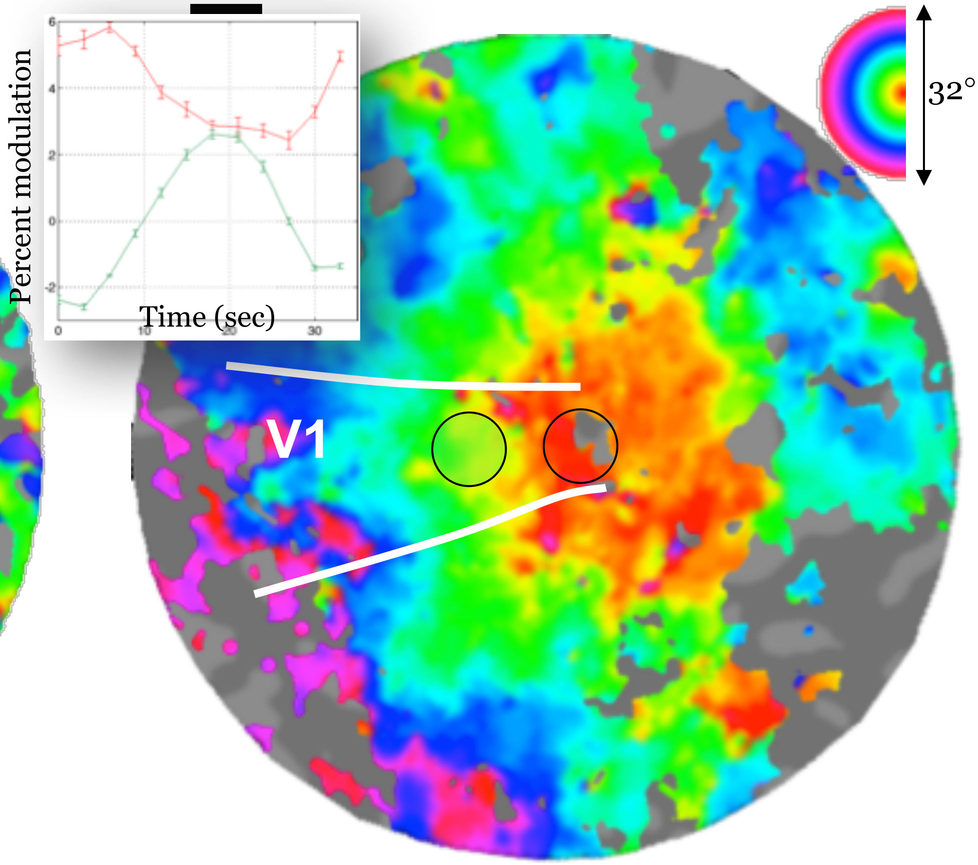
Also:
Hadjikhani, N. and Tootell, R. B.H. (2000), **Hum. Brain Mapping**

Rod monochromats: develop a visual response in the corresponding region

Rod monochromat



Trichromat



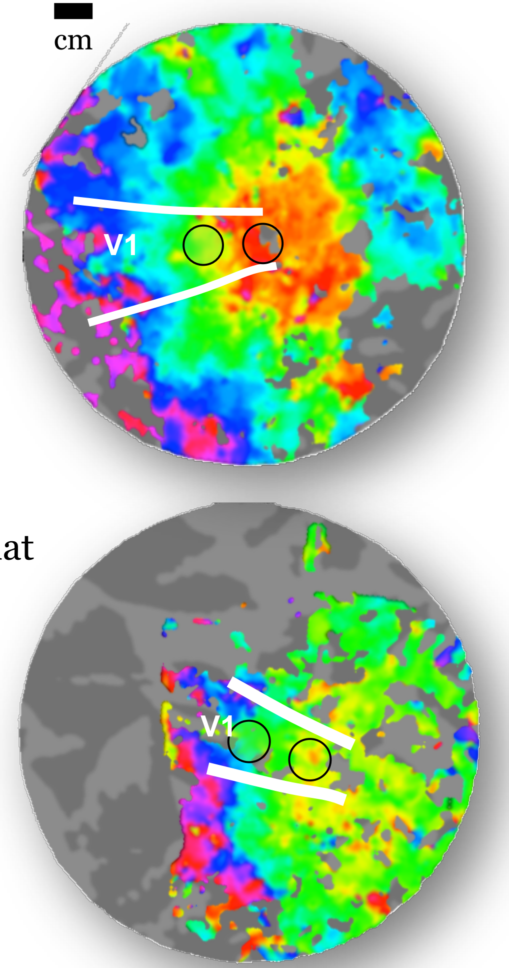
Summary

Congenital disruption of the cone transduction cascade changes the mapping from retina to V1, and probably impacting many systems (e.g., eye movements).

Implications for understanding the downstream consequences of genetic diseases.

Trichromat

Rod monochromat



Baseler et al., (2002) Nature Neuroscience

Congenital development: achiasmia

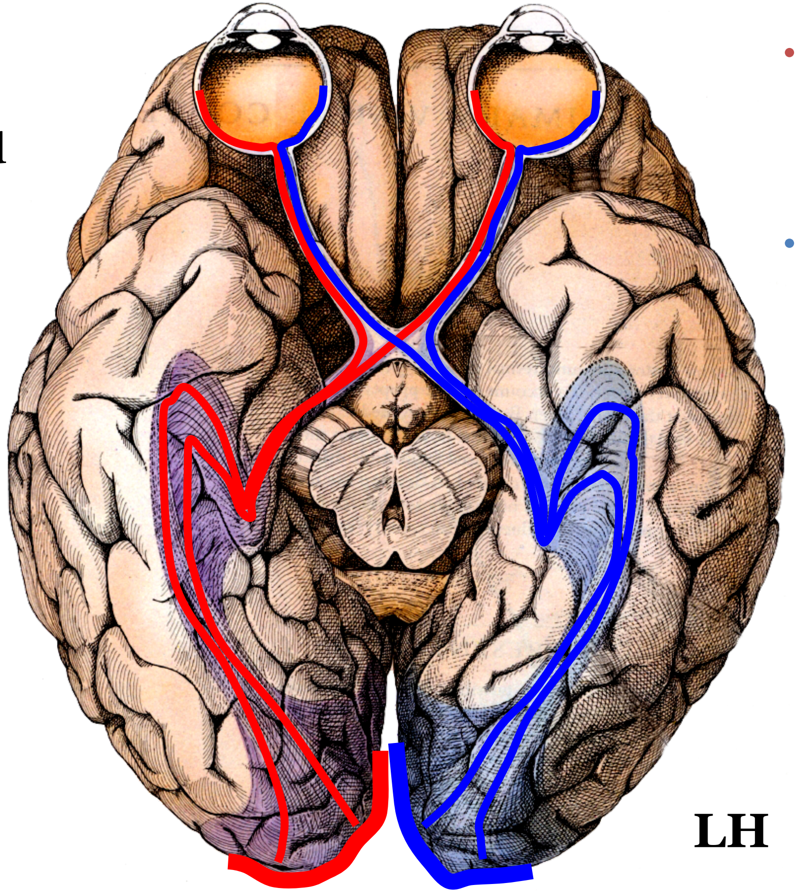
Plasticity and stability of the visual system in human achiasma (2012). Hoffman, et al. Neuron

Frisby, Illusion Brain and Mind

Major projections from retina to V1

Right visual field

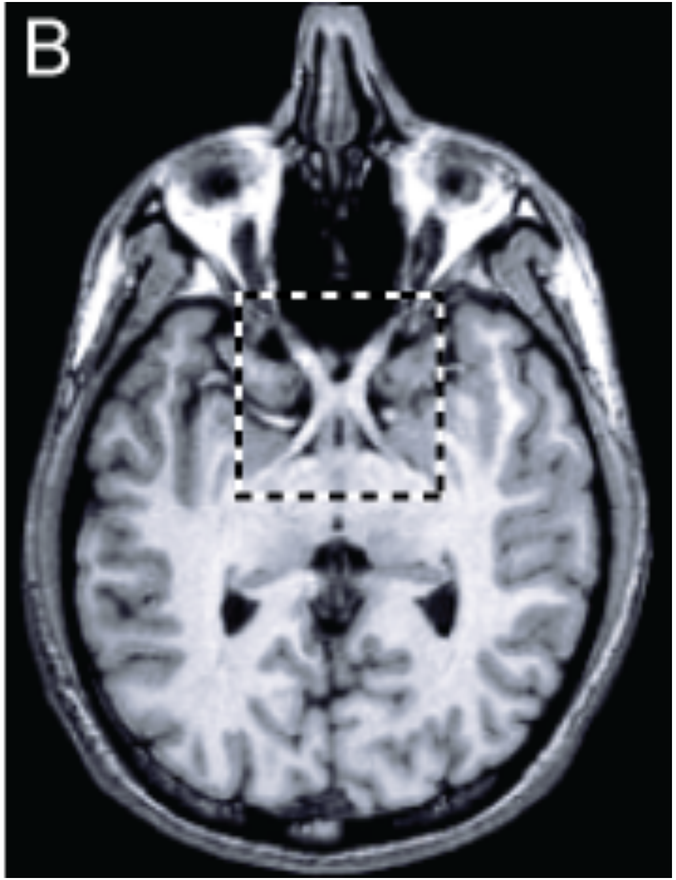
Left visual field



- Right visual field
  - left temporal retina
  - right nasal retina
- Left visual field
  - right temporal retina
  - left nasal retina

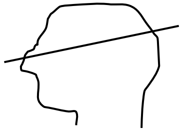
Molecular guidance at chiasm mediated by Ephrin-B2 and EphB1 (Williams et al., 2003, Neuron)

