The Natural Scenes Dataset (NSD): massive high-quality whole-brain 7T fMRI during visual perception and memory

Kendrick Kay

http://cvnlab.net

Center for Magnetic Resonance Research (CMRR)

University of Minnesota, Twin Cities

UNIVERSITY
OF MINNESOTA

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Outline

Why NSD?

What is in NSD?

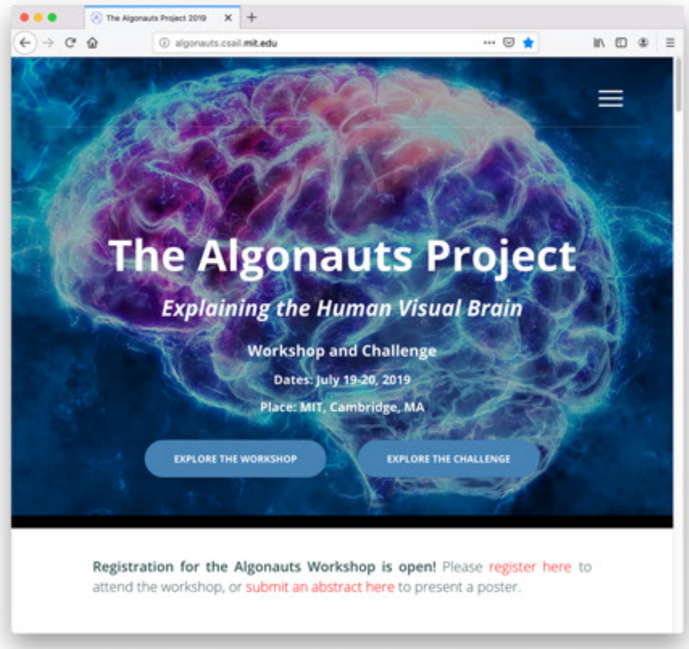
Results thus far

Future outlook

Why NSD?

- Algonauts... Benchmarks, models, code/data sharing, we're on board!

- We need the best possible data. This is essential.



- **Goal 1:** To establish a massive benchmark dataset that can be used to answer a variety of scientific questions about vision

- **Goal 2:** To answer some scientific questions

Why NSD?

- Many recent ‘big data sharing’ efforts
  - Algonauts
  - Allen Brain Observatory
  - BOLD5000
  - Brain-Score
  - DoctorWho
  - HCP (Human Connectome Project)
  - Individual Brain Charting
  - Midnight Scan Club
  - MyConnectome
  - StudyForrest
  - UK Biobank
  - vim-1, vim-2
  - (and others...)

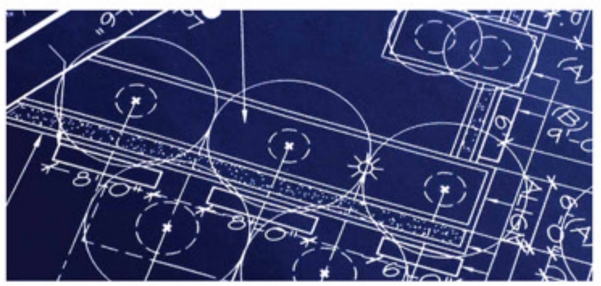
How is NSD different?

- **Priority 1:** Big.
  - Large data per subject
  - Large number of subjects

- **Priority 2:** High SNR, high resolution.
  - 7T fMRI
  - Screen for the best subjects

- **Priority 3:** Push envelope on acquisition and analysis methods.

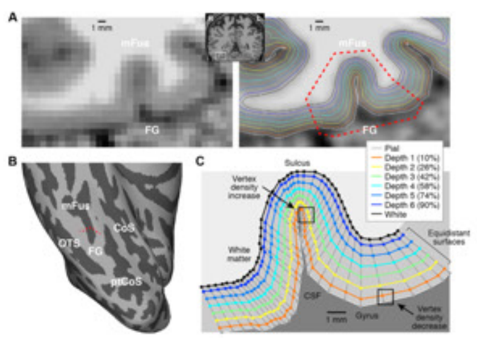
- **Priority 4:** Paranoid on details and documentation.



What is in NSD?

- **Type of data**
  - Functional data (7T)
    - NSD data (color natural scenes)
    - Resting-state data
    - Functional localizers (pRF mapping, category localizer)
    - Synthetic stimuli
  - Anatomical data (3T)
    - 6 T1s, 3 T2s
    - Diffusion
    - Angiogram, venogram
  - Behavioral data
  - Physiological data
- **Quantity of data**
  - 8 subjects
  - 40 hours of NSD data per subject
  - Whole-brain including cerebellum
  - 1.8-mm fMRI
- **Quality of data**
  - MRI image quality, imaging stability
  - Behavioral compliance (head motion, task performance)
  - Quality of BOLD response estimates
- **Value added by pre-processing**
  - Best possible spatial and temporal processing and denoising
  - Manually edited cortical surfaces and manually defined ROIs

fMRI acquisition details:
- 32-channel RF coil
- Caseforge headcases
- Whole-brain EPI (1.8 mm, 1.6 s, MB3, IPAT2)
- Multiple fieldmaps in each session



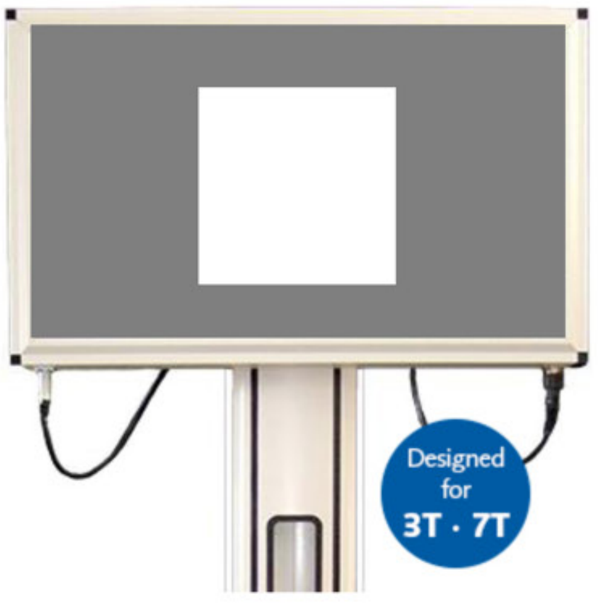
Adopt insights from sub-millimeter 0.8-mm fMRI
Kay, Jamison, Vizioli, Zhang, Margalit, Ugurbil
NeuroImage, 2019

The NSD experiment

- Images taken from Microsoft COCO database

- Stimulus size: 8.4 deg
- Presented via a linearized high-quality LCD monitor (BOLDscreen 32)
- Trial design: 3-s ON, 1-s OFF

- Task: for each image, indicate if it is
  __new__ (1) (I've never seen it before)
  __old__ (2) (I've seen before, either today or in a past scan session)

