

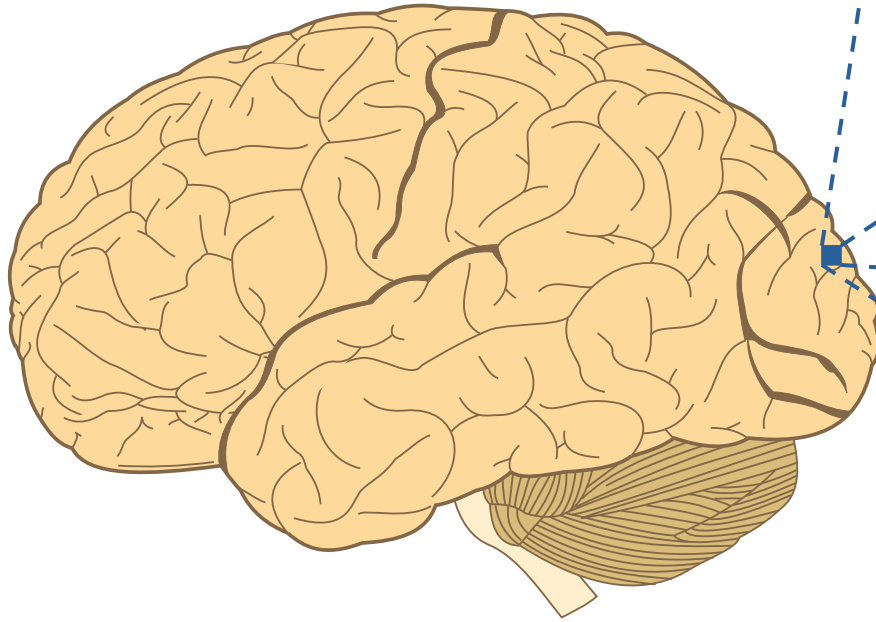
A very brief intro to fMRI and some processing



Outline

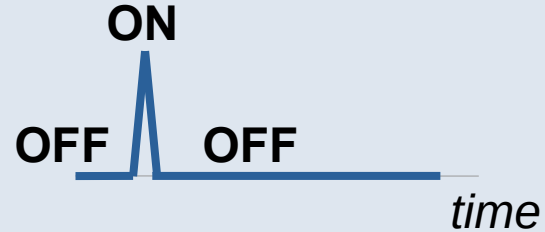
- **What does functional magnetic resonance imaging (fMRI) measure?**
 - Going from: Neuron firing → blood oxygenation response
- **What are good properties of fMRI?**
 - Safe, non-invasive, whole brain, time-resolved
- **What are some challenging properties of fMRI?**
 - Susceptible to motion, artifact and distortions
- **How does all this inform our processing and quality checks?**
 - Motivate some standard steps and things to look out for

A cartoon picture of task-based fMRI

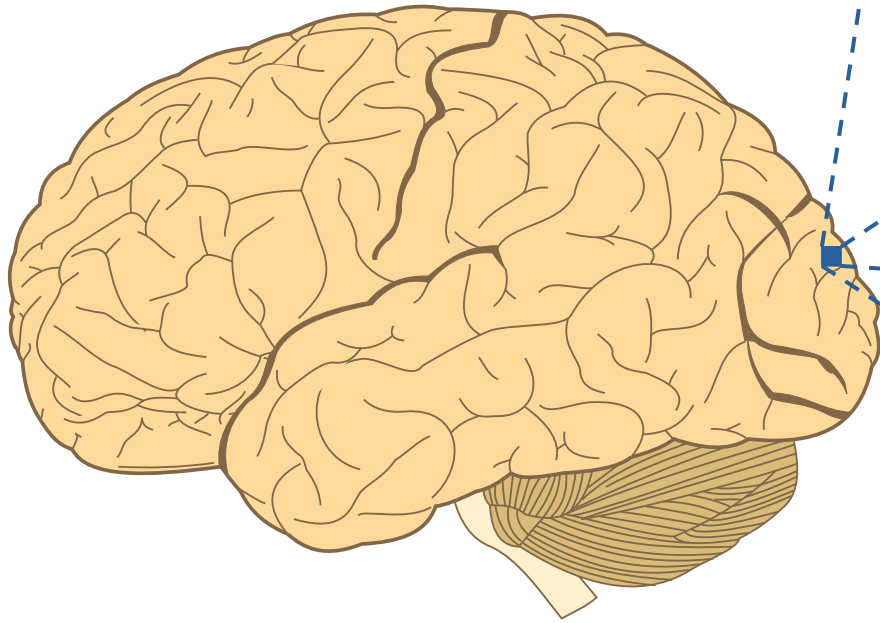


Brain activity:

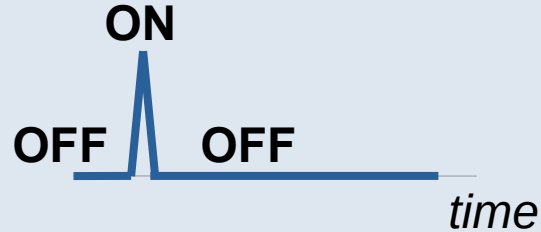
some neurons fire
(e.g., brief stimulus)



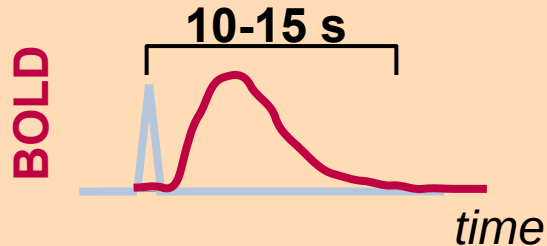
A cartoon picture of task-based fMRI



Brain activity:
some neurons fire
(e.g., brief stimulus)

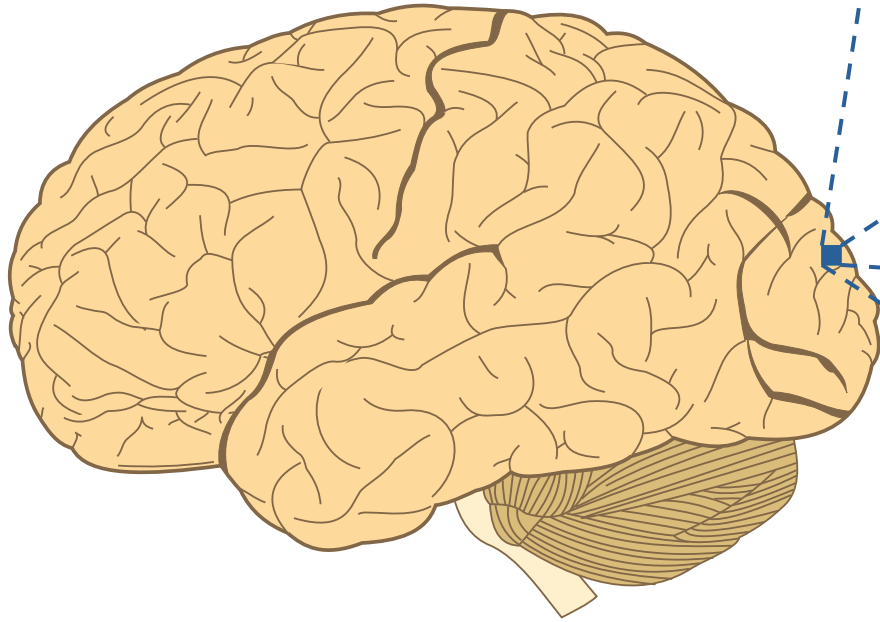


BOLD response:
blood oxygenation
changes locally

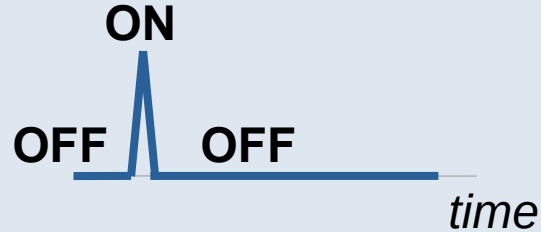


*BOLD = Blood Oxygen
Level-Dependent*

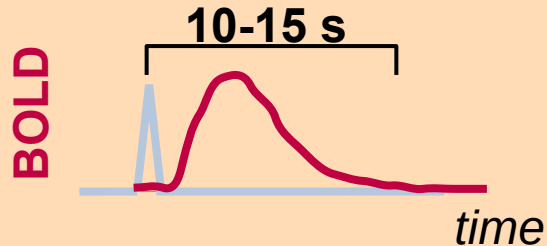
A cartoon picture of task-based fMRI



Brain activity:
some neurons fire
(e.g., brief stimulus)