The optic chiasm is easy to see in a T1-weighted MRI

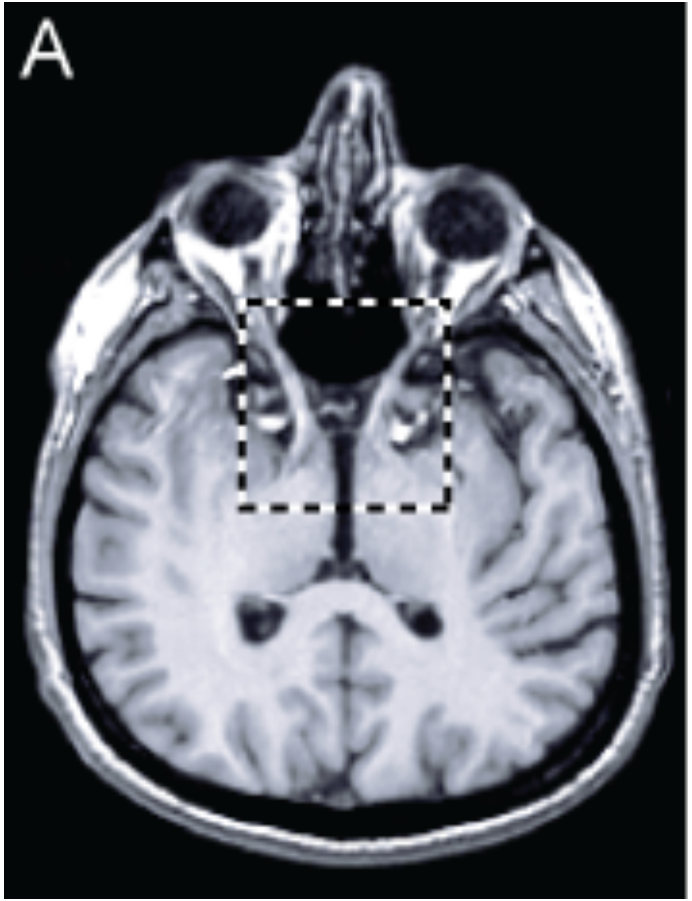


Conventional optic chiasm

Control

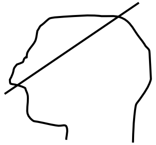


This subject doesn’t have an optic chiasm



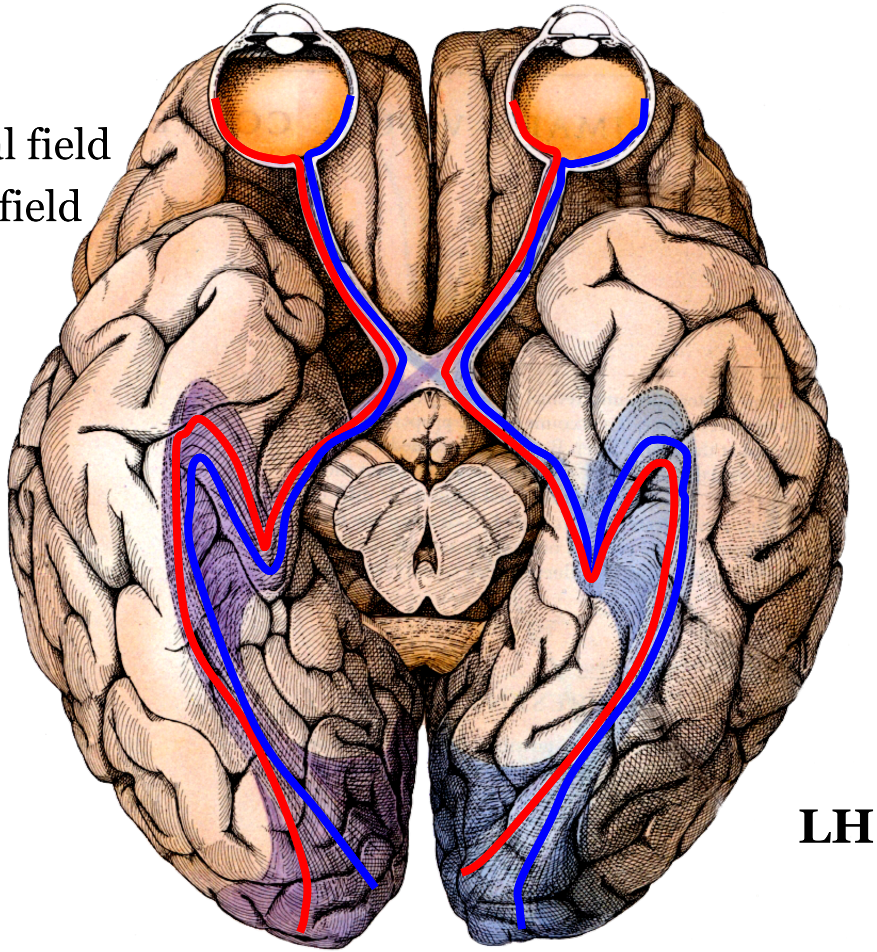
Missing optic chiasm

Achiasma



In the achiasmic, each eye maps to the ipsilateral cortex

Right visual field
Left visual field

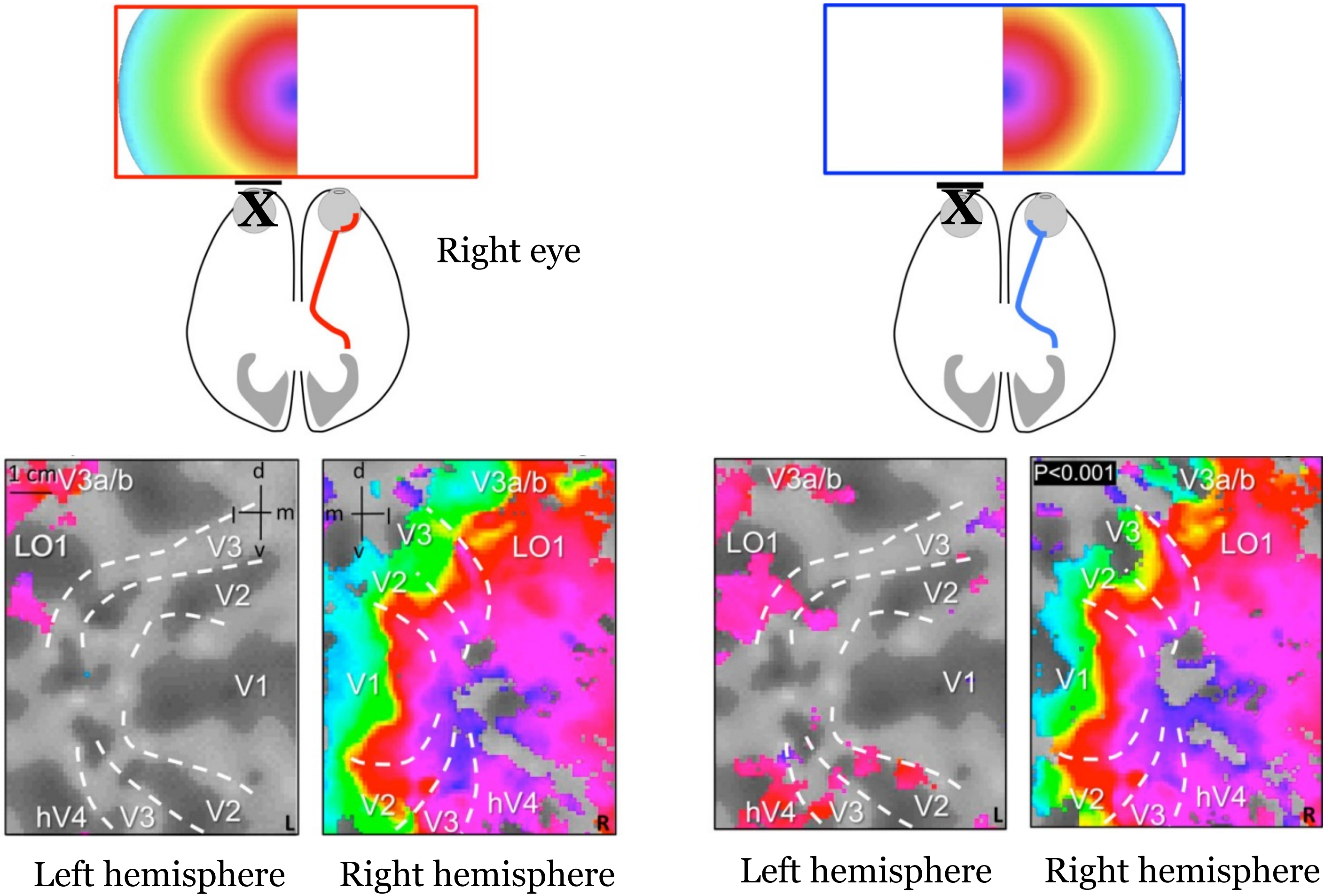


- Right visual field
  - left temporal retina
  - right nasal retina
- Left visual field
  - right temporal retina
  - left nasal retina

Apkarian et al., E.J.N. 1994
Apkarian et al., Brain, 1995
Victor et al., Cer. Cortex, 2000
Jansonius et al., JNO, 2001
Prakash et al., JNO, 2009

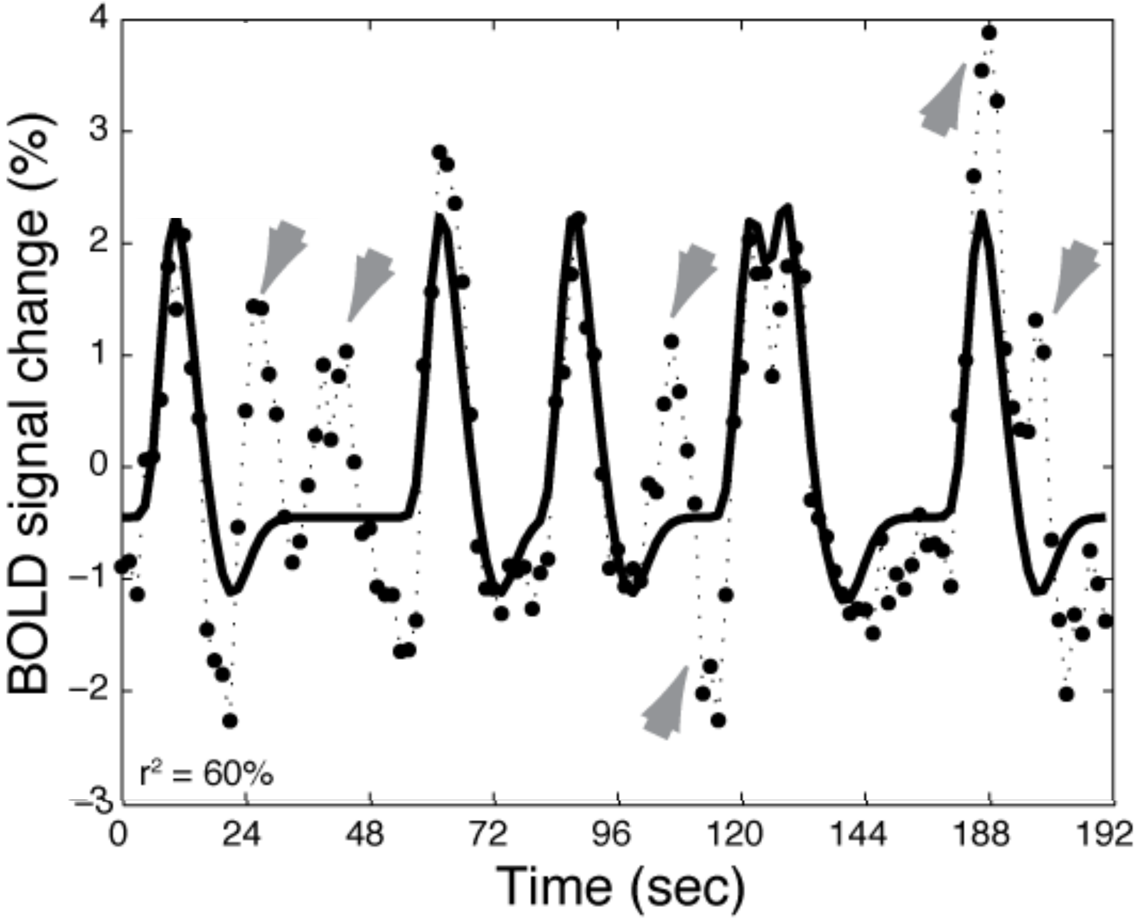
We confirm this in the fMRI measurements

Signals from the right eye stay in the right hemisphere, unlike controls



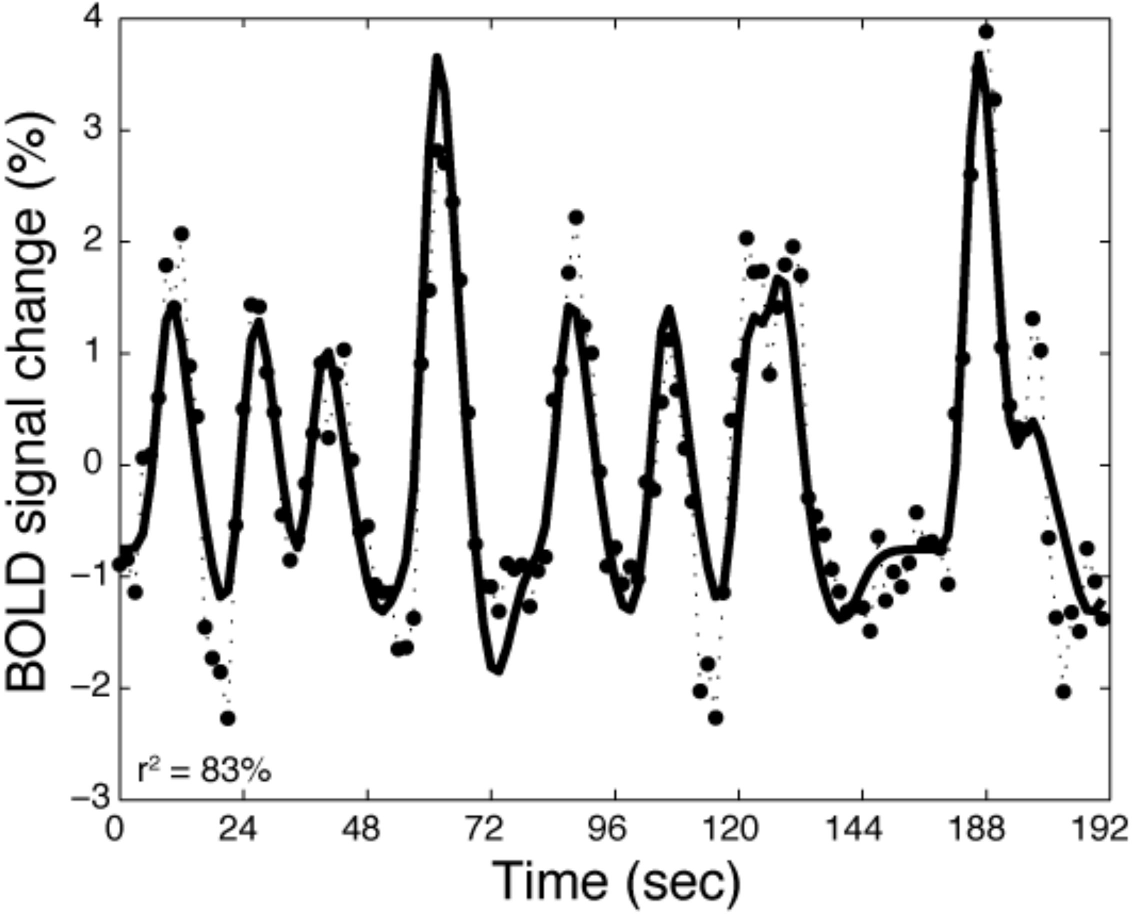
The population receptive fields are unconventional