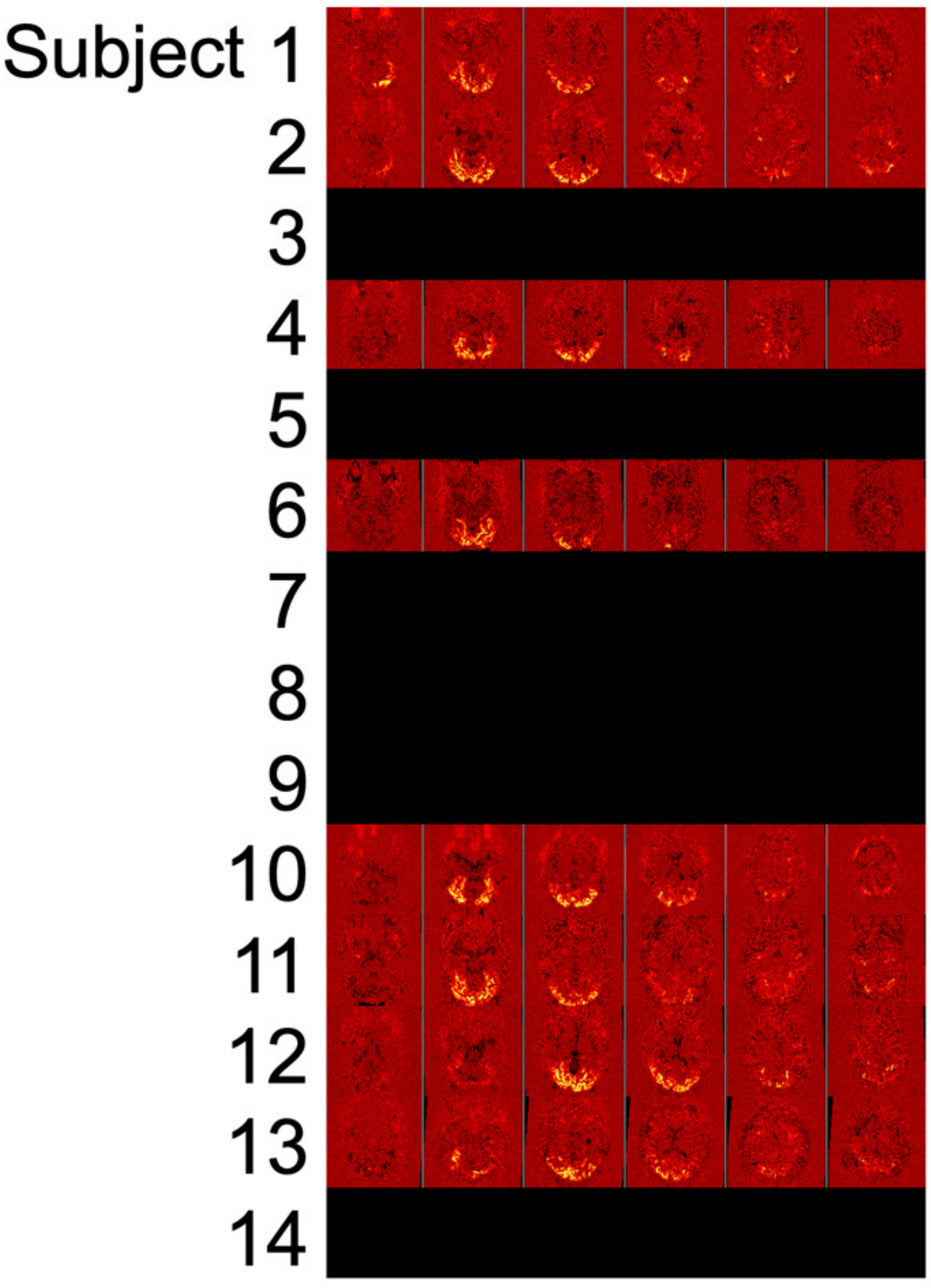



iPod

Screen for the best subjects

- BOLD signal strength varies substantially across subjects

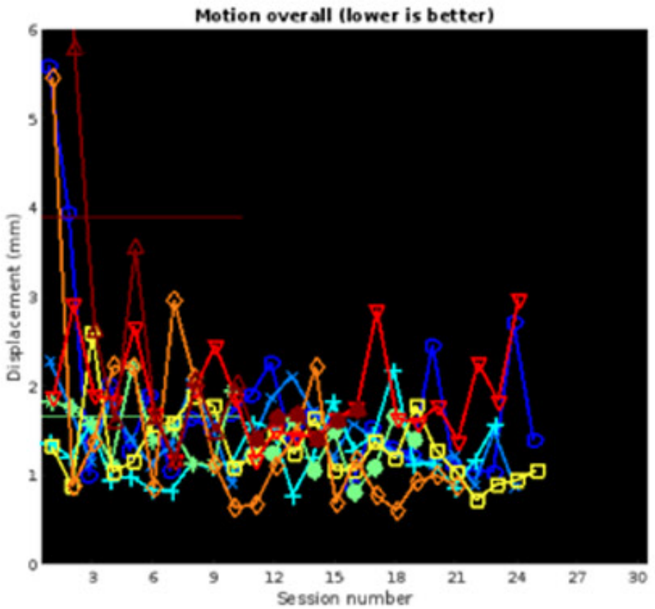
- Let's not waste scan time!

