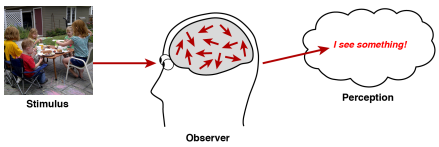
1

Why NSD?

- **How does visual cortex work?**
  - Characterize the computations by which information is transformed and re-represented in the brain.
  - Build models of neural information processing. (Kay, *NeuroImage*, 2018)
- We need to sample a lot of stimuli.
- **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



2

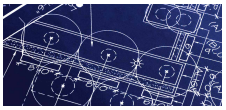
What were the priorities for this dataset?

- **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.



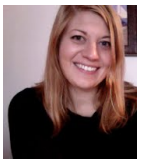
Kendrick Kay, CMRR, University of Minnesota

3

Core contributors

- Kendrick Kay, Assistant Professor, UMN

- Thomas Naselaris, Assistant Professor, Medical University of South Carolina

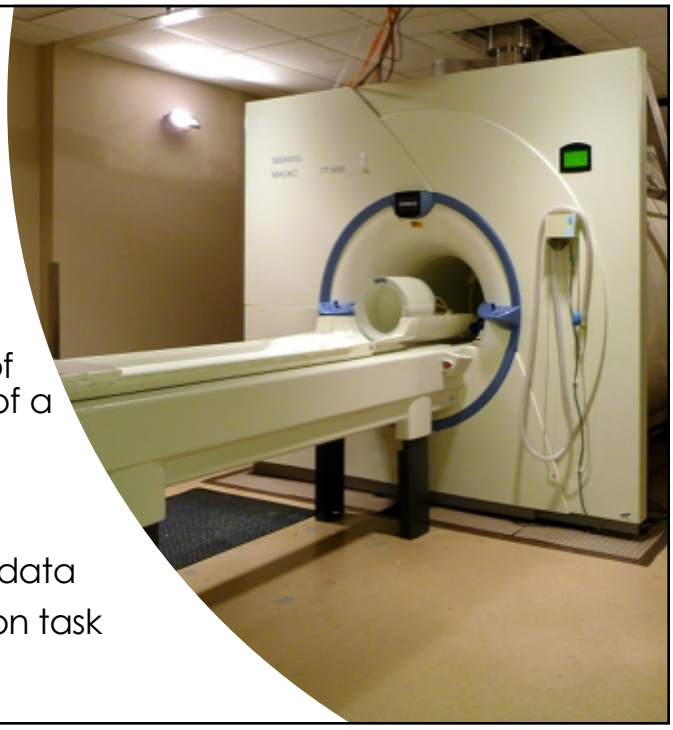


- Emily Allen, Postdoctoral Associate, UMN
- Yihan Wu, Graduate Student , UMN

Funding provided by NSF

4

Overview

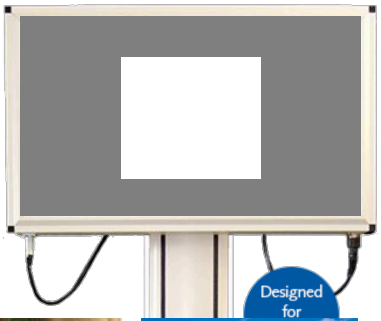


- 8 participants, 34-44 sessions (including anatomy)
- Exposure to 22,500-30,000 trials of natural scenes over the course of a year
- Whole brain data, including cerebellum, subcortical regions
- 7T, 1.6s TR, 1.8mm isotropic fMRI data
- Long-term continuous recognition task

5

Stimuli

- 8.4 x 8.4°
- Presented via a linearized high-quality LCD display, Cambridge Research Systems' BOLDscreen 32
- Each stimulus was on for 3 seconds, followed by a blank screen for 1 second



6

task: for every image you see, indicate if it is *new* (1)
(I've never seen it before) or *old* (2) (I've seen before, either today or in a past session)

7

COCO
Common Objects in Context

http://cocodataset.org

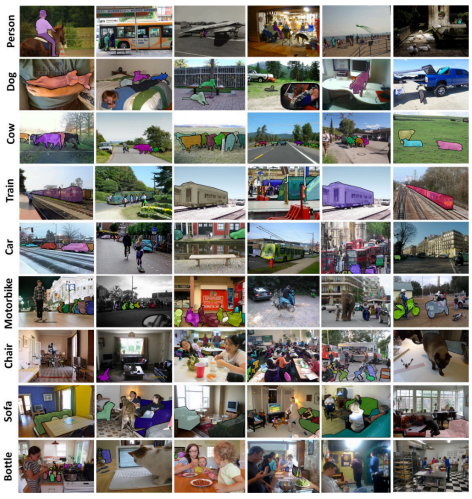
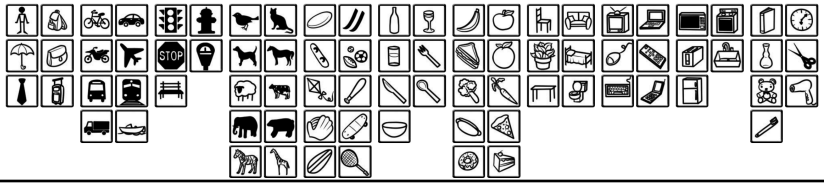


Fig. 6: Samples of annotated images in the MS COCO dataset.



What is COCO?