Single pRF model fails to fit this subject's data



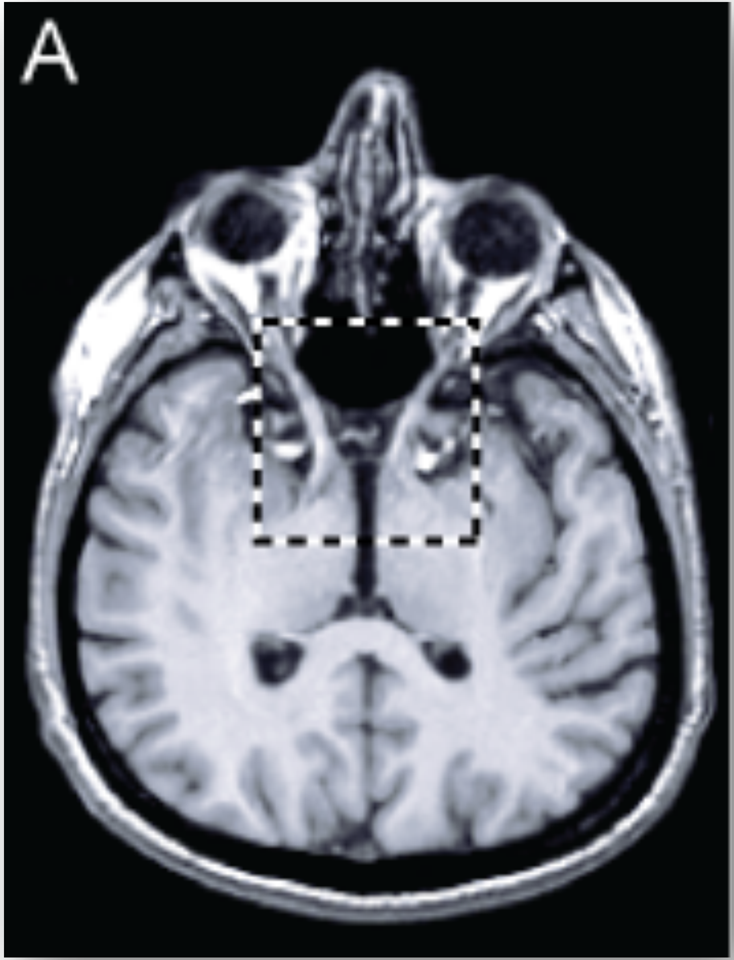
The population receptive fields are symmetric around the midline

Dual pRF model, with regions symmetric across the midline, fit the subject's data



Summary

Despite the profoundly disrupted V1 maps (wrong hemispheres and wrong pRF), the rest of the brain figures out what to do (patient sees well).



V1 system status following retinal damage or disease

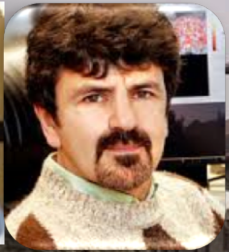
Lack of long-term cortical reorganization after macaque retinal lesions (2005). Smirnakis et al., Nature

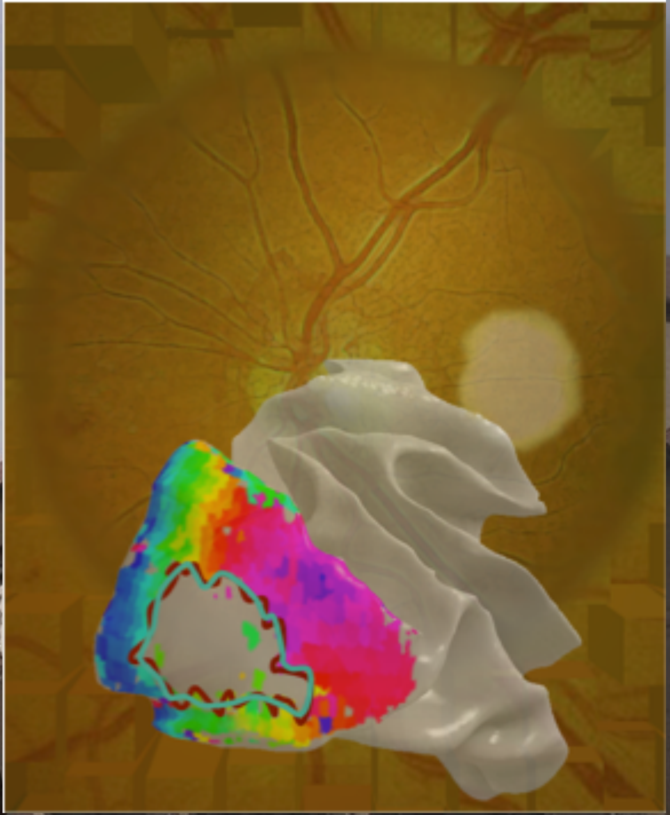
V1 Projection zone signals in human macular degeneration depend on task, not stimulus (2008). Y. Masuda, et al.. Cerebral Cortex

Plasticity and stability of visual field maps in adult primary visual cortex (2009). Wandell and Smirnakis Nature Reviews Neuroscience

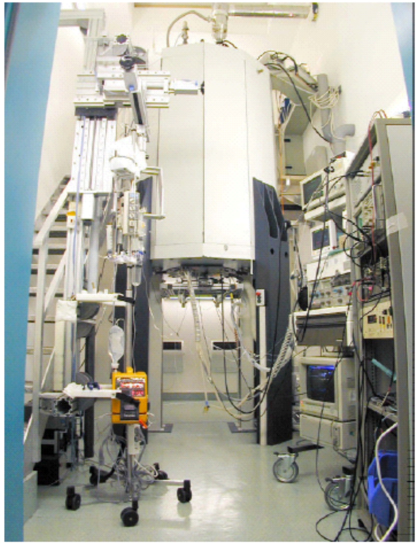
Task-Dependent V1 Responses in Human Retinitis Pigmentosa (2010). Masuda, et al. Invest. Ophthalmol. Vis. Sci.

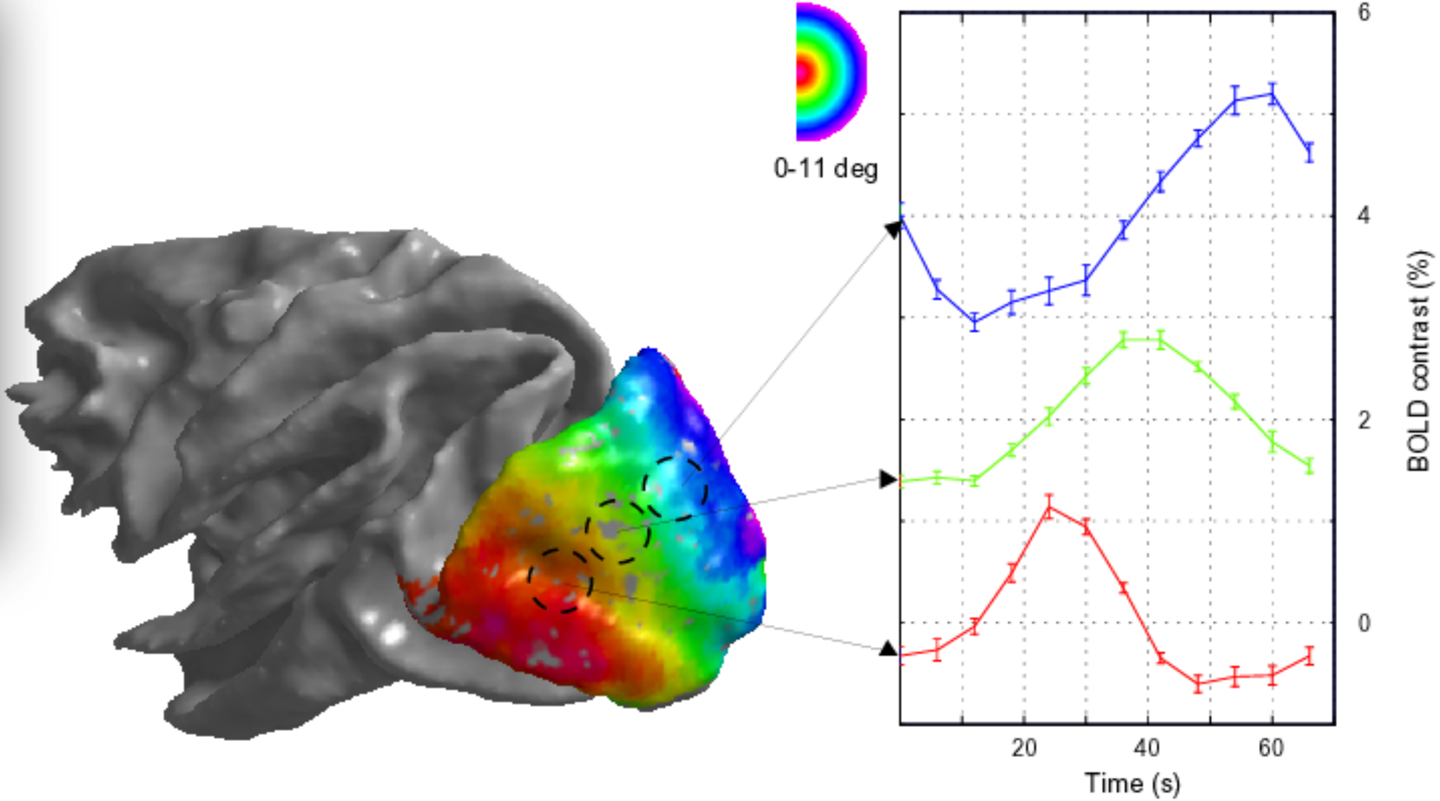




Visual field mapping using fMRI in macaque

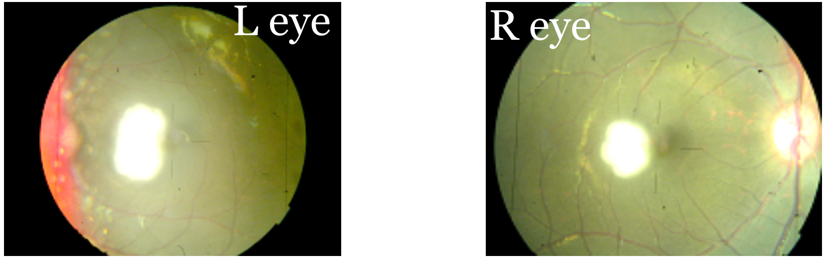




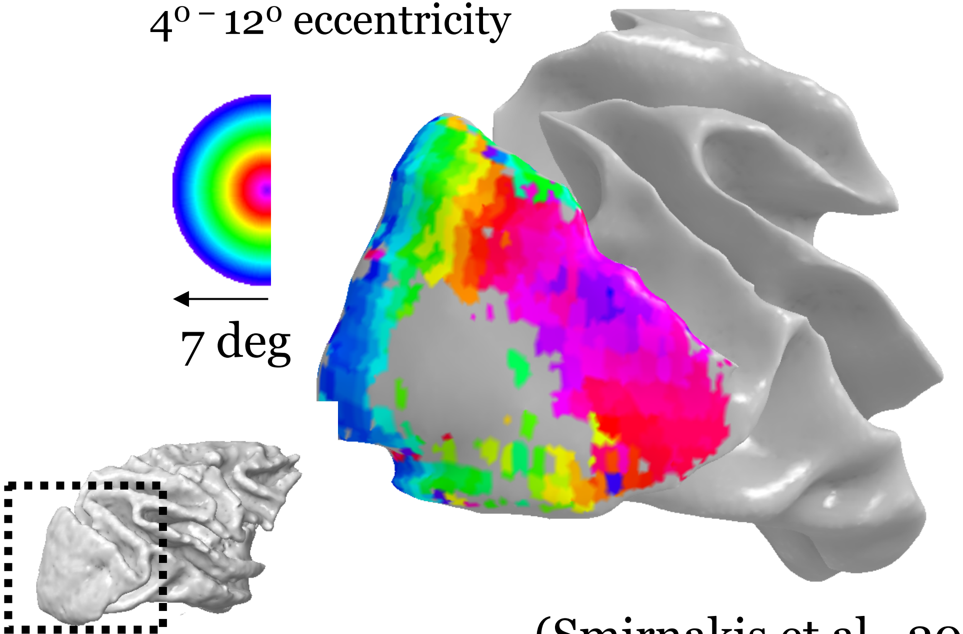
(Brewer et al., 2002, J. Neuroscience)

Retinal lesions eliminate activity in the projection zone

- Bilateral retinal lesions in the left visual field
- 3D rendering shows the data from the average of 9 expanding ring scans.
- The empty region within the colored data overlay is the representation of the scotoma at 4 mo (session kf1).
- Scotoma size at 4 mo = 123.5 mm2