BOLD response:
blood oxygenation
changes locally



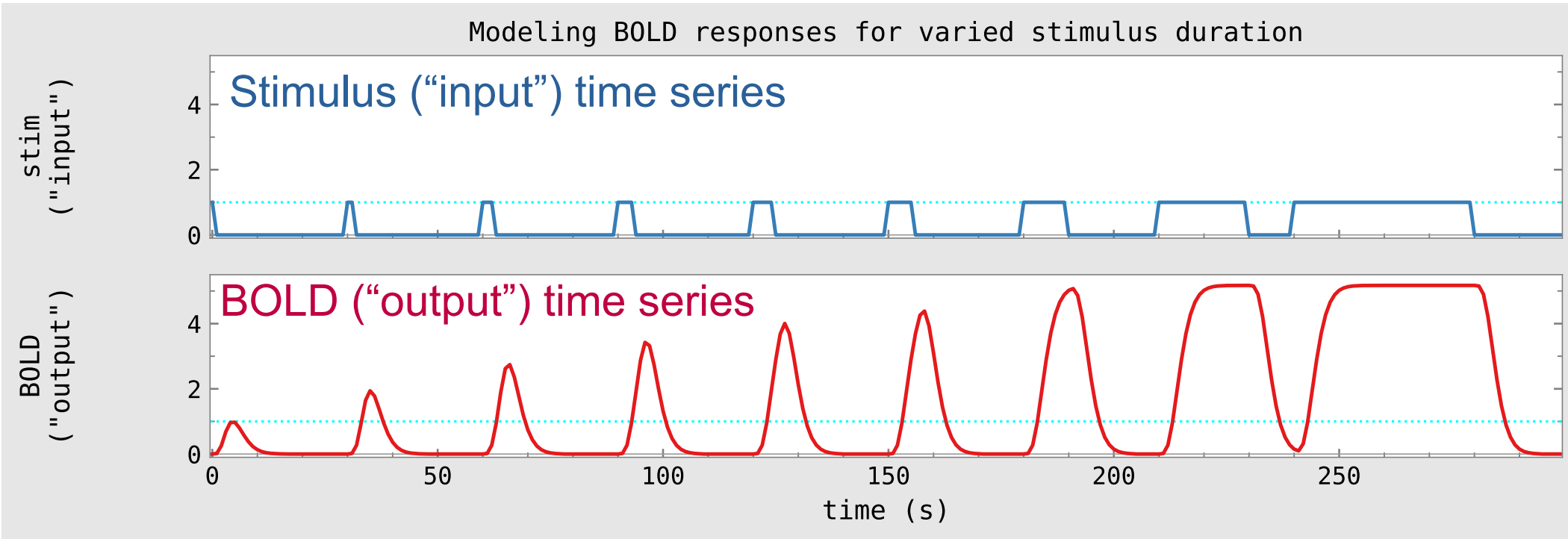
MRI measures:
BOLD changes
affect magnetic
field, which are
observed with
the MRI scanner

*BOLD = Blood Oxygen
Level-Dependent*

Modeling stimulus to BOLD response (idealized)

Q: For a longer stimulus, what happens to the BOLD response?

A: It is also longer *and* increases, up to a plateau.