COCO is a large-scale object detection, segmentation, and captioning dataset. COCO has several features:

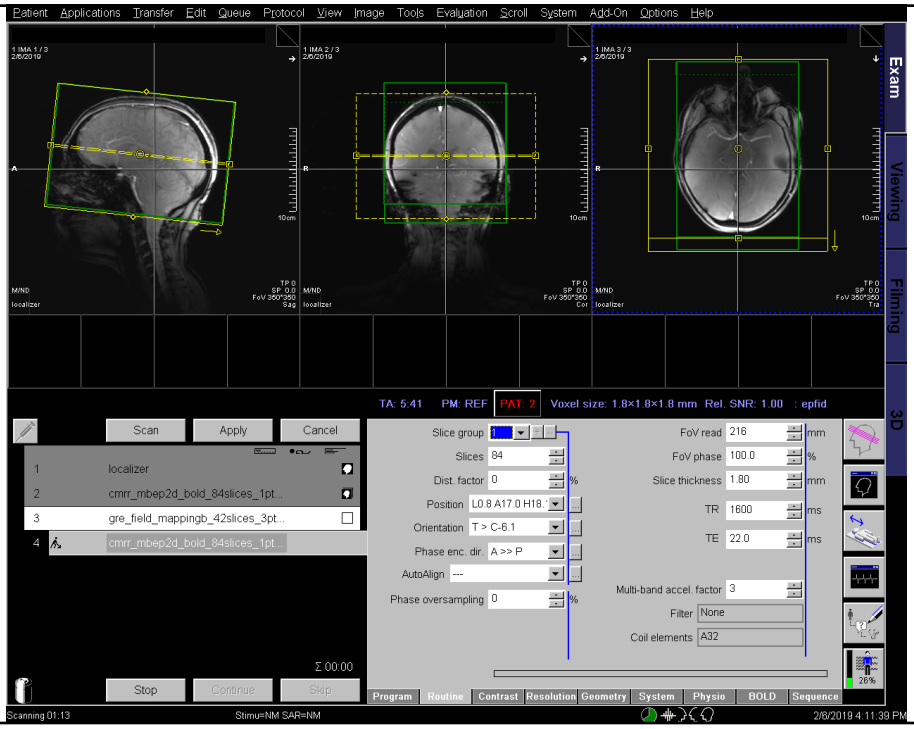
Object segmentation
Recognition in context
Superpixel stuff segmentation
330K images (>200K labeled)
1.5 million object instances
80 object categories
91 stuff categories
5 captions per image
250,000 people with keypoints

8

Data collected

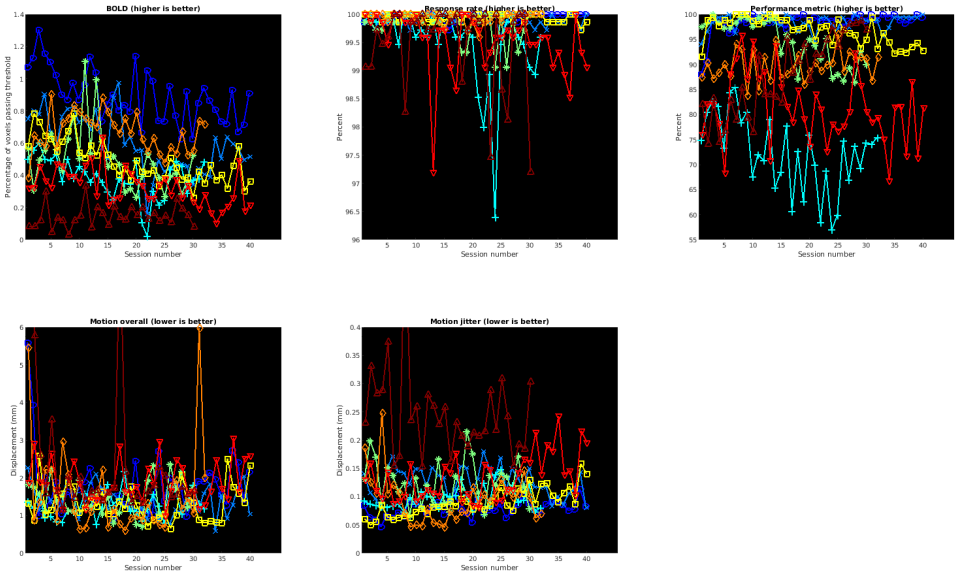
- **functional data**
  - Whole brain EPI data during task (1.8 mm, 1.6s TR, MBx3, iPAT2)
  - Resting state data
  - Retinotopy (pRF), category localizer
  - Synthetic stimuli data
  - Imagery data
- **field maps** (distortion correction)
- **anatomical data**
  - 6 T1s, 3 T2s, 4 dMRI (diffusion data), MR TOF angiogram (3T)
  - SWI venogram (7T)
- **behavioral data**
- **physiological data** (for *some* sessions: pulse, respiration)
- **detailed information about each session**
  - Day/time/duration of scan, subject feedback, general notes, equipment used, sequences used, hardware issues, screen shot of slice placement…