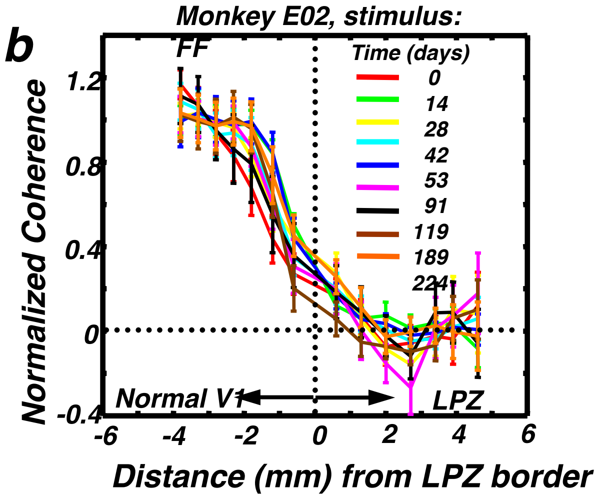


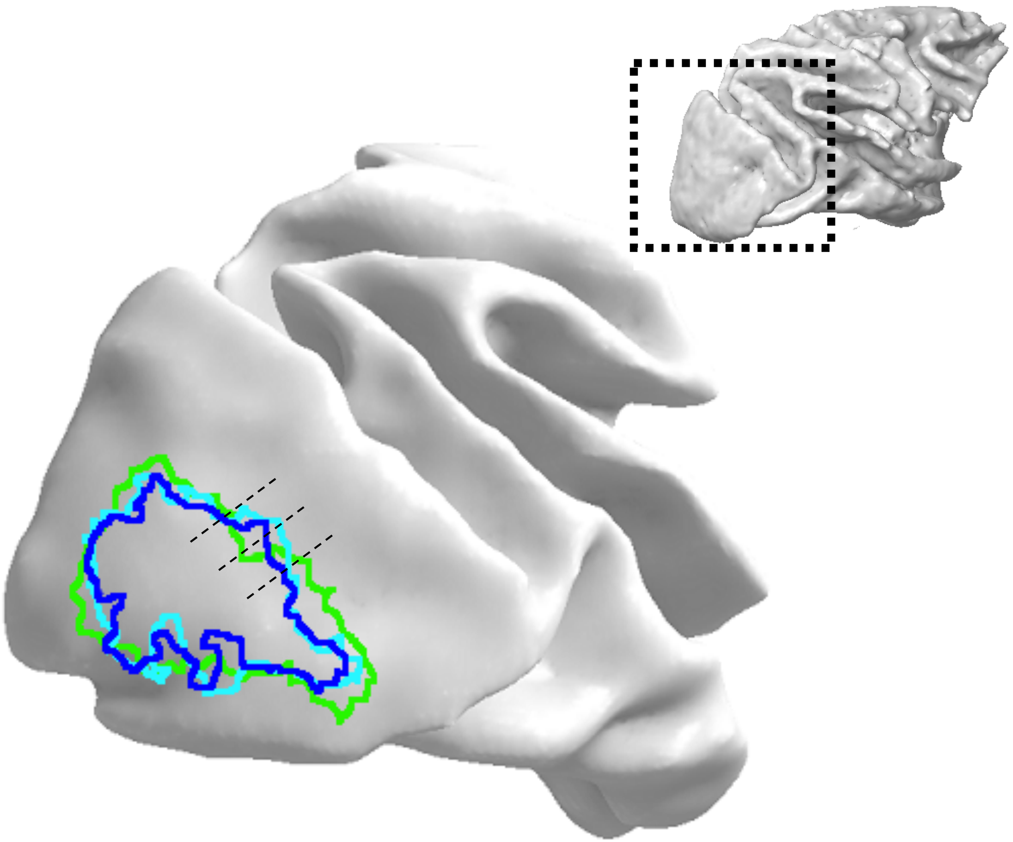
$4^o - 12^o$ eccentricity



(Smirnakis et al., 2005)

The margins of the scotoma did not change systematically



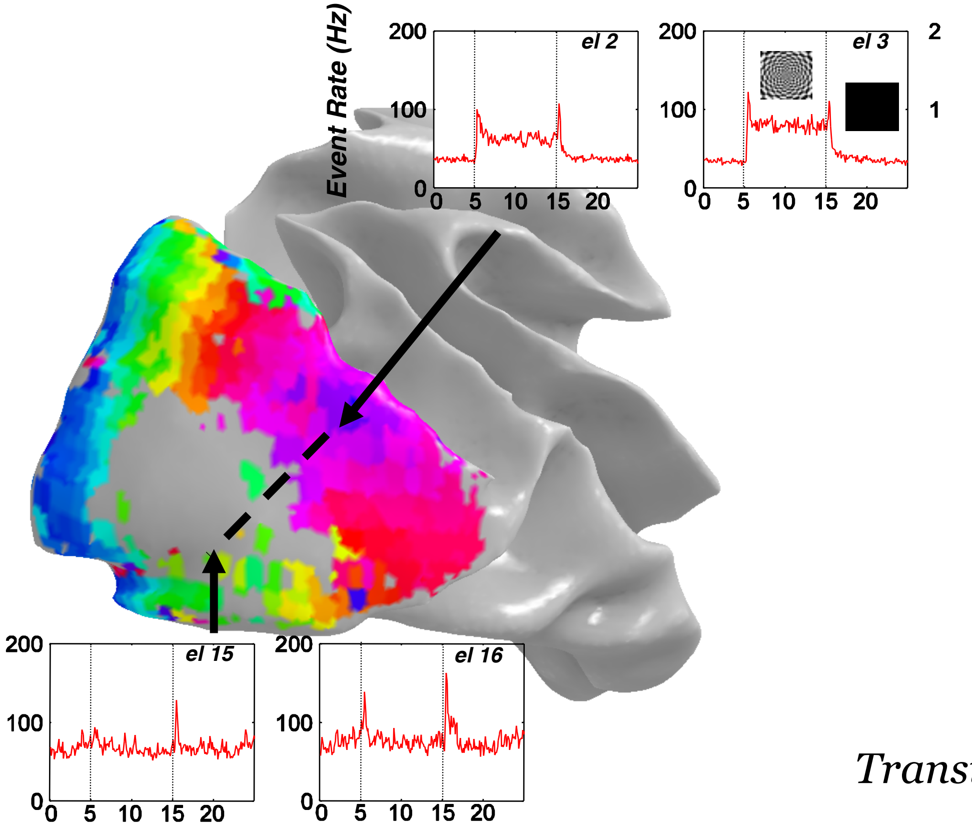


Scotoma at 0 days

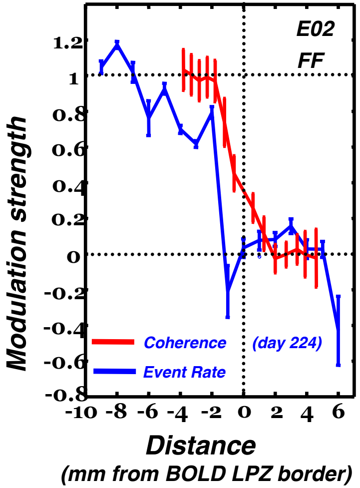
Scotoma at 2 wks

Scotoma at 4 months

Single-unit recordings confirm limited responses in LPZ



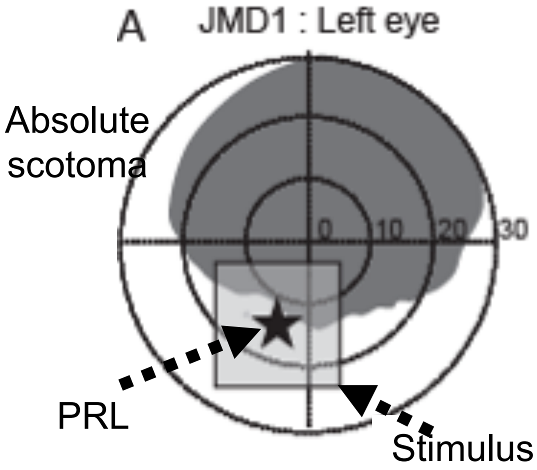
Recordings across LPZ border

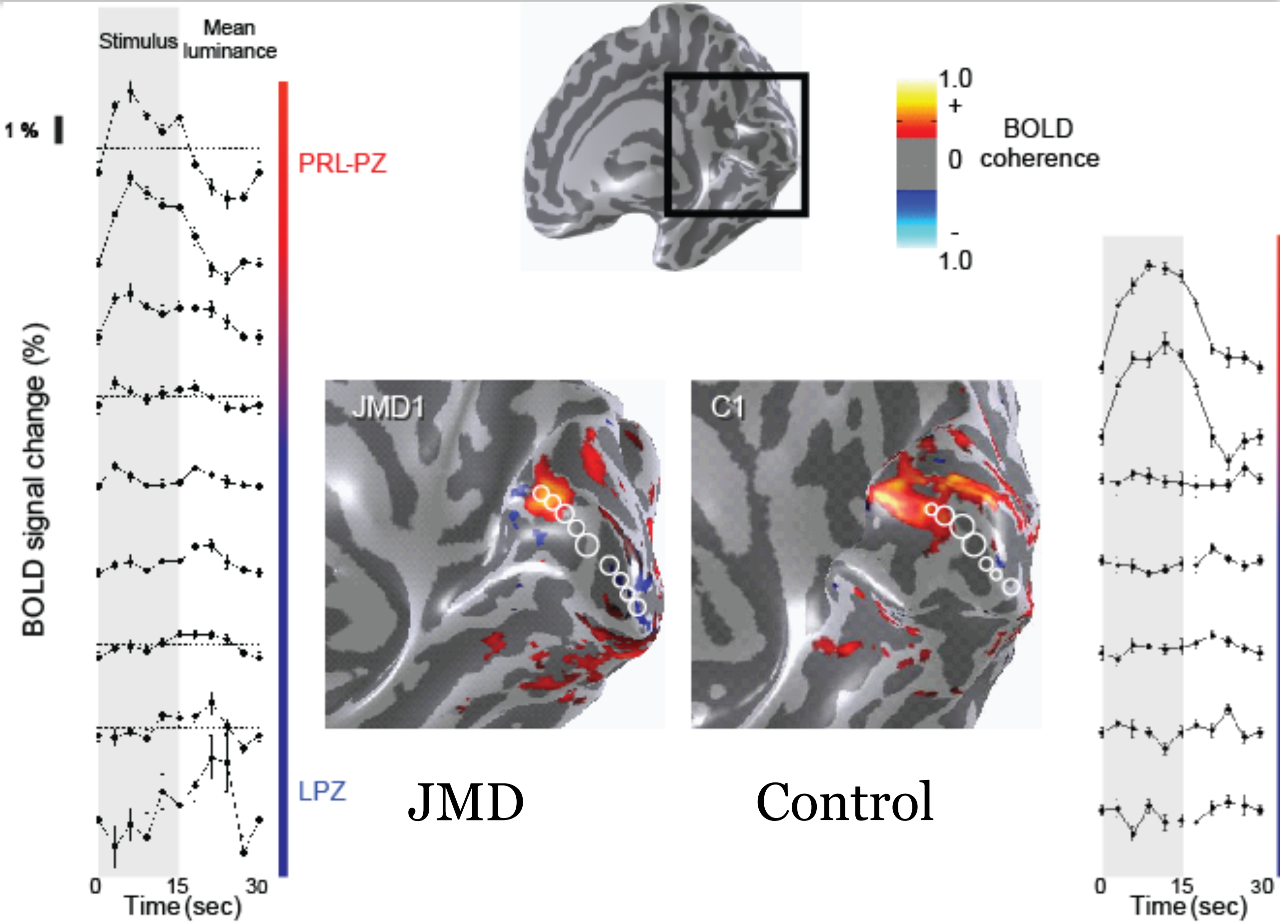


Transients are present in control also with large stimuli;
not present when using small stimuli