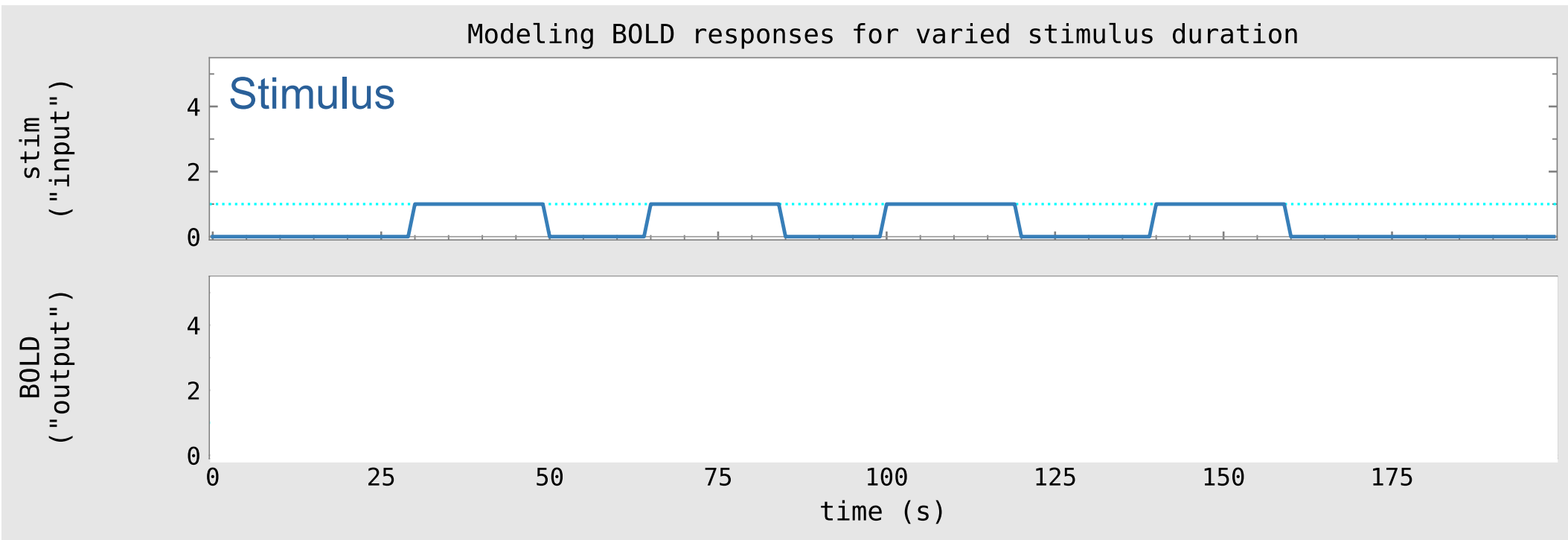


Note: The BOLD peak is a few seconds after the stim start, and slowly decreases after the stim ends.

Modeling stimulus to BOLD response (idealized)

**** Pop quiz ****

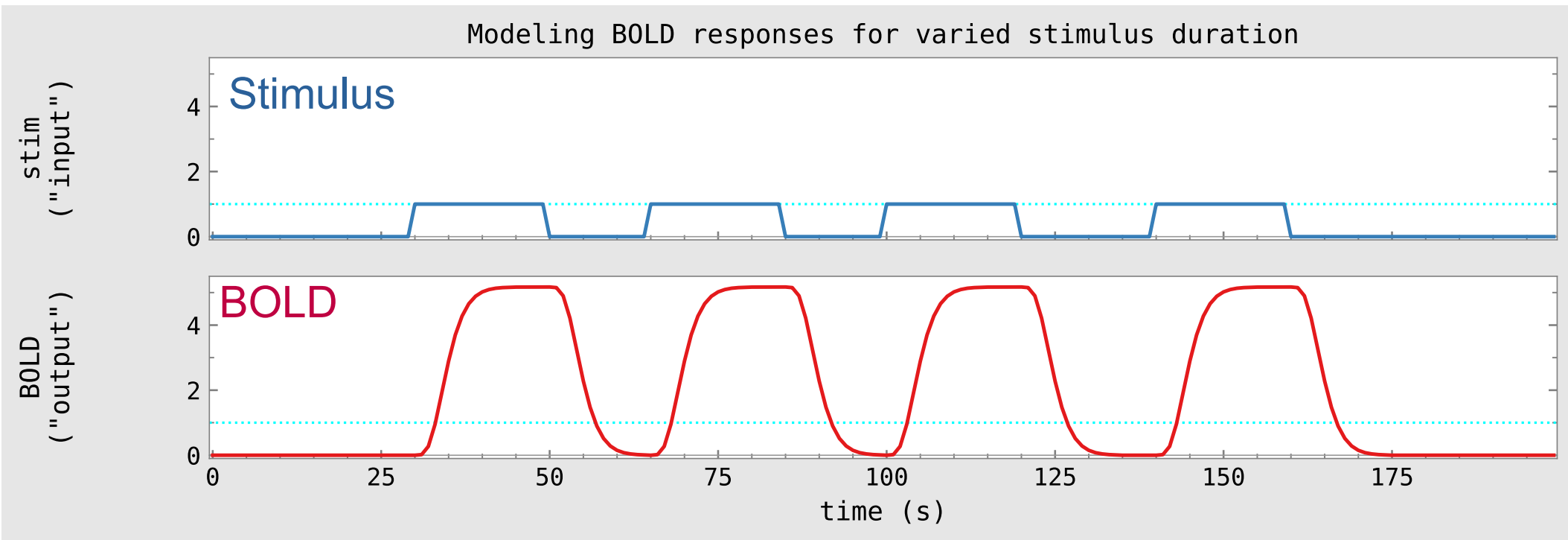
What should the **BOLD response** for this set of stimuli look like?