9



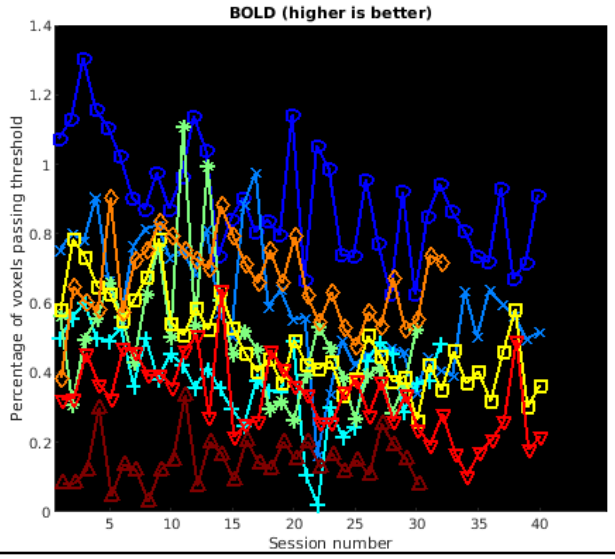
10

Subject leaderboard



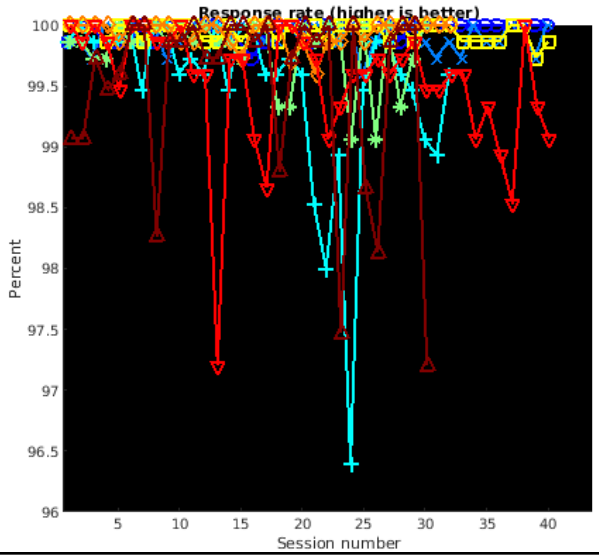
11

BOLD (higher is better)



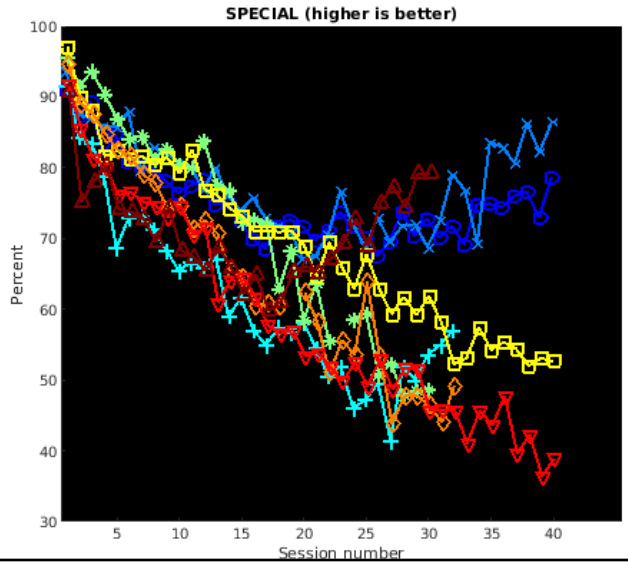
12

Response rate (higher is better)



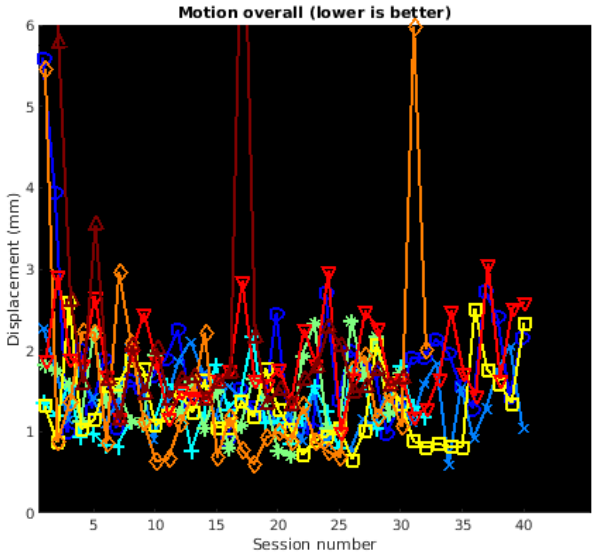
13

Task performance (higher is better)



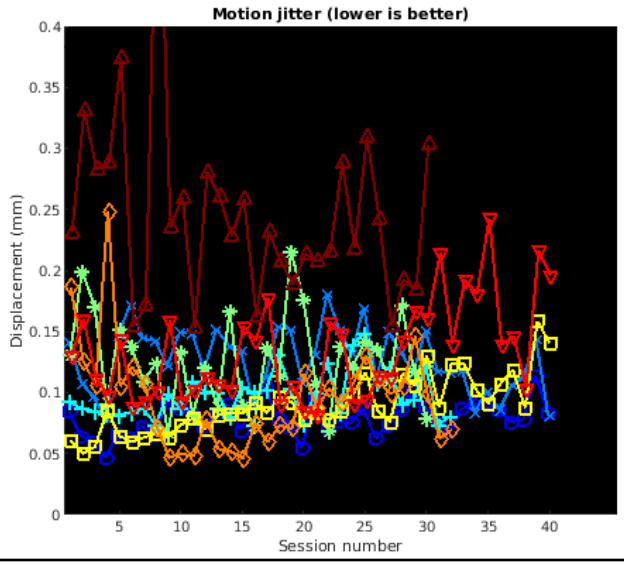
14

Motion across session (lower is better)



15

Motion within run (lower is better)