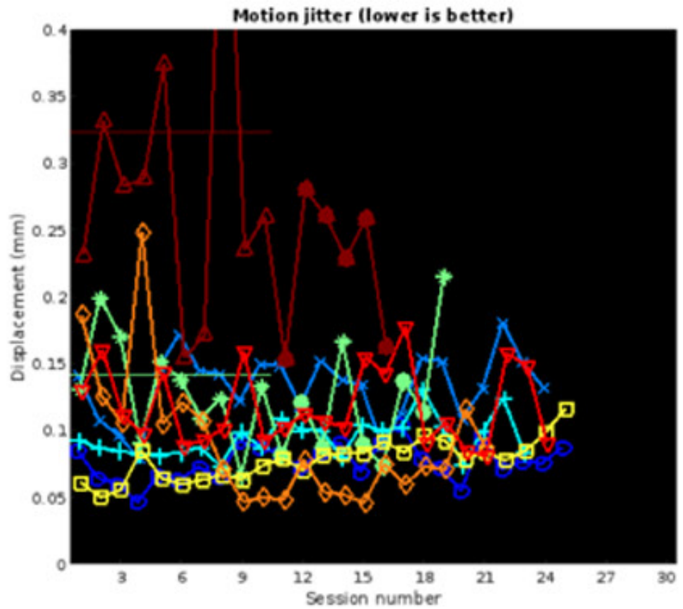


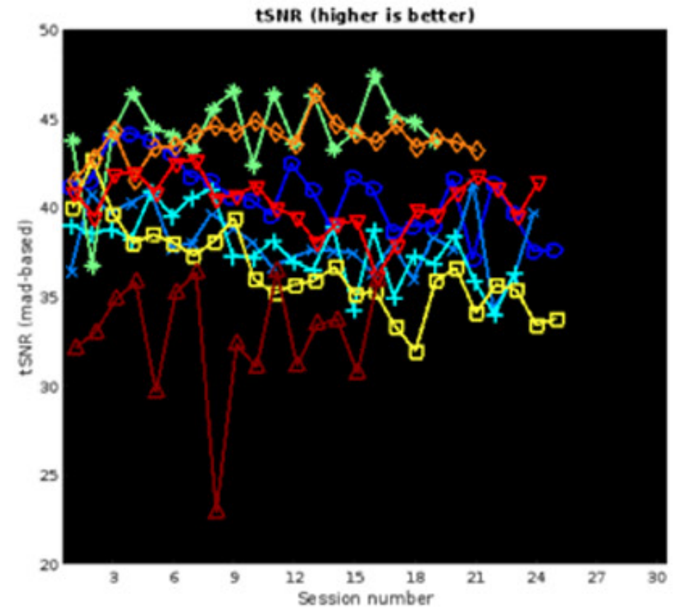
Leaderboard

- Keep tabs on:
  - BOLD activity
  - Behavioral performance
  - Head motion

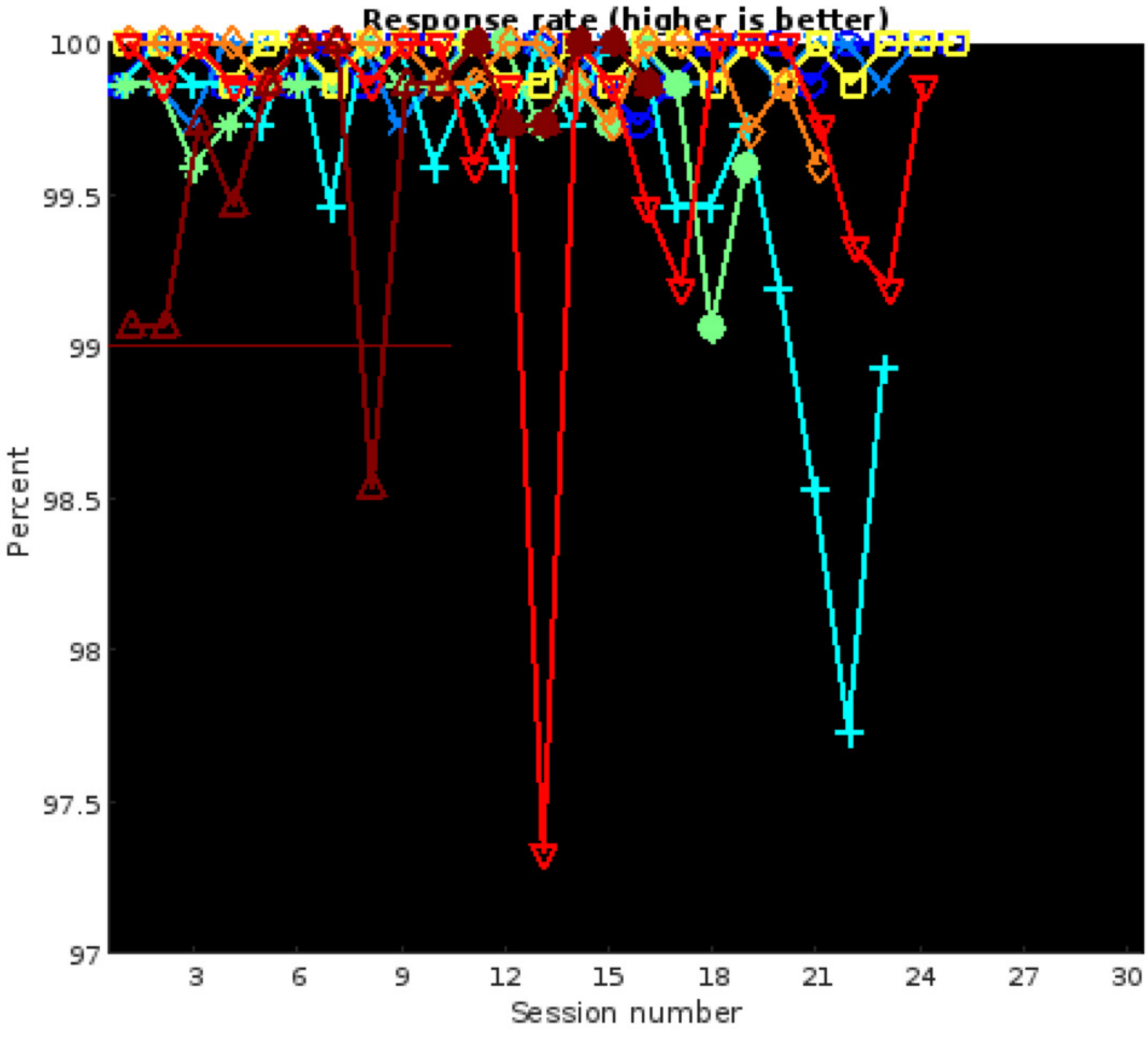