Modeling stimulus to BOLD response (idealized)

**** Pop quiz ****

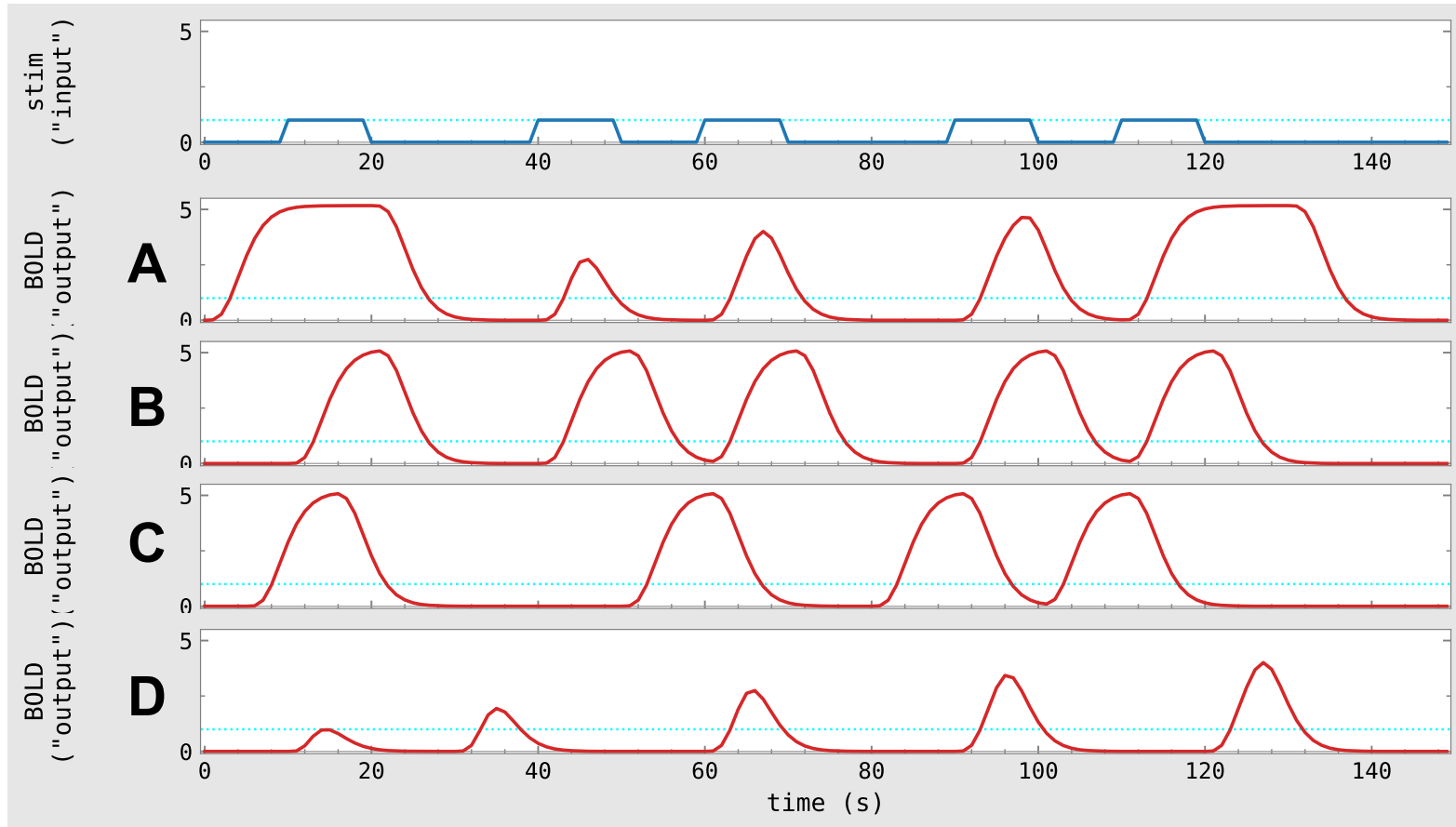
What should the **BOLD response** for this set of stimuli look like?