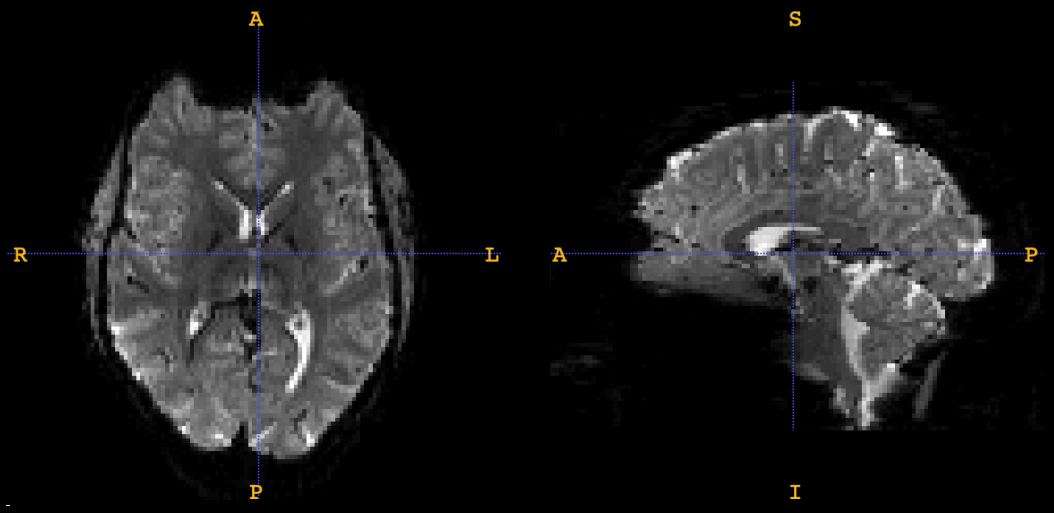
16

CASE FORGE

Precision, Stability, Comfort

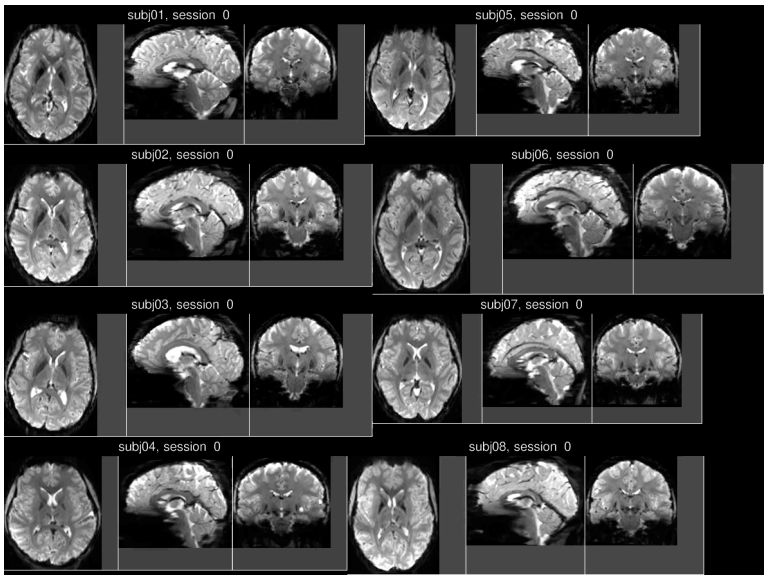
17

High-quality raw images



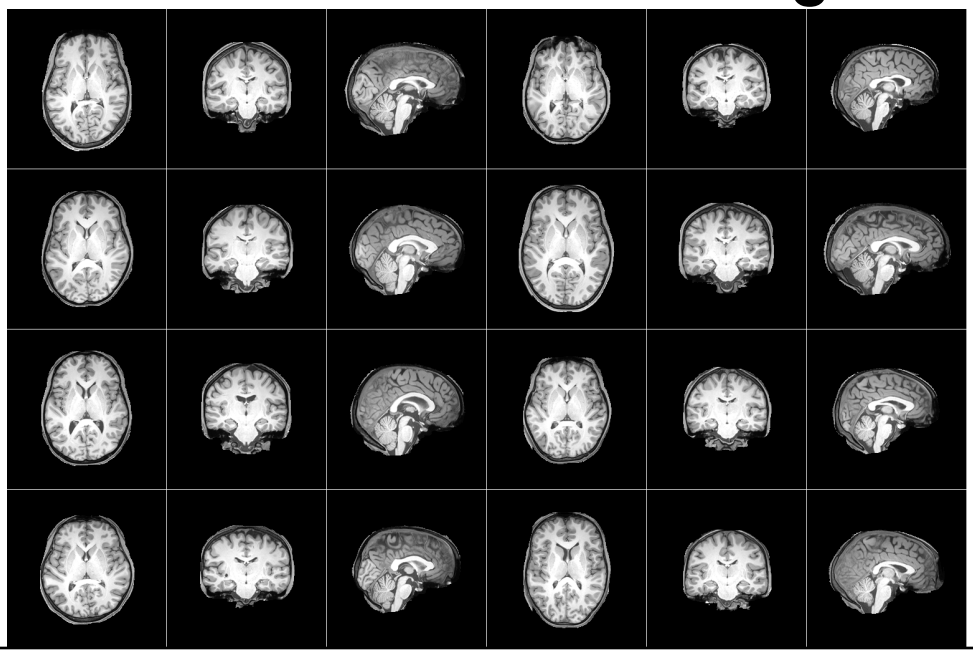
18