Leaderboard



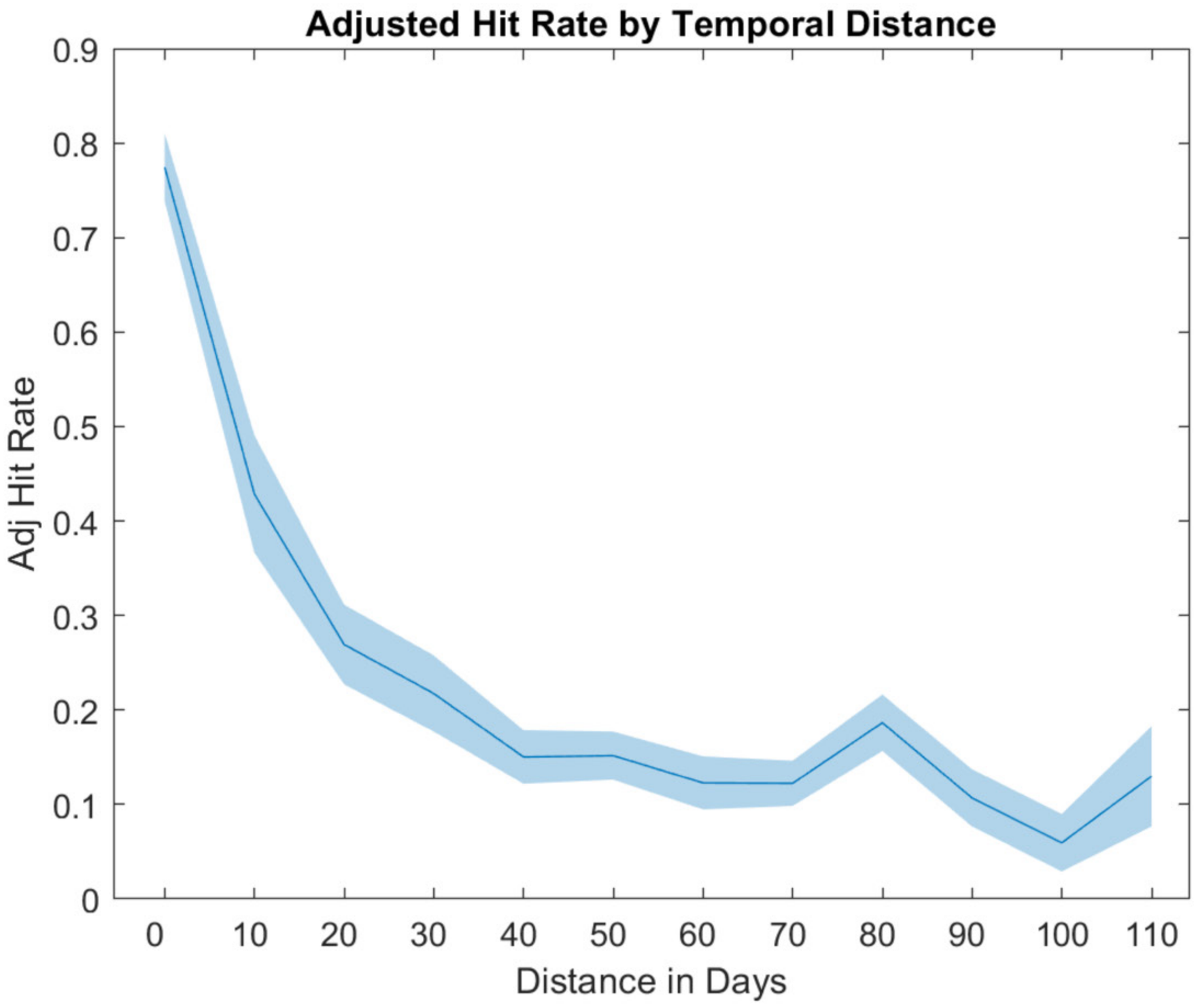




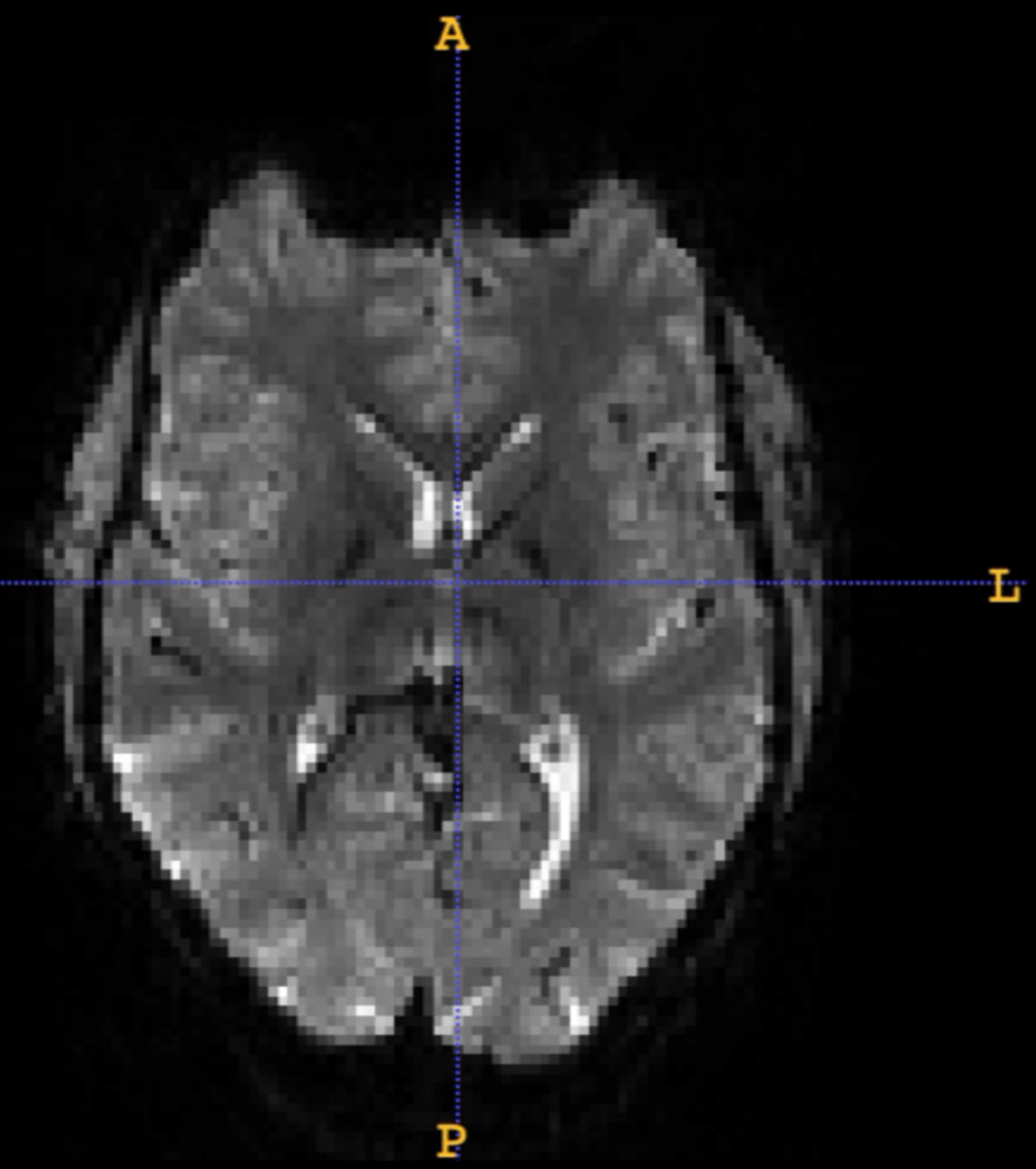
Nearly perfect response rates

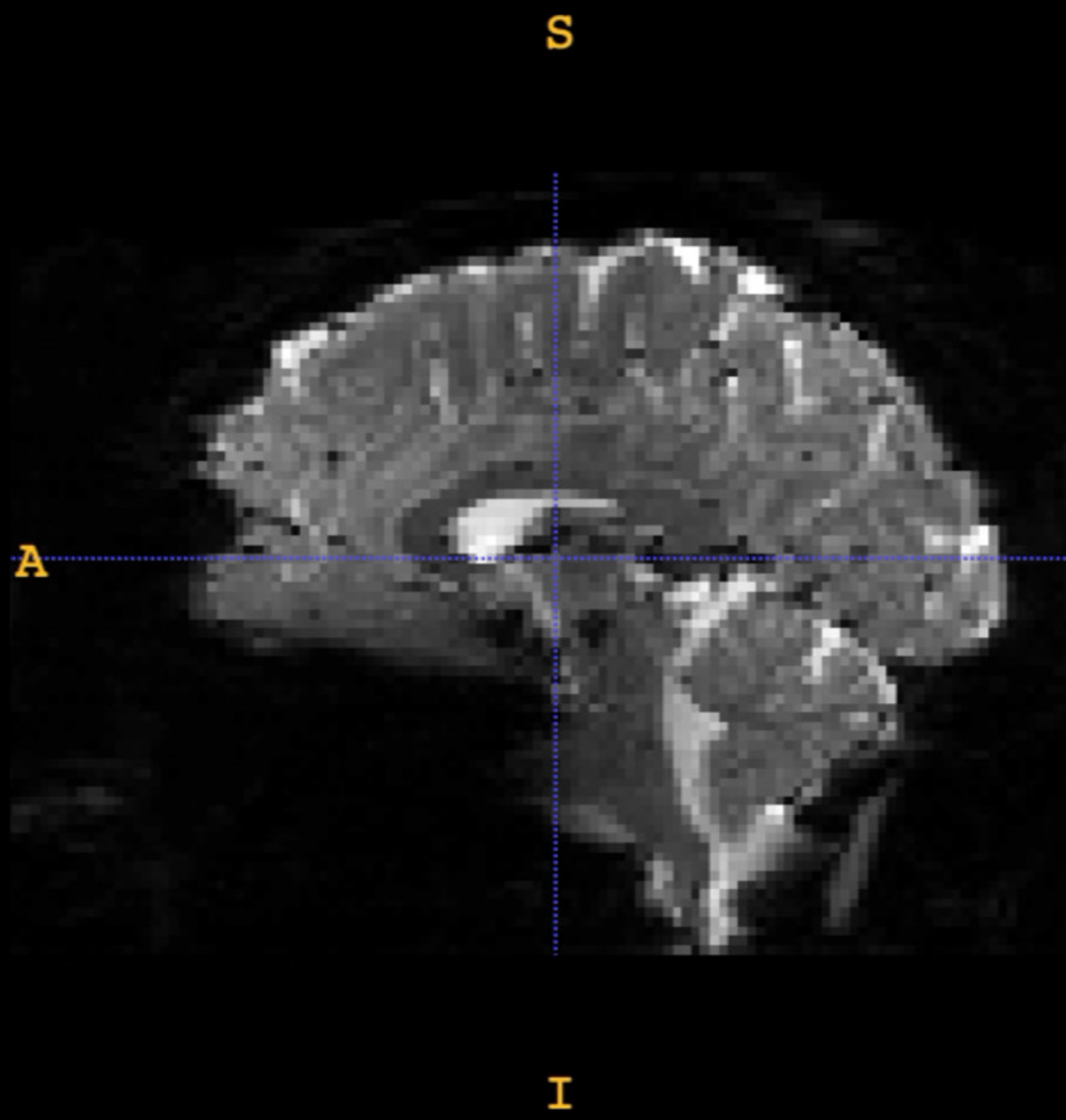


Remarkable recall performance