Modeling stimulus to BOLD response (idealized)

**** Pop quiz ****

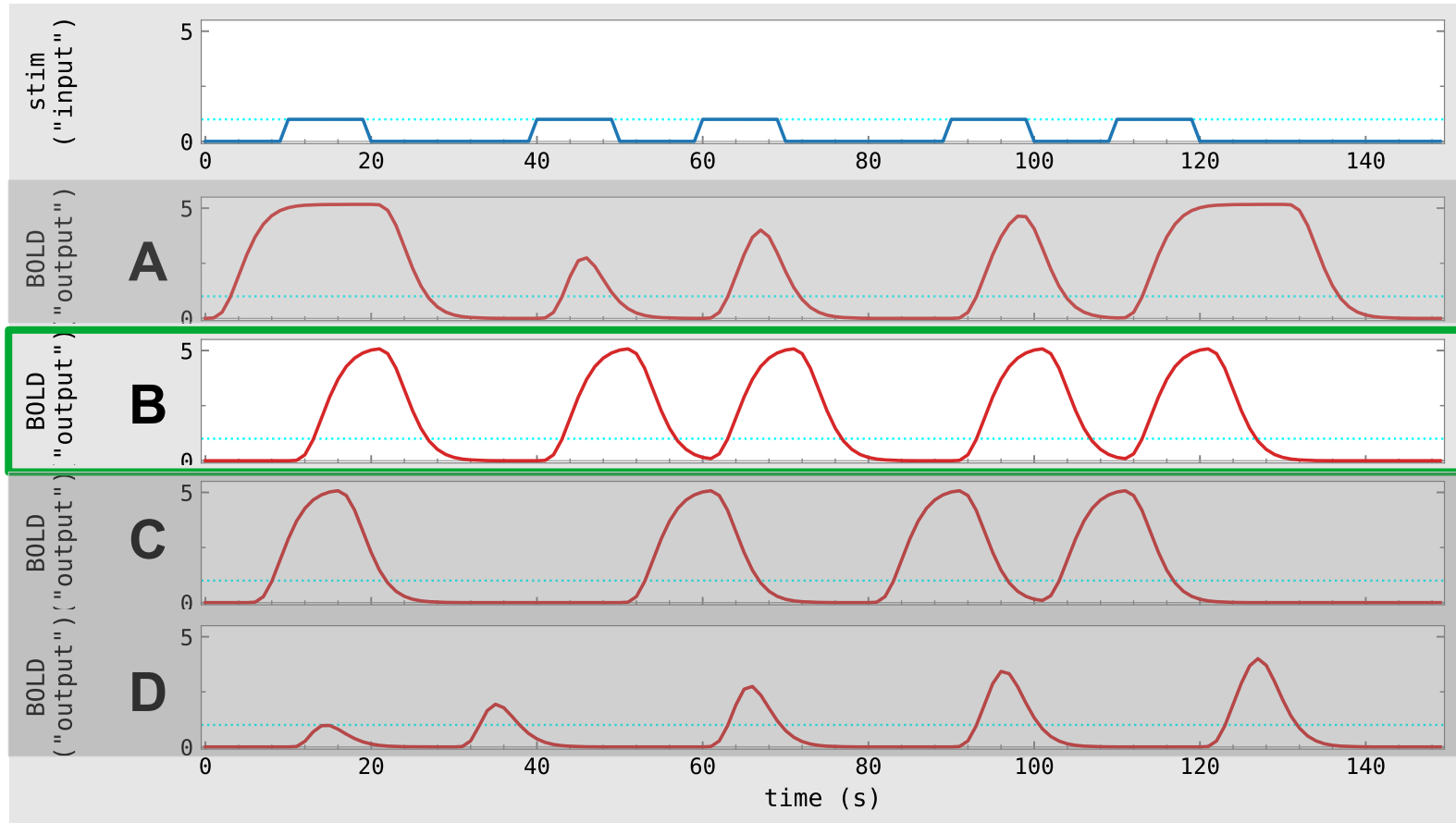
Which **BOLD response** goes with the input stimulus?



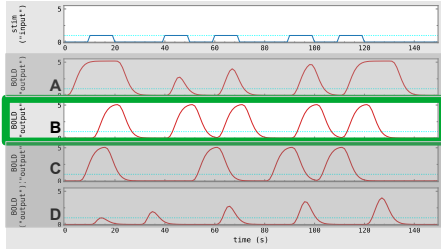
Modeling stimulus to BOLD response (idealized)

**** Pop quiz ****

Which **BOLD response** goes with the input stimulus?