Very good data quality and stability

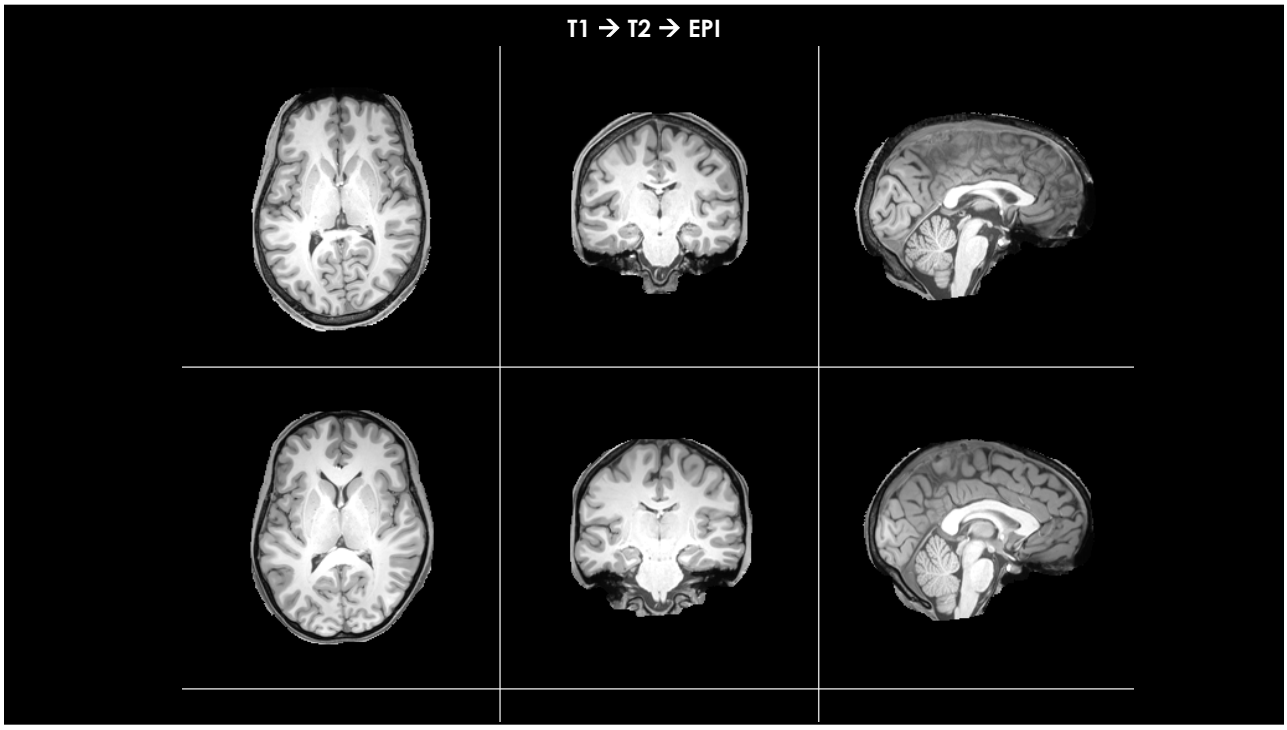


19

Good functional-structural alignment

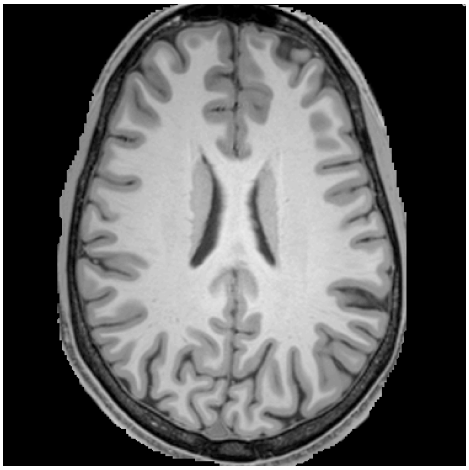


20

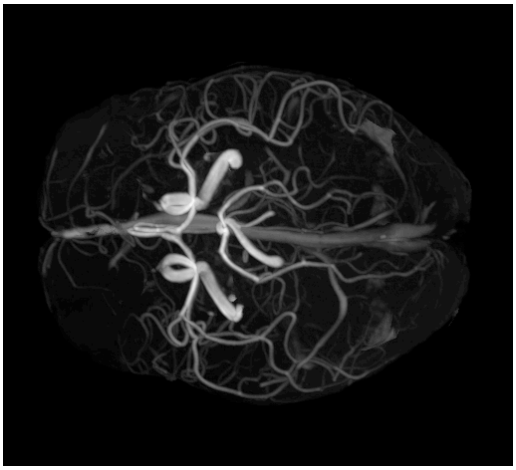


21

T1



MR angiogram (MRA)