Human JMD subjets – passive viewing: No signal in LPZ

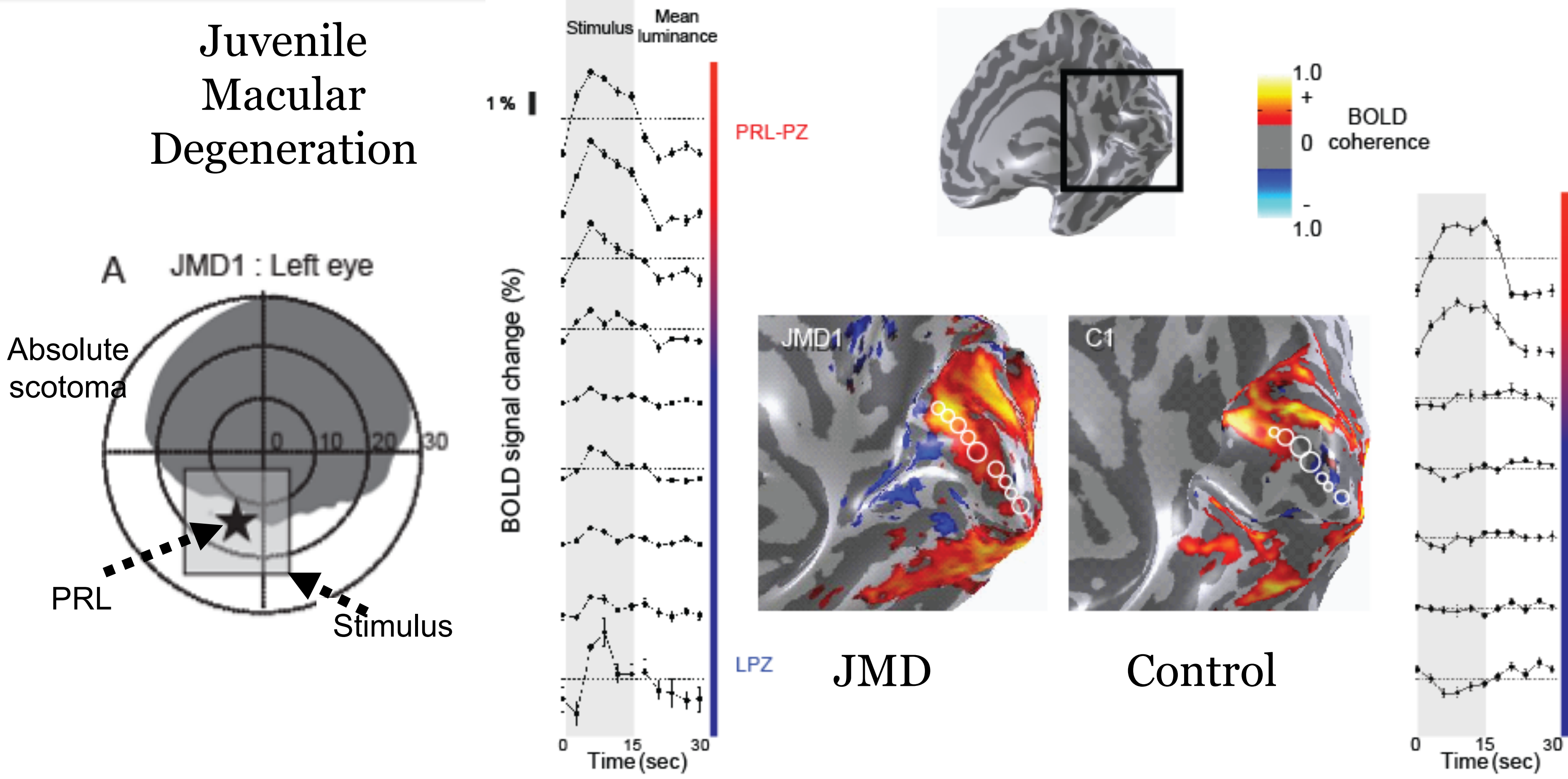
Juvenile
Macular
Degeneration





Y. Masuda, S.O. Dumoulin, S. Nakadomari and B.A. Wandell (2008).

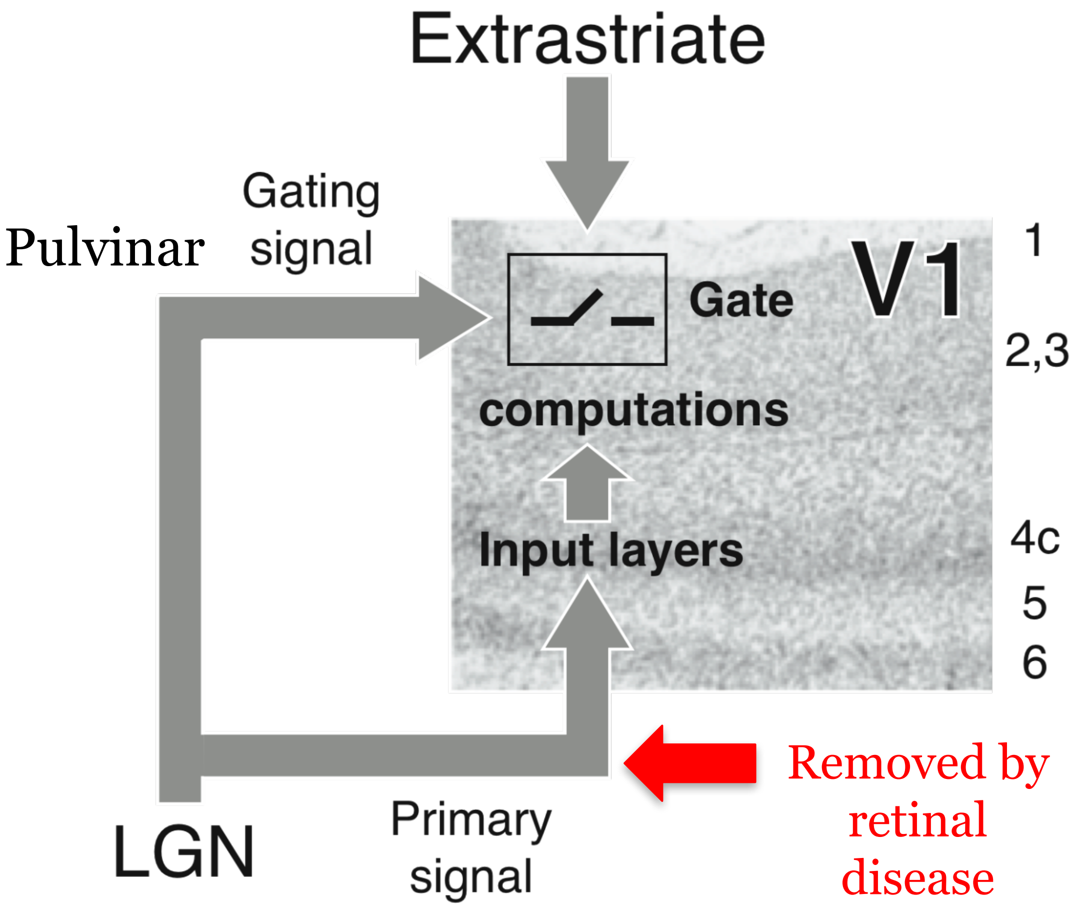
Human subject one-back task: Evokes activity in lesion projection zone



Y. Masuda, S.O. Dumoulin, S. Nakadomari and B.A. Wandell (2008).

We need models that go beyond pRF and conventional visual models

- We concluded that to understand the cortical signals we must build more complete, circuit models that extend pRF style
- pRF modeling was a start, but we need more
- Reading circuitry development calls for such circuit models, too – see Kay and Yeatman

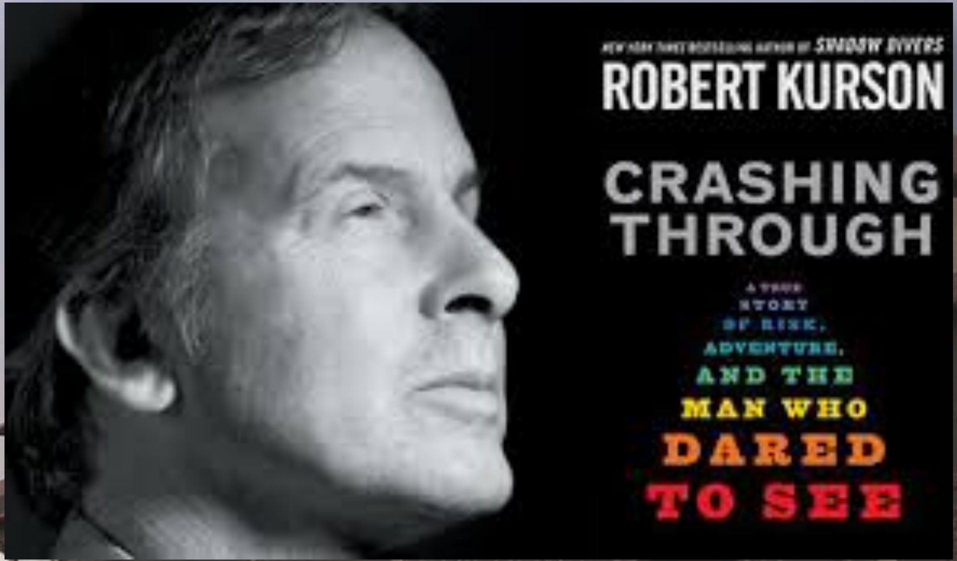


Developmental plasticity following damage at 3 years of age

A Lack of Experience-Dependent Plasticity after More than a Decade of Recovered Sight (2015).
Huber, et al. Psychological Science.

Long-term deprivation affects visual perception and cortex.
Fine I, et al. (2003). Nature Neuroscience

Cortical maps and white matter tracts following long period of visual deprivation and retinal image restoration,
Levin et al. (2010). Neuron

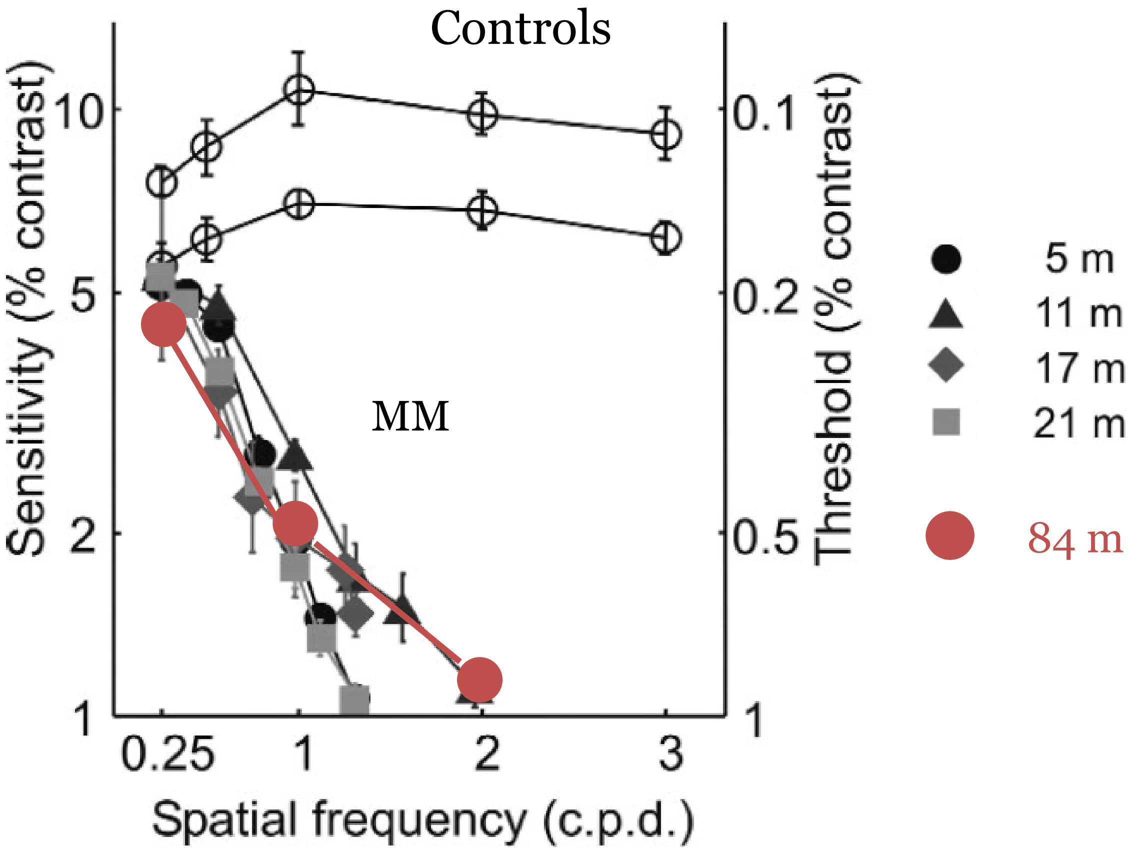



Developmental plasticity following damage at 3 years of age

- At three and a half years of age, MM lost one eye and was blinded in the other (chemical and thermal damage to his corneas).
- One unsuccessful corneal replacement in childhood
- **For the next 43 years he had some light perception, but no experience of contrast or form; he reports no visual memories or imagery.**
- At age 46, MM received a corneal and limbal stem-cell transplant in his right eye; this restored his retinal image