High-quality raw images





fMRI pre-processing

- One temporal interpolation
  (slice time correction, upsampling)

- One spatial interpolation
  (time-varying fieldmaps, gradient nonlinearities, head motion, upsampling)

Upsampling improves
fine-scale detail

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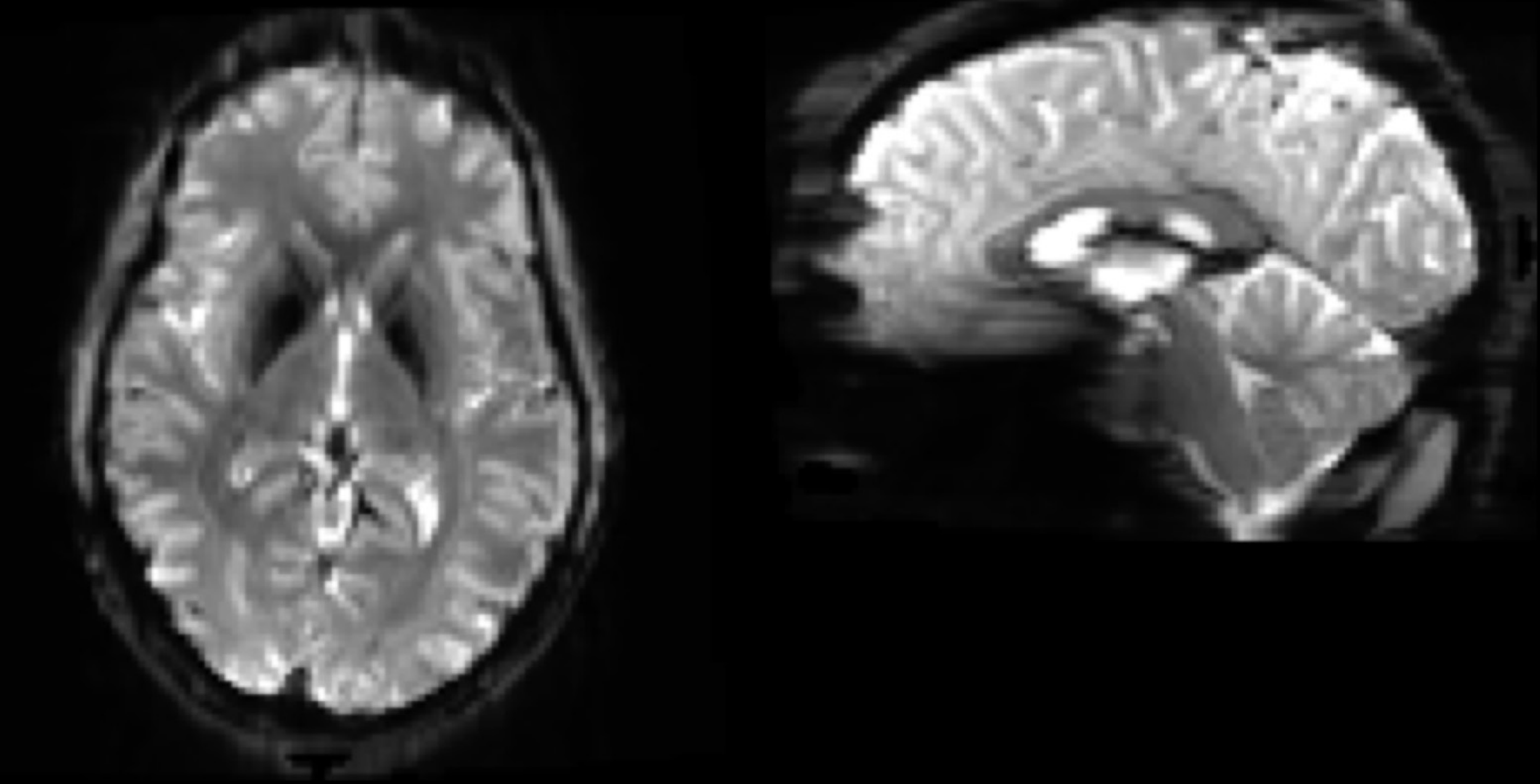
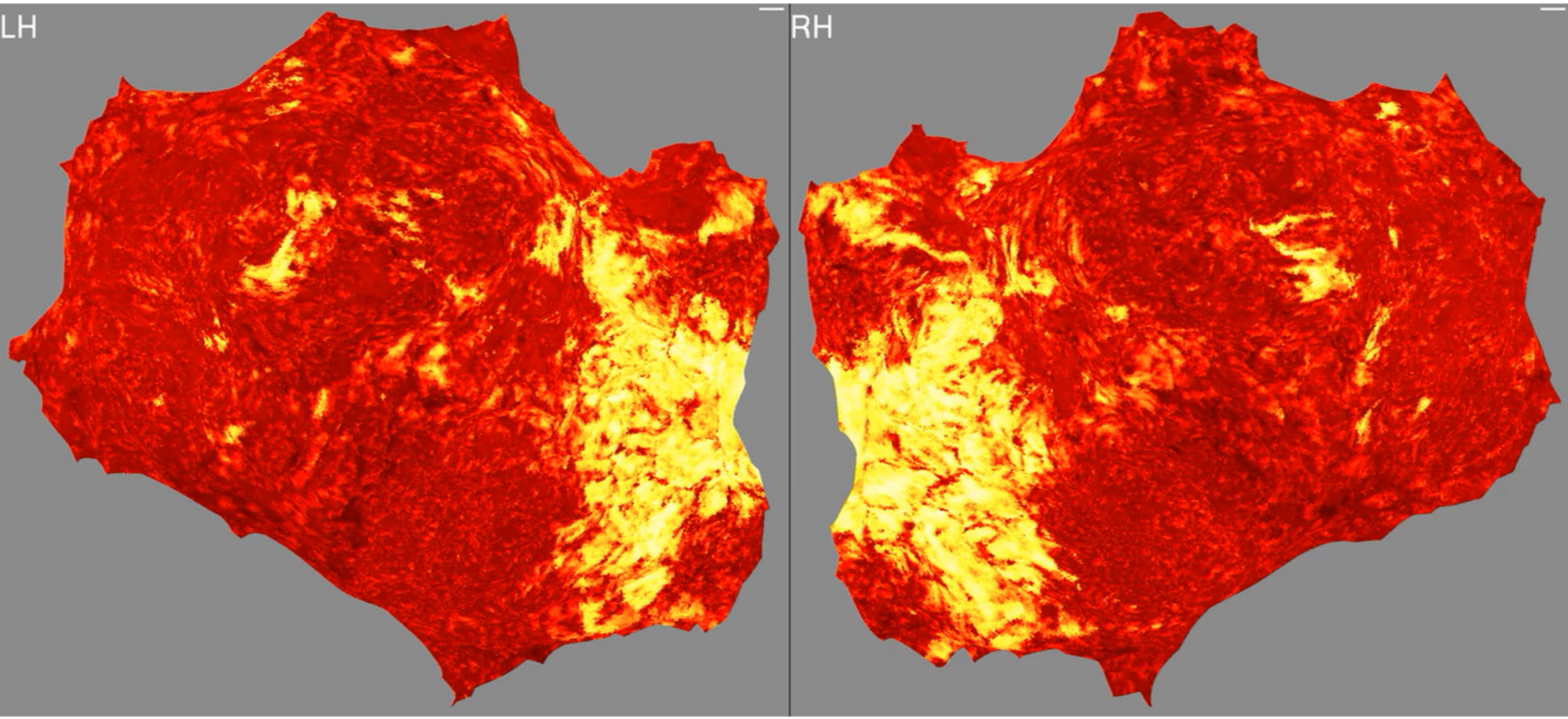
High measurement stability