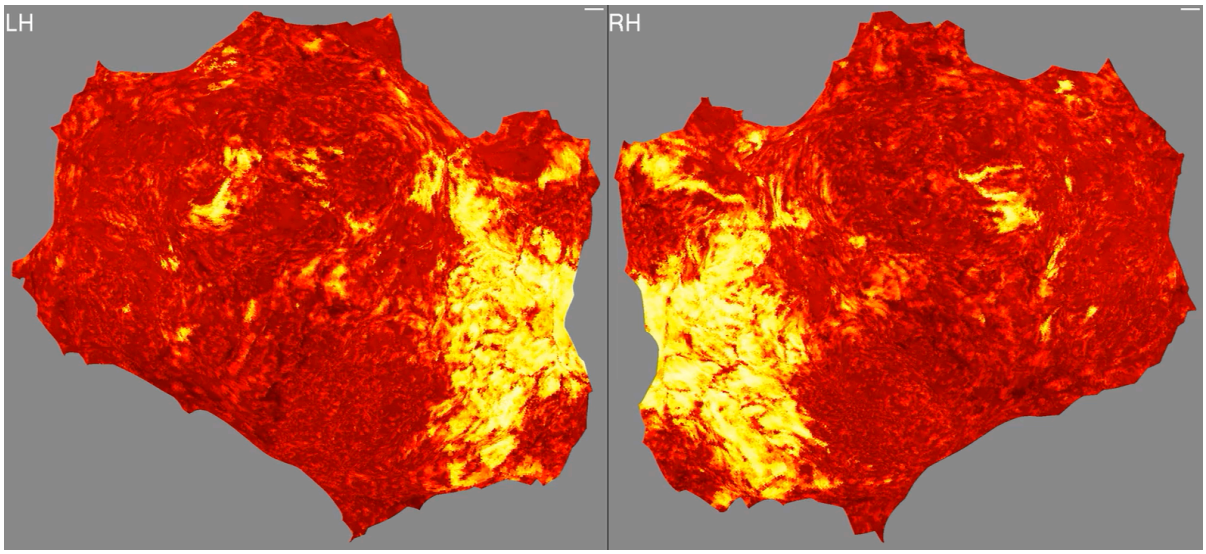


22

Robust and stable BOLD responses

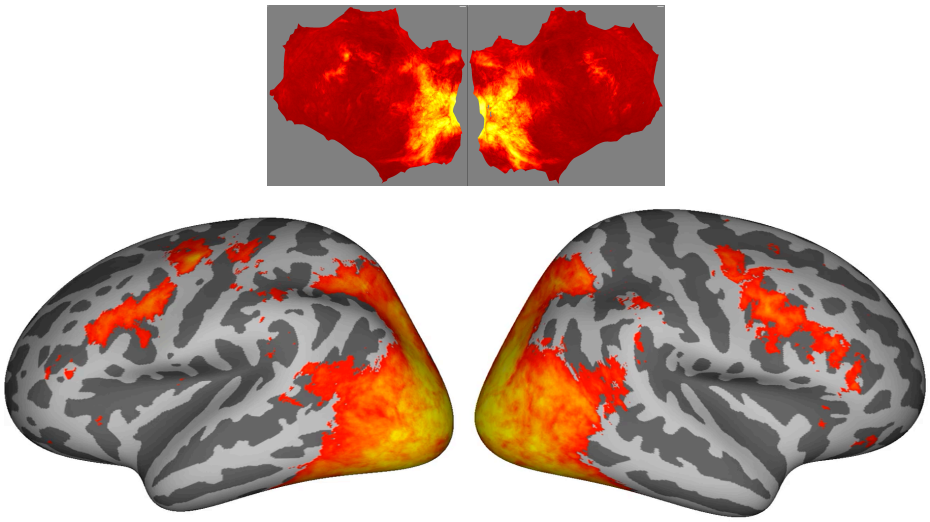
23

Very good data quality and stability (more evidence)



24

Brain regions driven by NSD

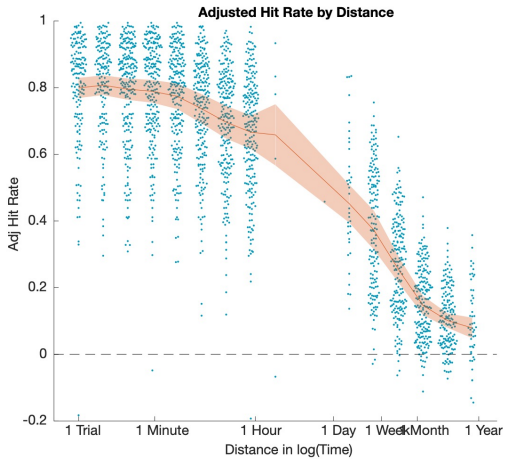


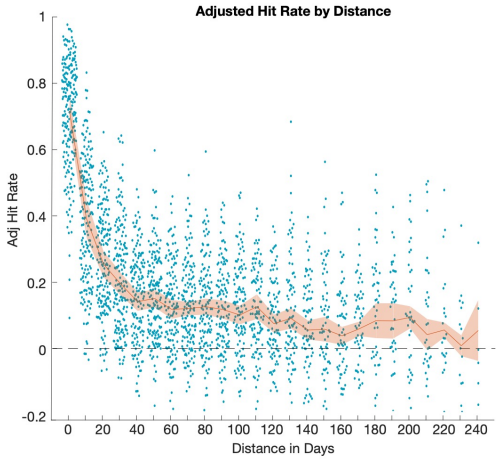
Kendrick Kay, CMRR, University of Minnesota

25

Memory at long timescales

courtesy of
B. Hutchinson





Subjects show above-chance memory performance, even at extremely long delays (6+ months).

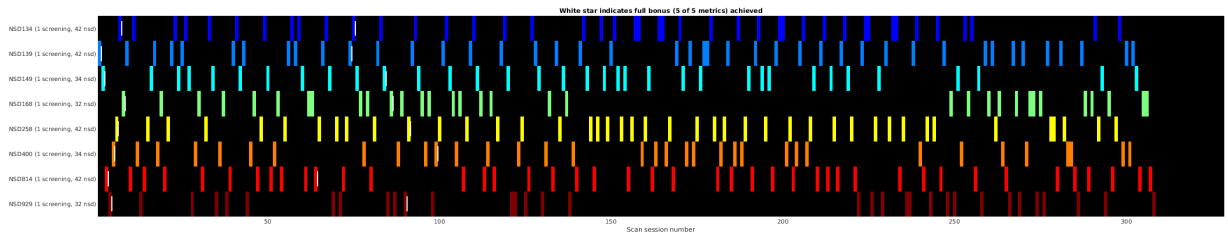
26

What you need to pull off such a project?

- A LOT of server space.
- A lot of $$$ (scanner costs, subjects hourly payment + bonuses)
- Amazing participants (both in their performance as subjects and also their willingness to be scanned every week for ~a year).
- 2 researchers available (one 7T operator) for every scan.
- A huge stimulus set (73k images)
- Carefully crafted, solid experimental design
- High-quality, streamlined data acquisition protocol
- Ongoing (daily) quality control checks of all data as it comes in.
- A stable (largely automated) pre-processing/processing pipeline.
- People who are interested in analyzing it!!

27

Shout out to our great participants!



28

What could NSD data be useful for?

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

29

Army of collaborators on the NSD data

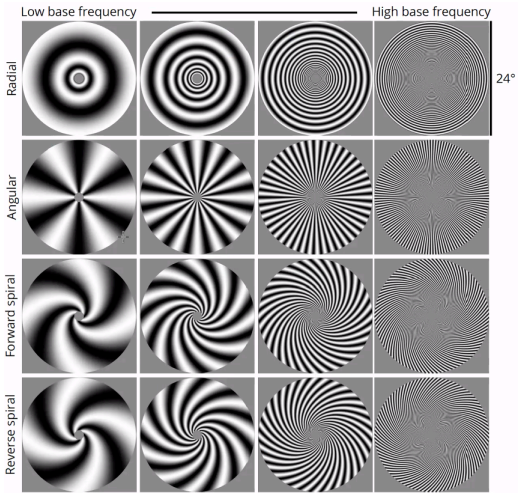
Kendrick Kay, CMRR, University of Minnesota

30

Army of collaborators on the NSD data

Billy Broderick, Jon Winawer (NYU)

What are spatial frequency tuning properties during natural vision?