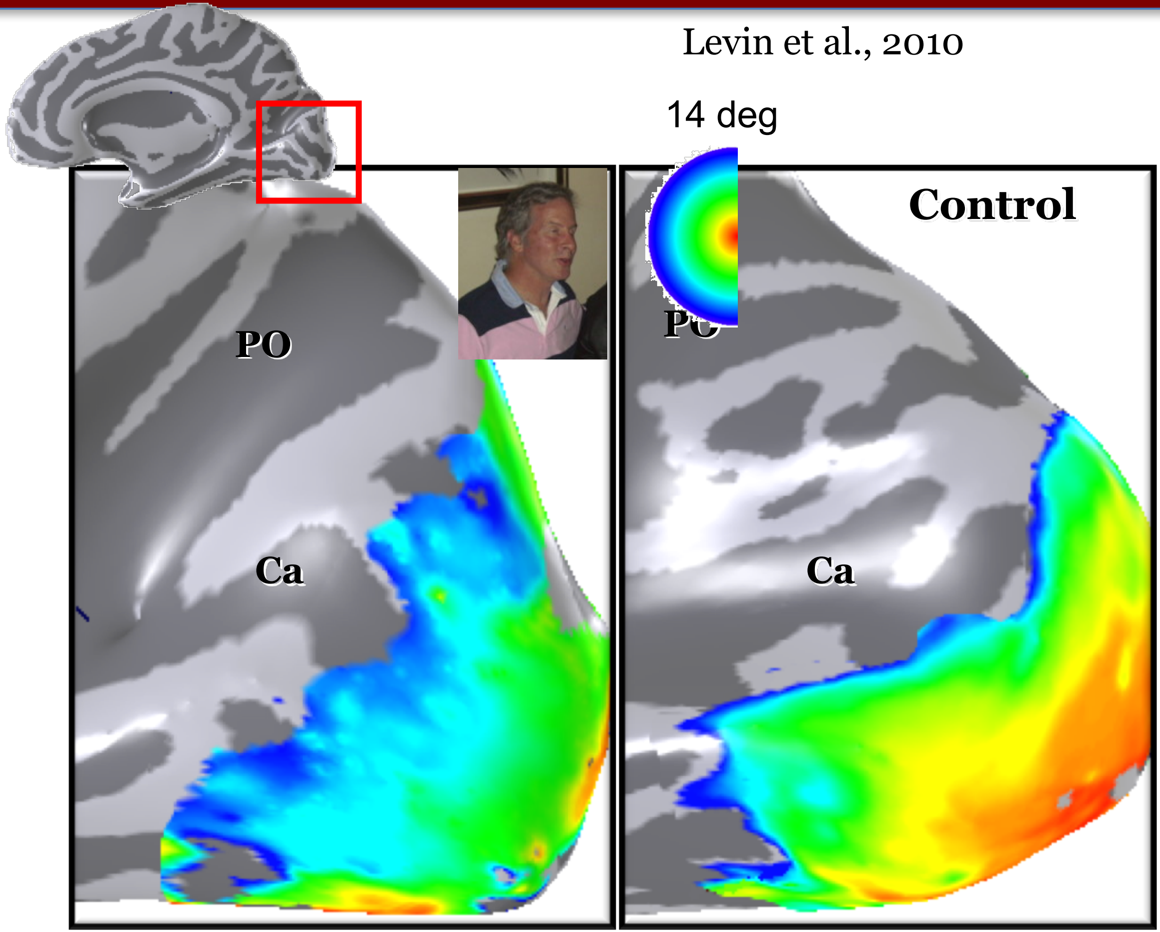
Contrast sensitivity functions post-surgical (MM)

- Sensitivity is similar to controls at low spatial frequency
- Substantially worse above 0.25 cycles/deg
- Behavior has remained constant for 10 years following surgery



Why can't Mike see? Missing signals to visual cortex

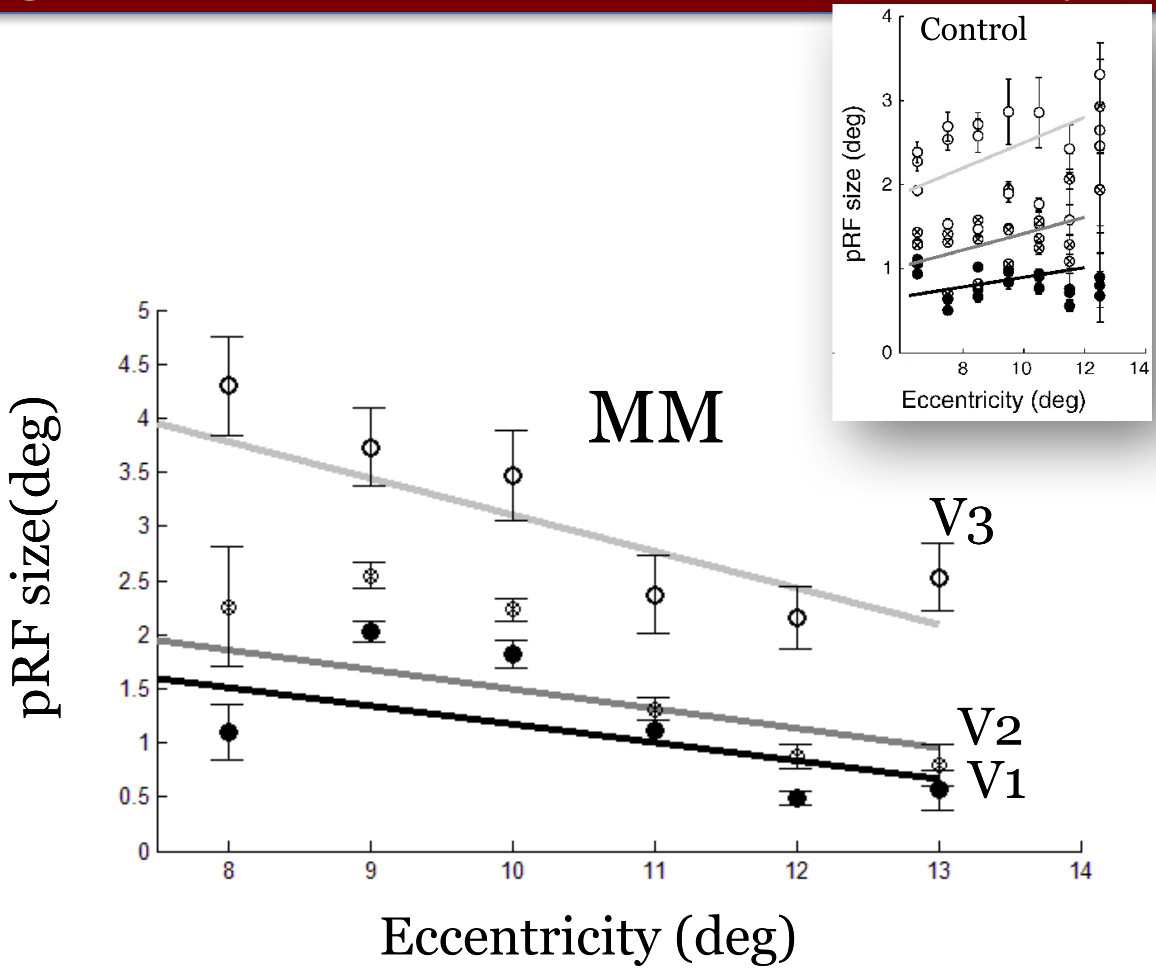
Levin et al., 2010



The pRF sizes are much larger and the reverse scale with eccentricity

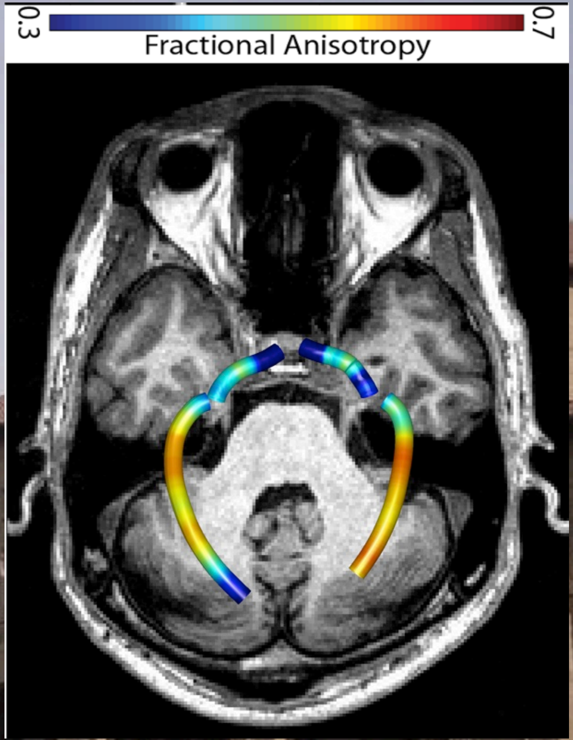
- In typical development, there are many neurons with small receptive fields that compete for synaptic space in V1.

- Perhaps because of their inactivity, the **small receptive field cortical neurons** are absent in MM, and their synaptic space is given over to neurons with larger receptive fields – implications for extrastriate VOT?



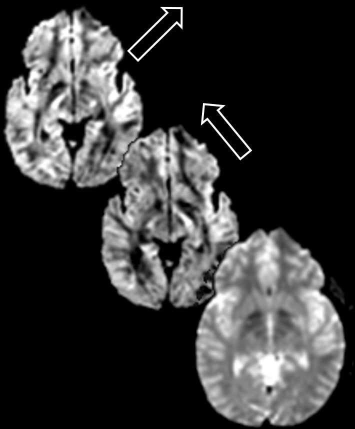
White matter changes in retinal disease

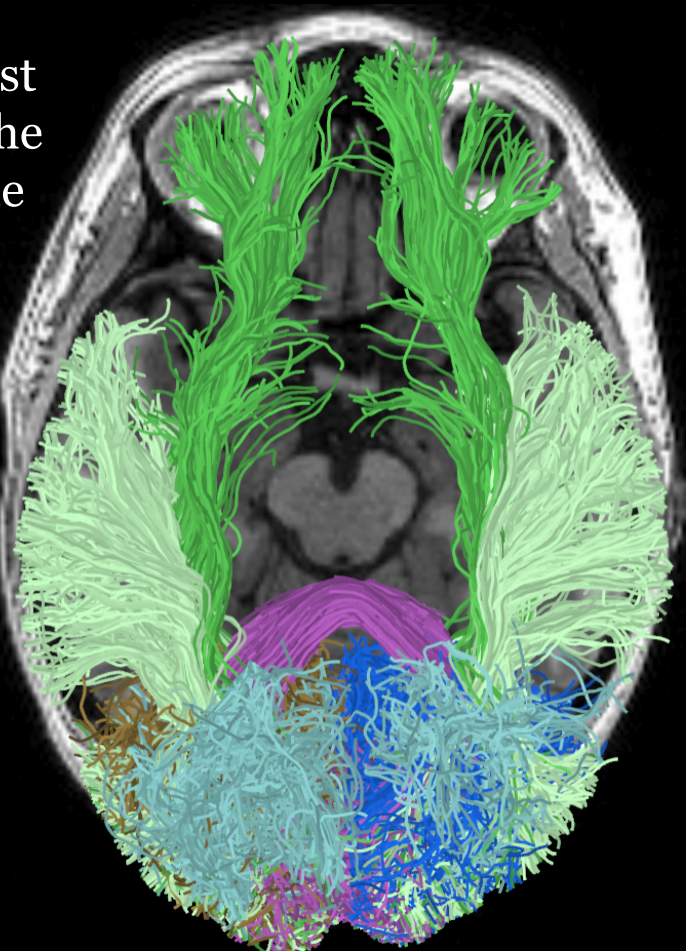
White Matter Consequences of Retinal Receptor and Ganglion Cell Damage. Ogawa et al. (2014) Investigative Ophthalmology & Visual Science



DMRI and tractography models

Tracts with at least one endpoint in the visual parts of the brain





nature methods

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NATURE METHODS | ARTICLE

Evaluation and statistical inference for human connectomes

Franco Pestilli, Jason D Yeatman, Ariel Rokem, Kendrick N Kay & Brian A Wandell

PLOS | COMPUTATIONAL BIOLOGY

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RESEARCH ARTICLE

Ensemble Tractography

Hiromasa Takemura, Cesar F. Caiafa, Brian A. Wandell, Franco Pestilli

Published: February 4, 2016 • http://dx.doi.org/10.1371/journal.pcbi.1004692

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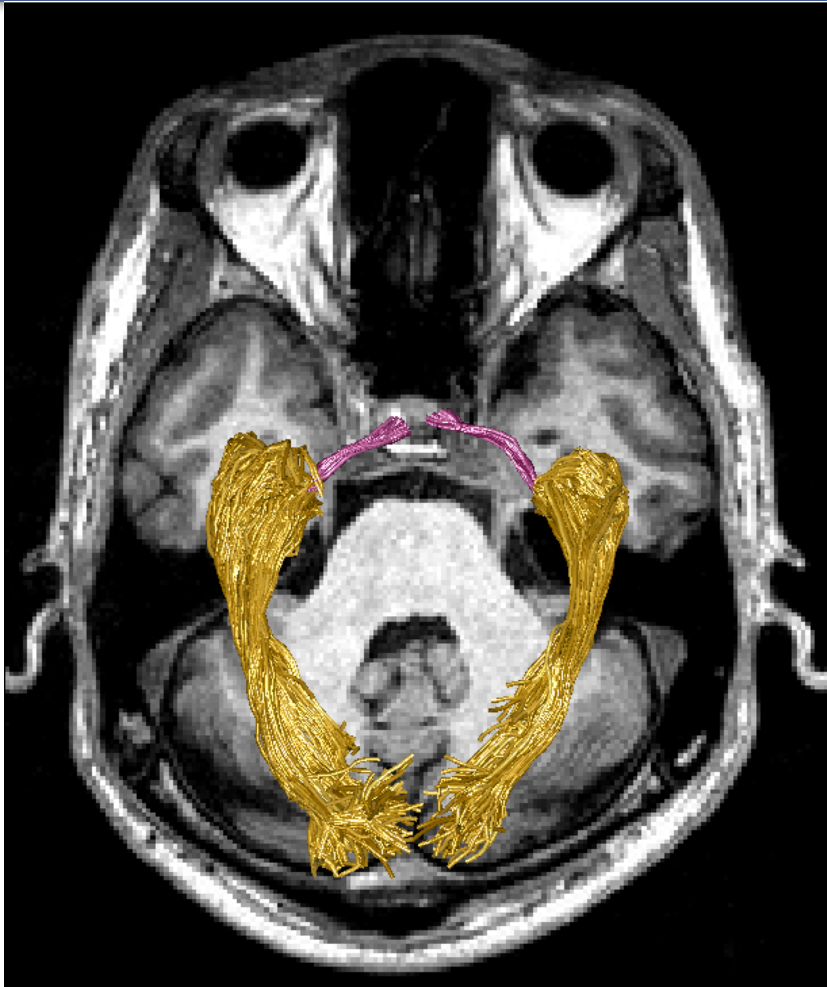
Clarifying Human White Matter