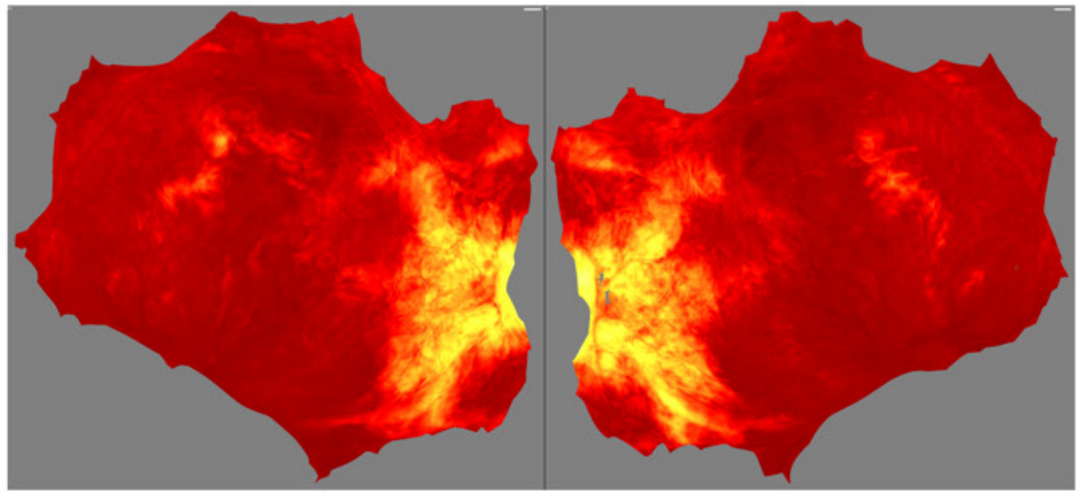


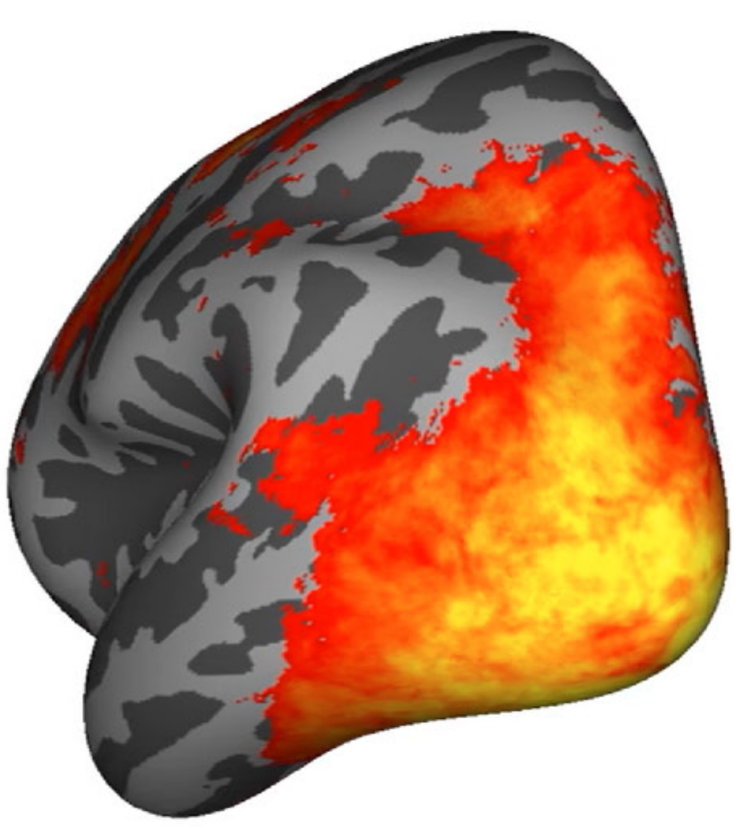
High measurement stability

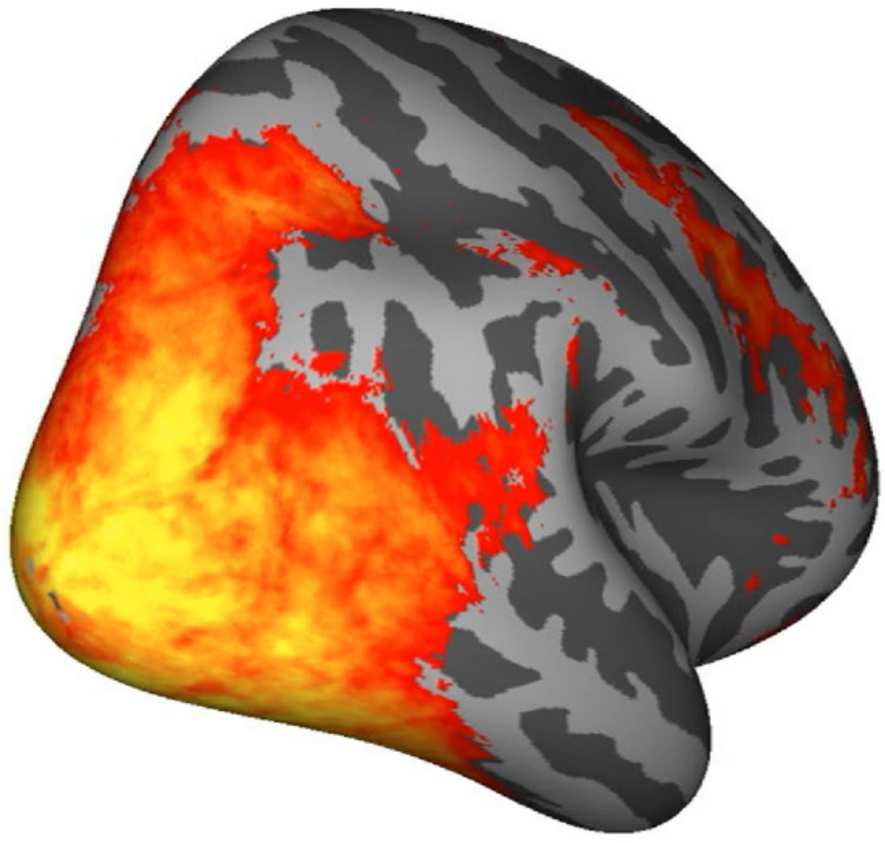
Robust and stable BOLD responses



Brain regions driven by NSD







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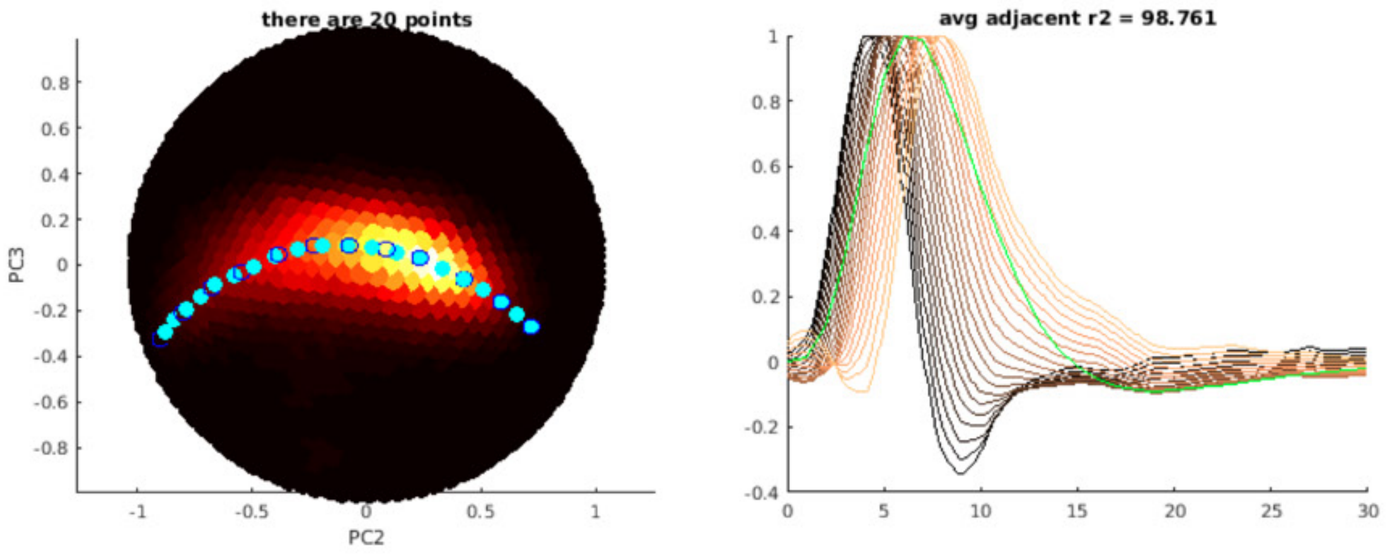
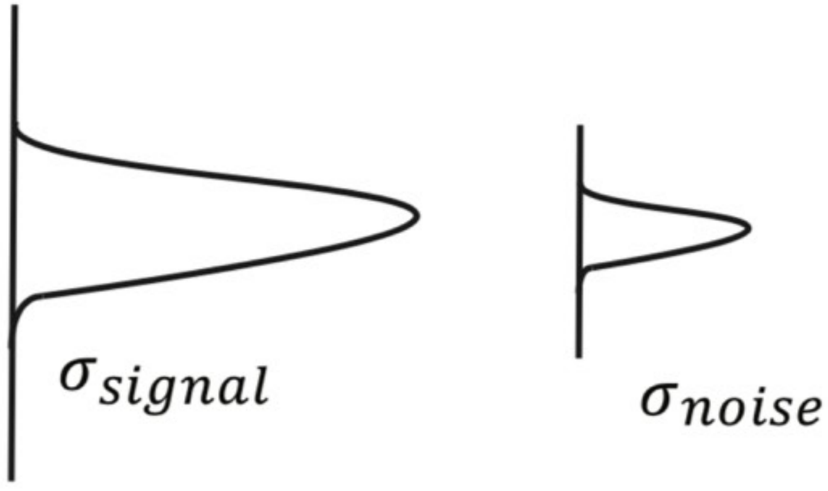
GLM analysis

- Single-trial beta estimates
- HRF estimation for each voxel
- Data-driven denoising (GLMdenoise)
- Ridge regression to stabilize single-trial estimates