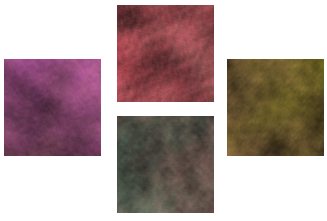
Kendrick Kay, CMRR, University of Minnesota

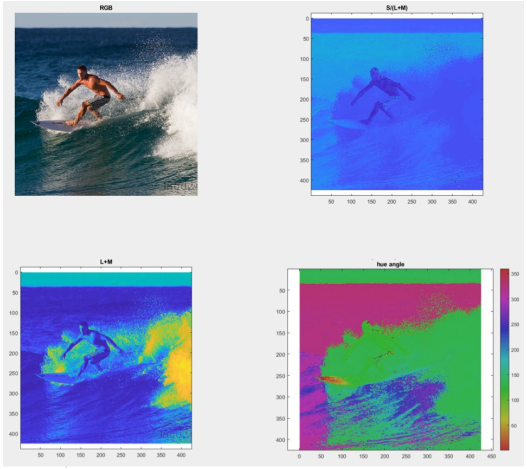
31

Army of collaborators on the NSD data

Chris Racey, Jenny Bosten, Anna Franklin (Univ. of Sussex)

Encoding models for color





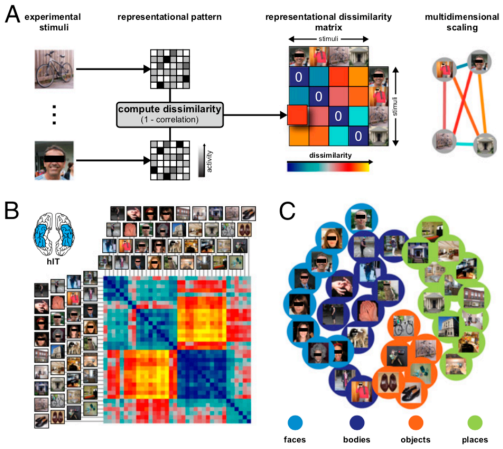
Kendrick Kay, CMRR, University of Minnesota

32

Army of collaborators on the NSD data

Ian Charest (Univ. of Birmingham)

Characterize the semantic spaces in individual subjects (using RSA)



33

Army of collaborators on the NSD data

Radek Cichy, Gemma Roig, Aude Oliva (MIT)



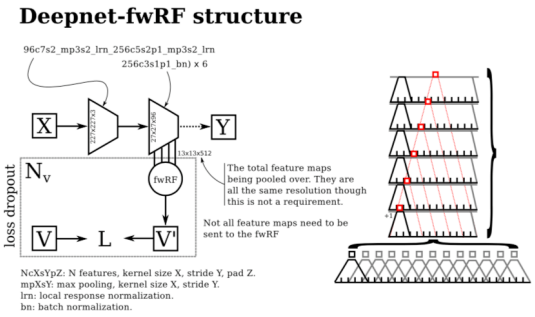
Establishing competitive benchmarks for computational models of vision

34

Army of collaborators on the NSD data

Ghislain St.-Yves, Thomas Naselaris (Medical Univ. of South Carolina)

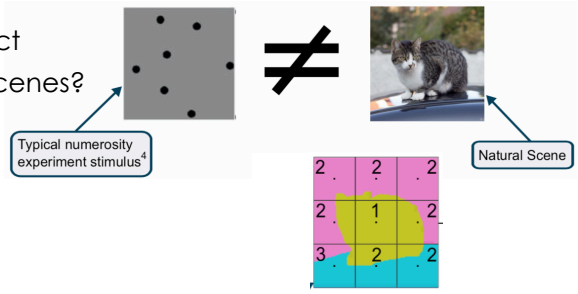
Use huge amounts of data to directly train a deep neural network to predict brain activity



Army of collaborators on the NSD data

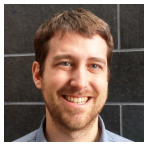
Maggie Mell, Thomas Naselaris (Medical Univ. of South Carolina)

How does the brain extract numerosity from natural scenes?

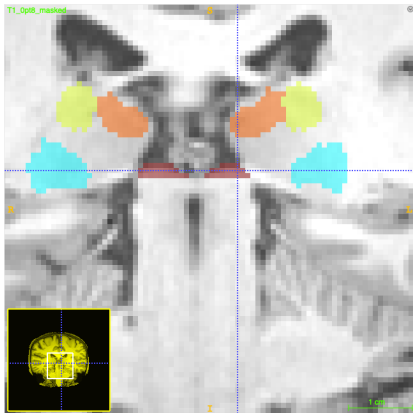


Army of collaborators on the NSD data

Danny Guest (UMN), Mike Arcaro (UPenn)



Exploit high-quality fMRI measurements in the thalamus (LGN, pulvinar, SC)



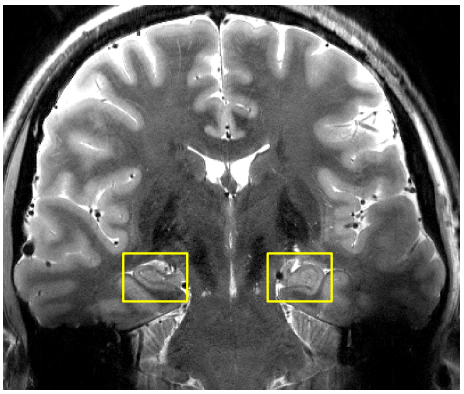
Kendrick Kay, CMRR, University of Minnesota