Brian A. Wandell

Department of Psychology and Neurosciences Institute, Stanford University, Stanford, California 94305; email: Wandell@stanford.edu

We and others have developed methods for finding the OT and OR

The Optic Radiation and Optic Tract identification methods are largely automatized



Tract Profiles

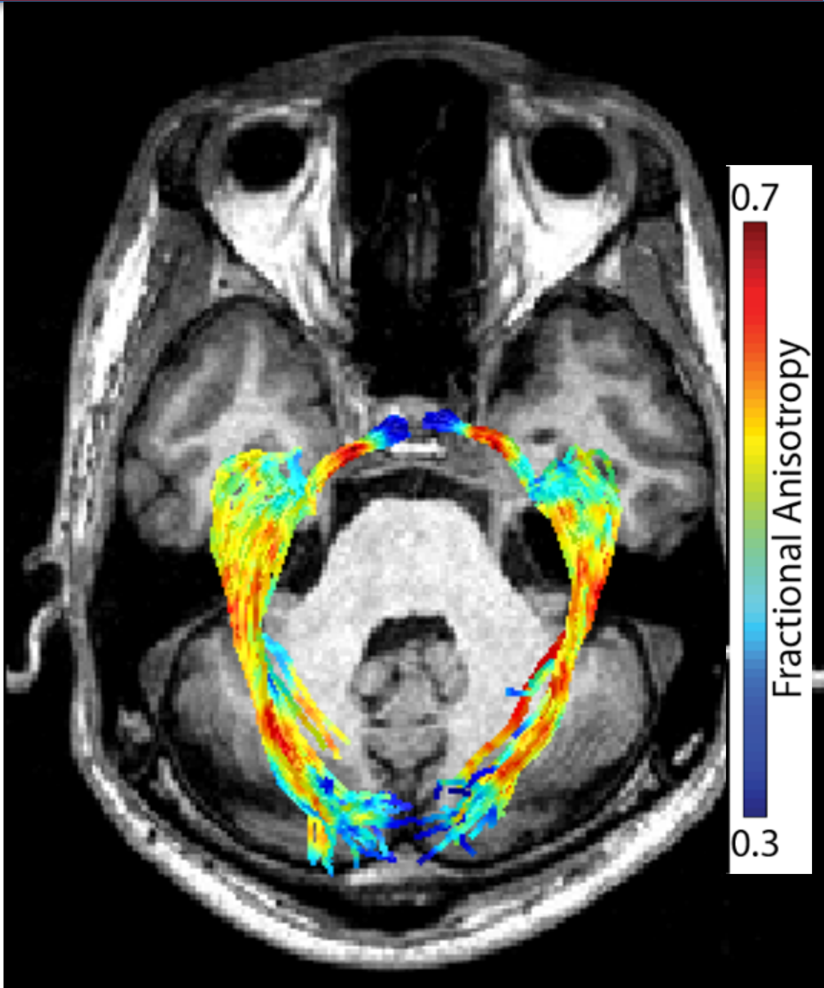
Make a measurement at each estimated streamline

Compute a mean value along the core (central part) of the whole track

Tract Profiles of White Matter Properties: Automating Fiber-Tract Quantification

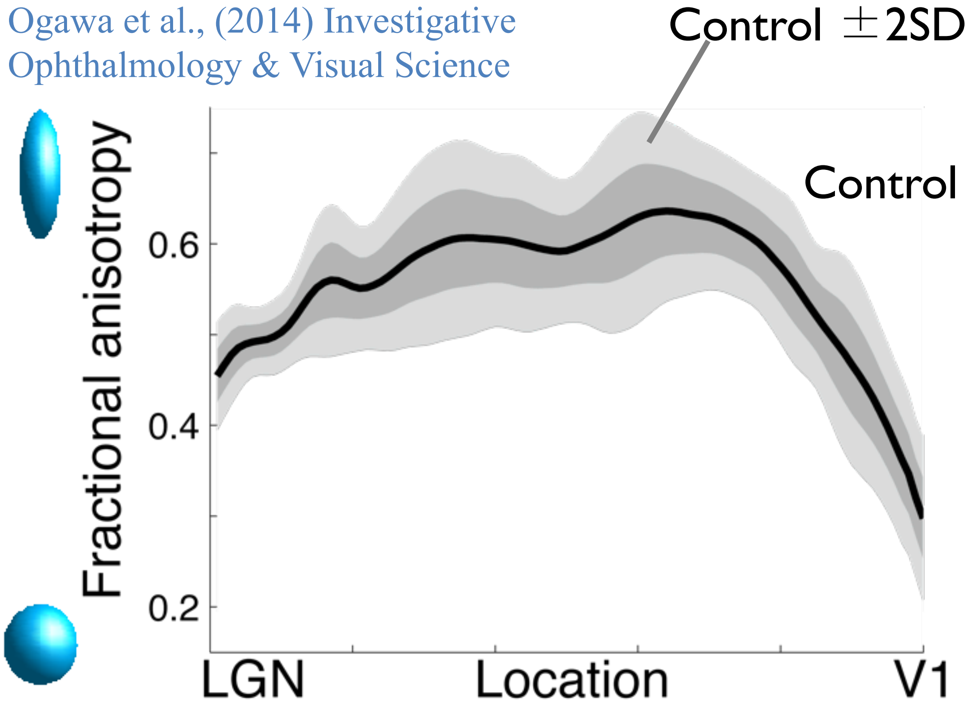
Jason D. Yeatman, Robert F. Dougherty, Nathaniel J. Myall, Brian A. Wandell, Heidi M. Feldman

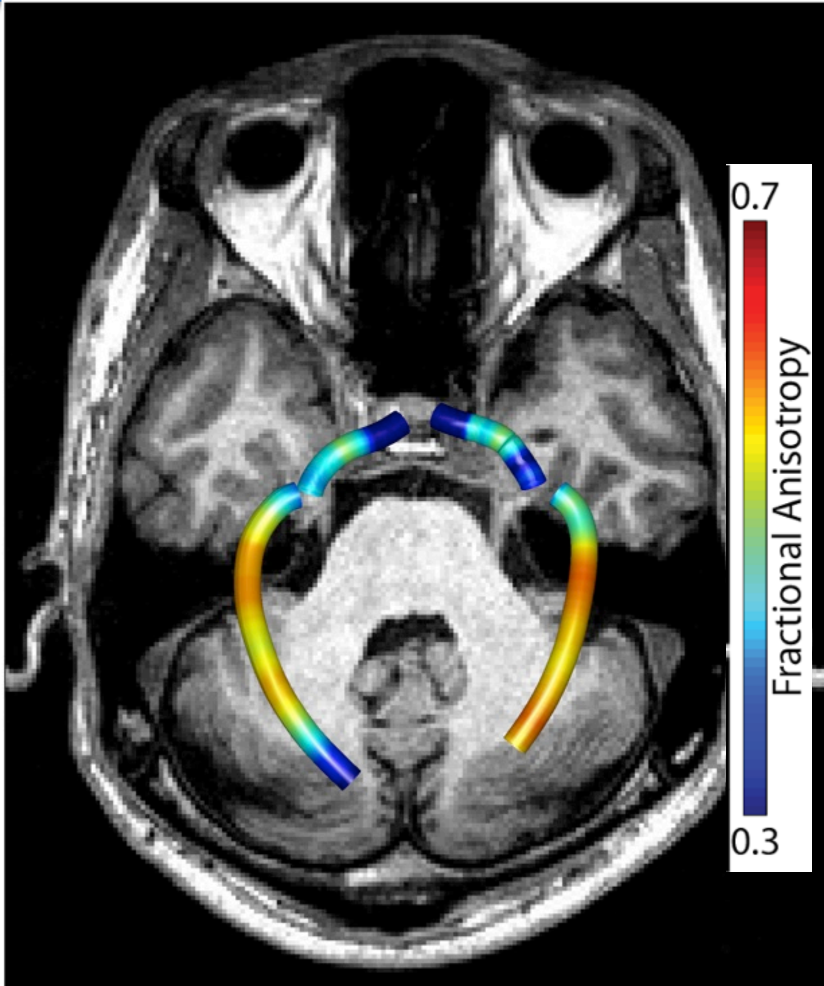
Published: November 14, 2012 • http://dx.doi.org/10.1371/journal.pone.0049790



Typical control population measurements

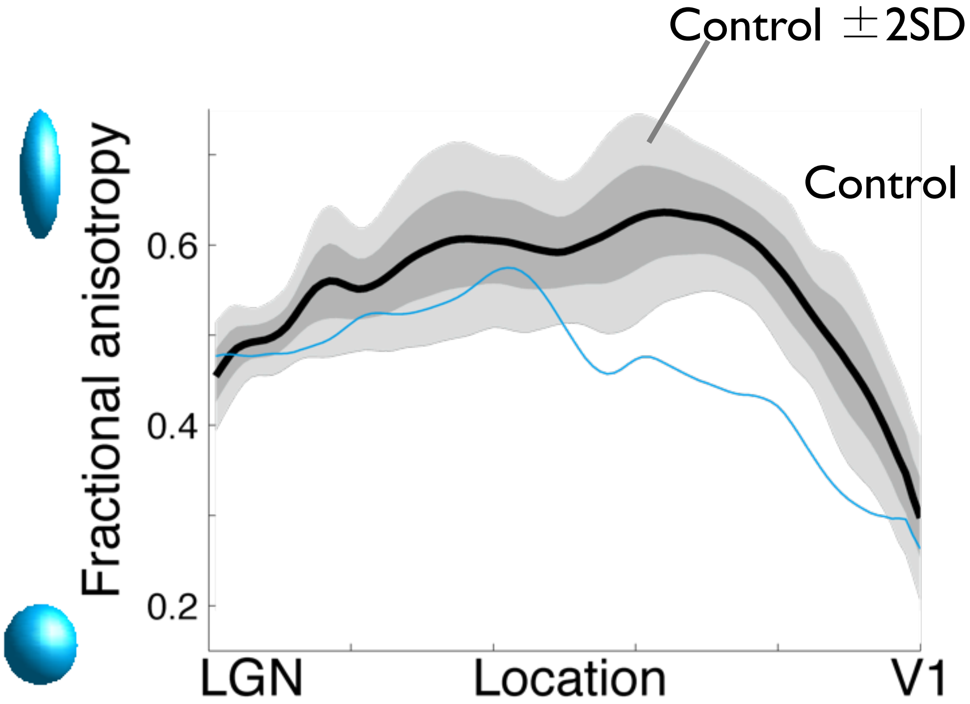
Ogawa et al., (2014) Investigative Ophthalmology & Visual Science