Derive global HRF manifold; select from 20 HRFs



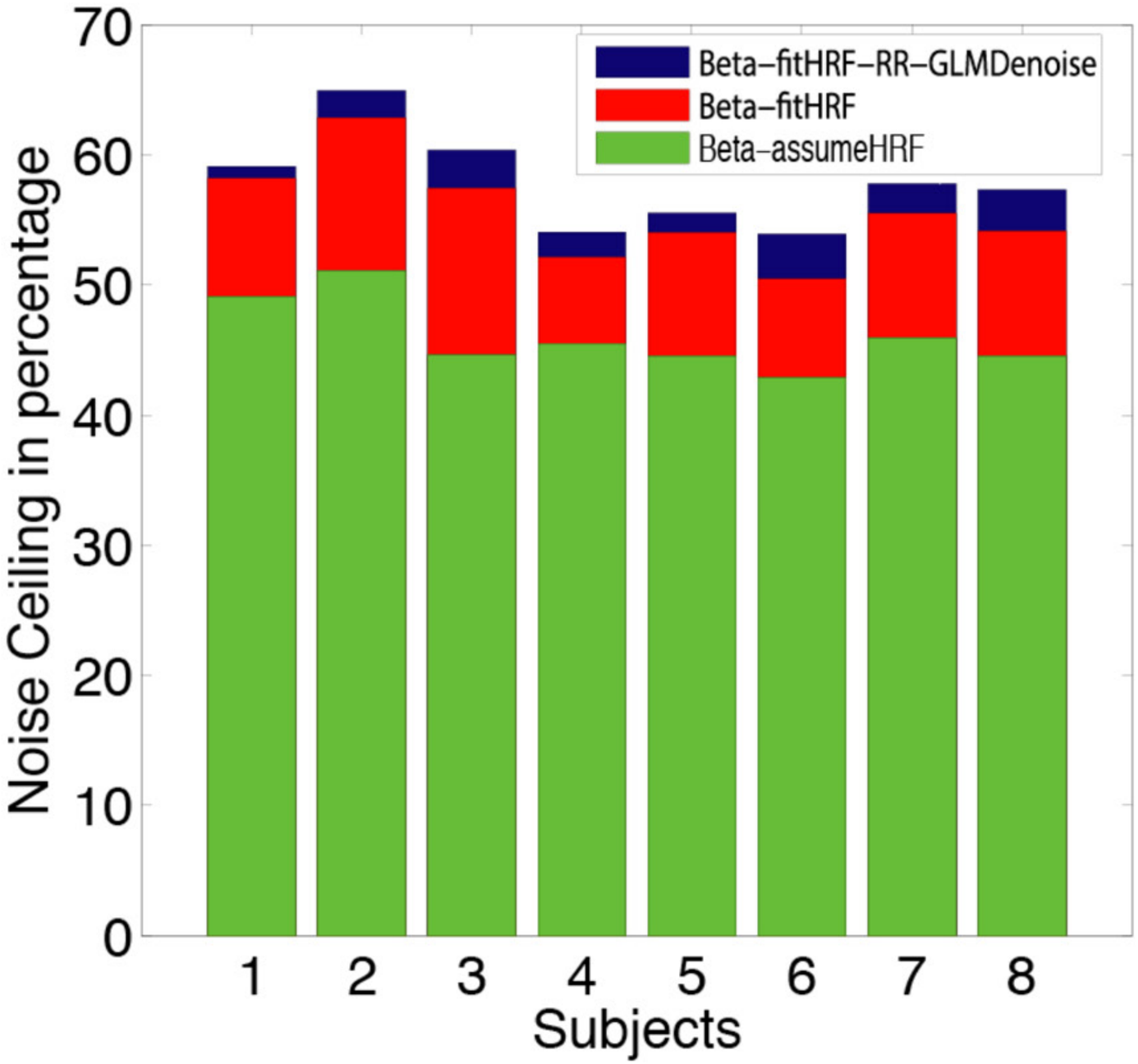
High SNR in voxel responses



$$\text{Noise Ceiling} = \frac{{\sigma_{signal}}^2}{{\sigma_{signal}}^2 + {\sigma_{noise}}^2}$$

David and Gallant, *J Neurophys*, 2005
Kay et al., *J Neurophys*, 2013
Lage-Castellanos et al., *PLOS Comp Bio*, 2019

High SNR in voxel responses

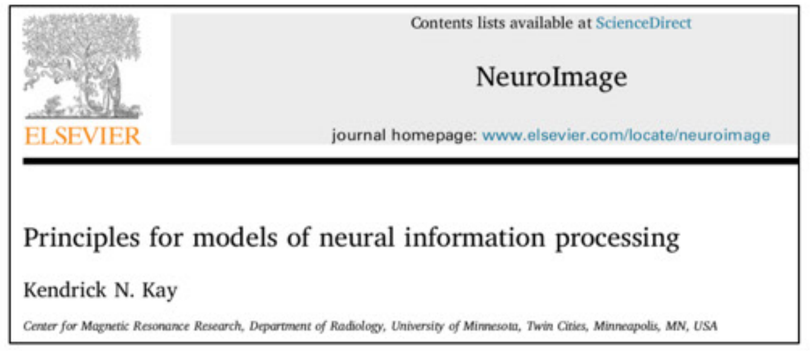


How can NSD data be used?

- Study representation of visual dimensions (orientation, spatial frequency, contrast, color, objects, scenes, etc.)
- Benchmark encoding models
- Train neural networks
- Characterize individual differences
- Topography and mapping
- Integration with other neuroimaging modalities
- Study short-term and long-term memory
- Investigate subcortical regions (LGN, cerebellum)
- Develop fMRI analysis methods

How can NSD data be used?

- Open questions for Algonauts and model benchmarking:
  - What types of models should we aim for?
  - RDMs? Individual units?
  - Group average or individual subjects?
  - What about spatial organization in the brain?


Contents lists available at ScienceDirect

NeuroImage

journal homepage: www.elsevier.com/locate/neuroimage

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Principles for models of neural information processing

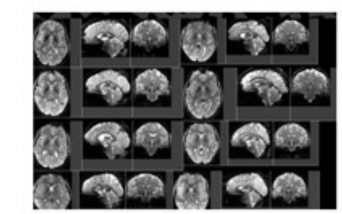
Kendrick N. Kay

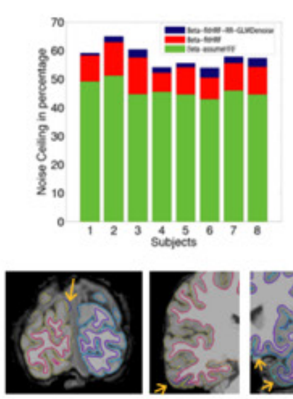
Center for Magnetic Resonance Research, Department of Radiology, University of Minnesota, Twin Cities, Minneapolis, MN, USA

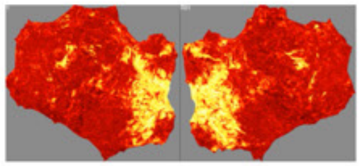
Take-home points

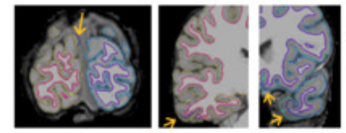
- NSD is a large 7T fMRI dataset with perception and memory of natural scenes

- Data are demonstrated to have high SNR, high resolution, and high stability



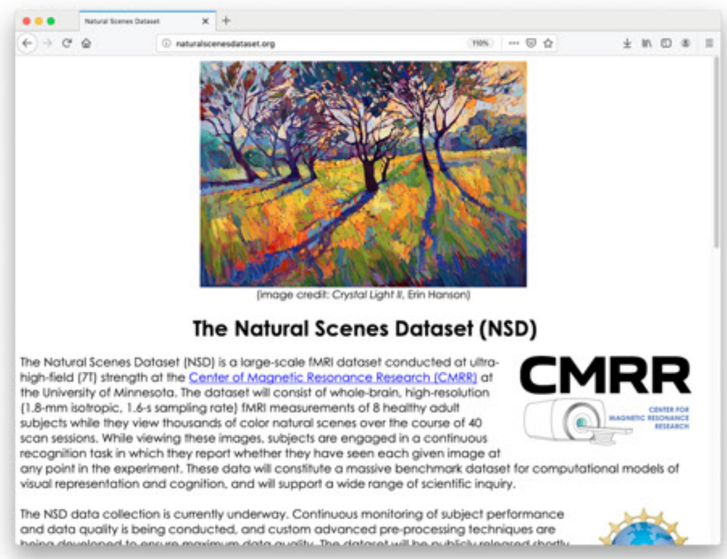






- NSD data can support a variety of uses including model benchmarking

- NSD data will be freely available: **http://naturalscenesdataset.org**



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