37

Army of collaborators on the NSD data

Ben Hutchinson, Brice Kuhl, Sarah DuBrow (Univ. of Oregon)

Neural mechanisms underlying short- and long-term memory



Kendrick Kay, CMRR, University of Minnesota

38

Army of collaborators on the NSD data

Alex White, Jason Yeatman (Stanford)

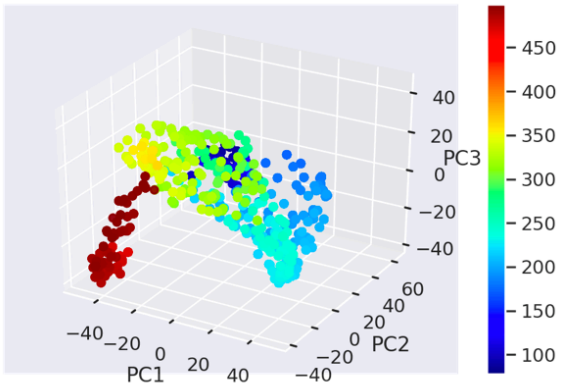
How does VWFA encode written words?

39

Army of collaborators on the NSD data

Tom Gebhart (UMN)

Manifold and topography of image representation in ventral visual cortex

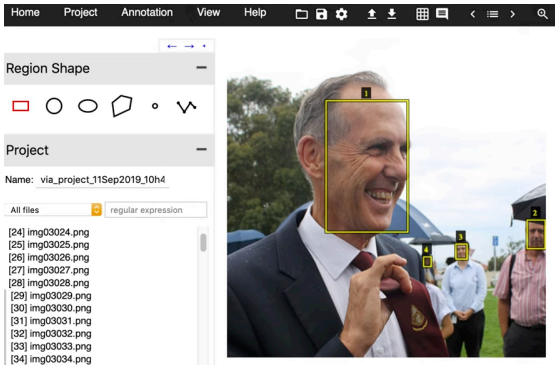


40

Army of collaborators on the NSD data

Asha Ramalaxmi (UMN)

How does visual cortex encode faces in the wild?

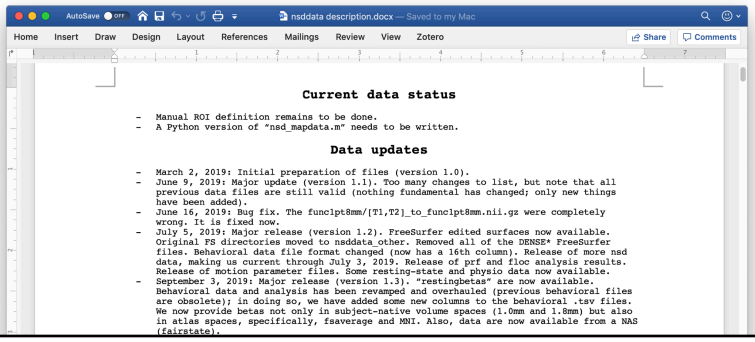


Kendrick Kay, CMRR, University of Minnesota

41

NSD data description file

- **nsddata description.docx**
  - Contains a wealth of technical details about what is provided in the prepared data files.
  - Still being written (work in progress).
  - Should read this offline!



42

NSD data description highlights:

- Pre-processed functional and structural data
- Freesurfer outputs
- Native subject and group spaces
- Behavioral data
- Resting-state data
- Physiological data and eyetracking data
- Timing details
- ROI files
- General experiment information
- Analysis code

43

Preprocessing of the fMRI data

- **One temporal resampling** using cubic interpolation
  - Upsampling of the data
    (high-res version: 1s; low-res version: 1.333 s)
  - Slice time correction included in this
  - First time point coincident with start of the first volume
- **One spatial resampling** using cubic interpolation
  - Upsampling of the data
    (high res version: 1 mm, low-res version: 1.8 mm)
  - Motion correction
  - Distortion correction
  - Across-session alignment

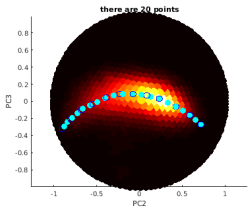
44

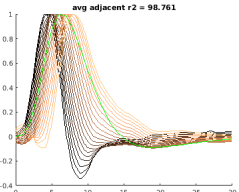
Preprocessing of the fMRI data

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

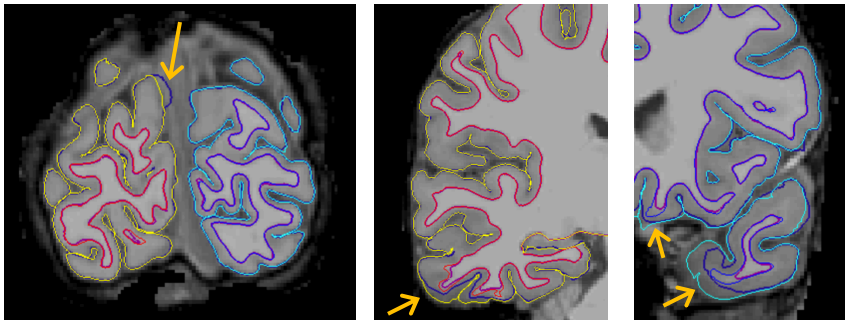




Kendrick Kay, CMRR, University of Minnesota

45

Manual edits of FreeSurfer surfaces

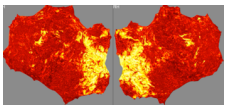


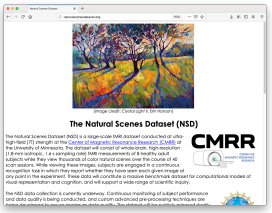
46

47

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





Kendrick Kay, CMRR, University of Minnesota

48