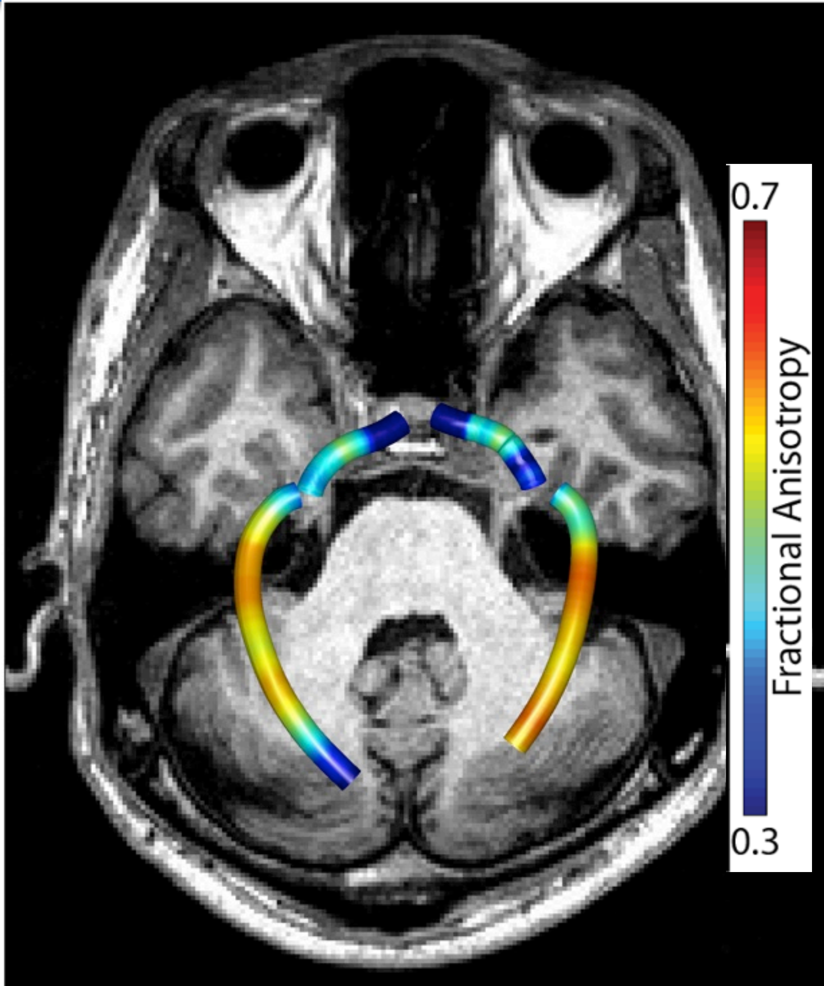




The expectation based on data acquired and stored in the SDM

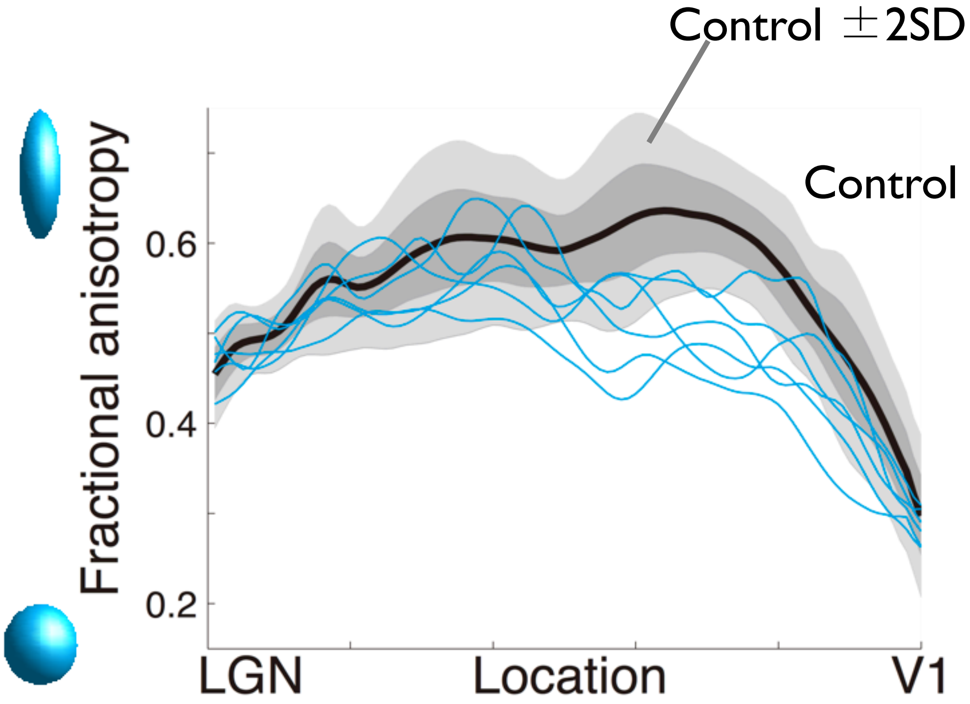
Compare individual patients with the baseline distribution

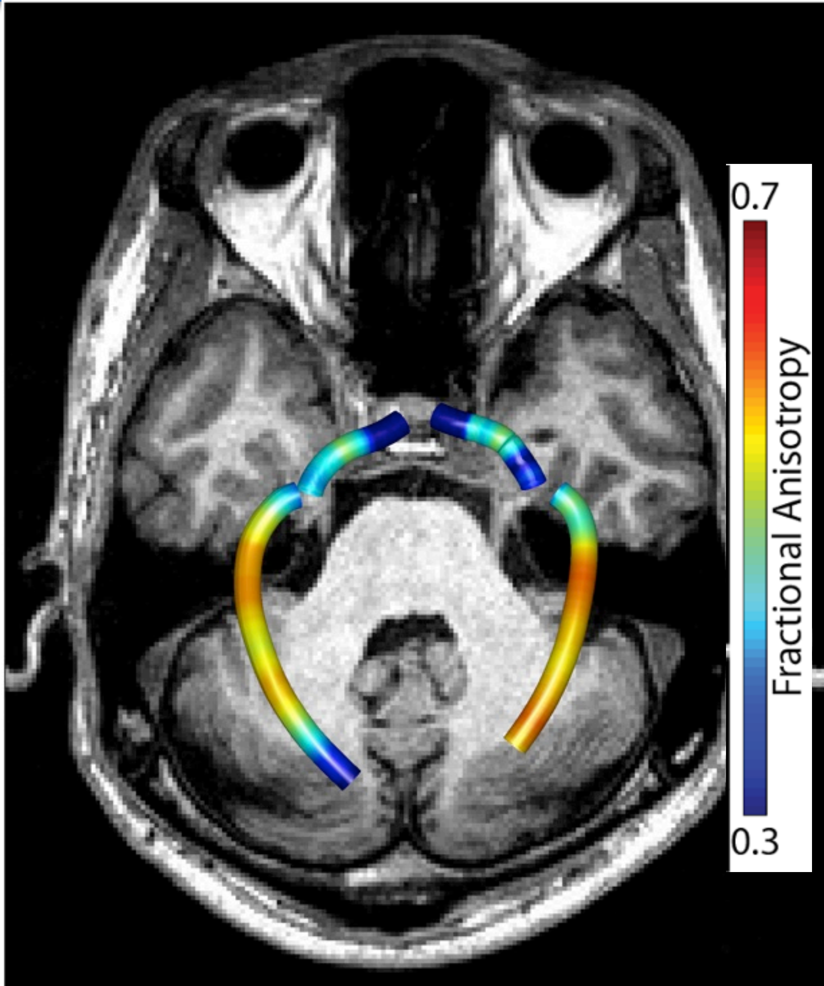




The expectation based on data acquired and stored in the SDM

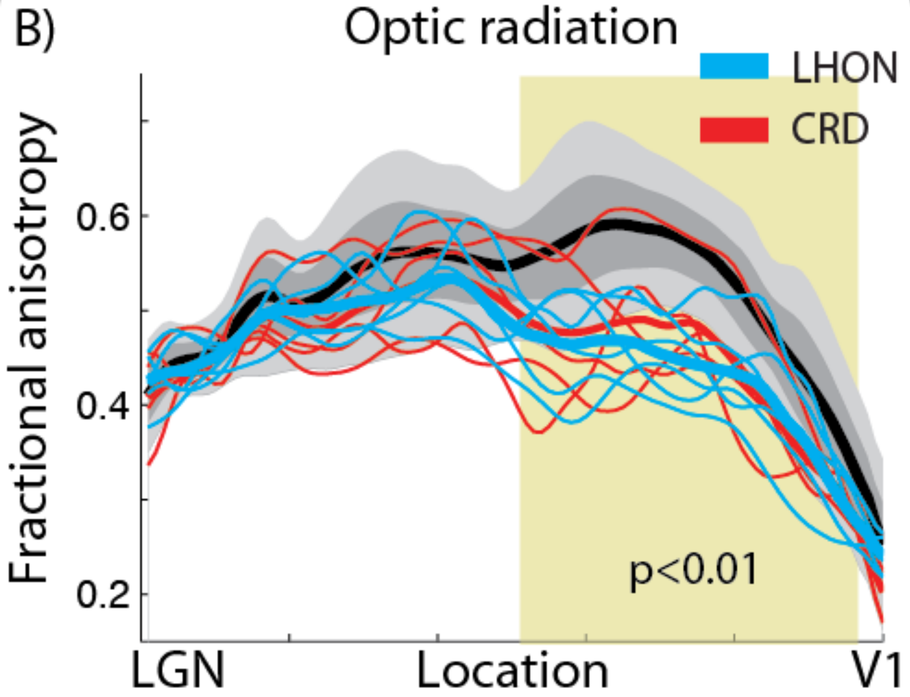
Other patients are added here

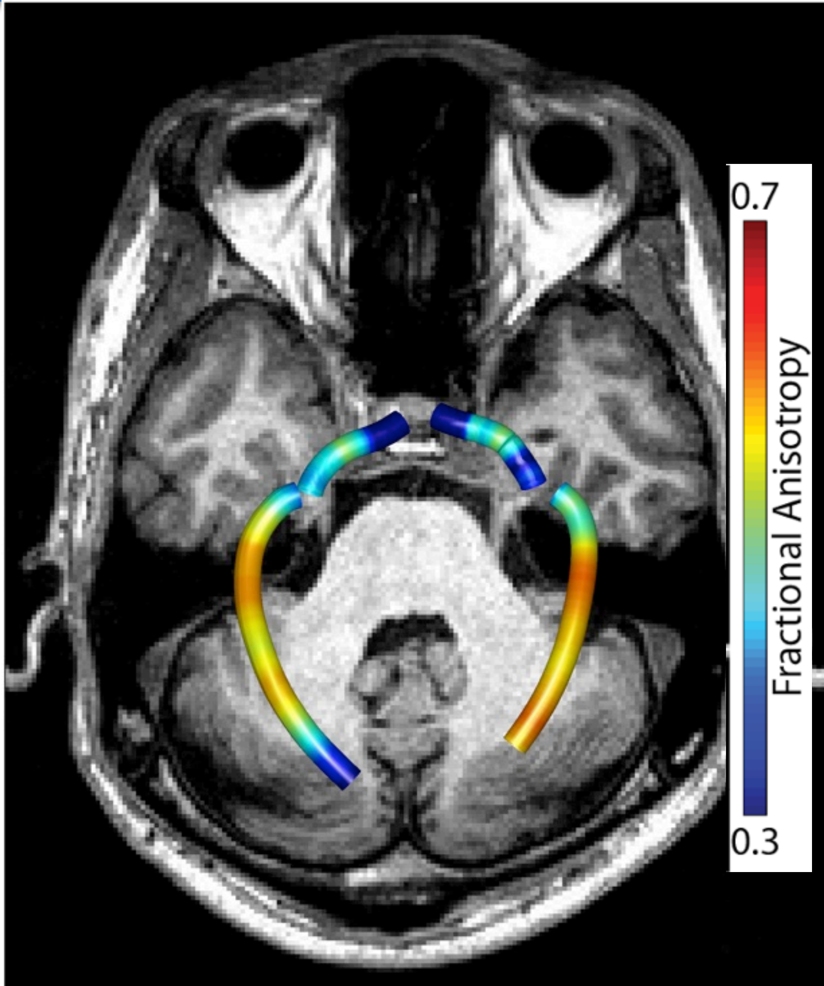




The expectation based on data acquired and stored in the SDM

Other types of patients (CRD) are added as well





Receptor disease

Ganglion cell disease

White matter consequences of retinal disease

- Diffusion statistics in white matter tracts are influenced LHON and CRD patients
- Retinal disease produces trans-synaptic degeneration

Ogawa et al., (2014) Investigative Ophthalmology & Visual Science

Plasticity and stability in human visual cortex

Brief methods background

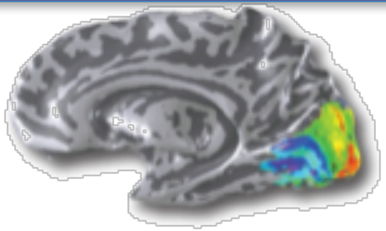
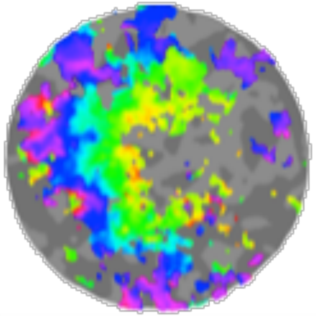
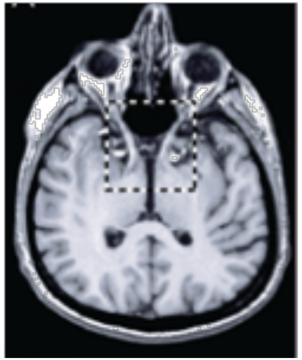
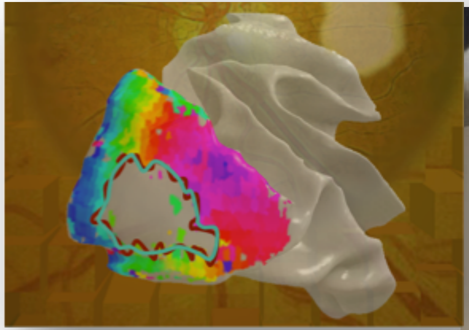
V1 maps in (congenital) rod monochromats

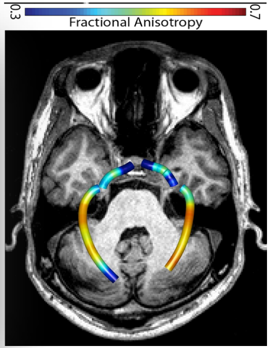
Achiasmic subjects

Retinal lesions (macaque and human JMD)

Miracle cures: (restored optics, MM)

White matter consequences of retinal disease



Stability and plasticity in visual cortex at the resolution of MRI