FMRI studies: looking for expected BOLD in data



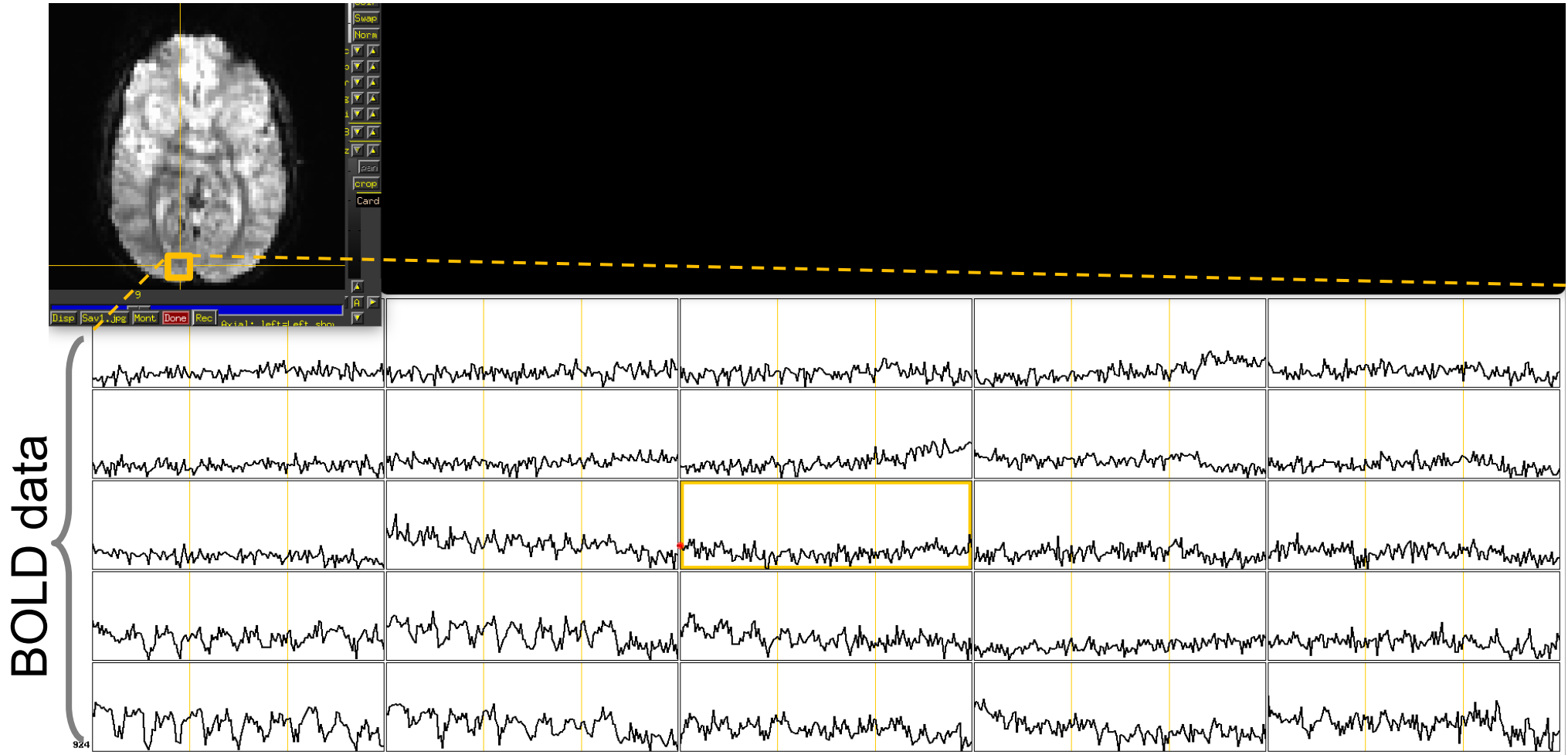
Actually, such pattern matching is at the root task

FMRI analysis:

1. Make a **stim pattern** for a task (e.g., button pushing)
2. Estimate the **“idealized” BOLD response** to it
3. Measure BOLD responses in the brain while a participant does the task in MRI scanner
4. Find where BOLD responses look like the idealized response---*there be interesting brain activation!*

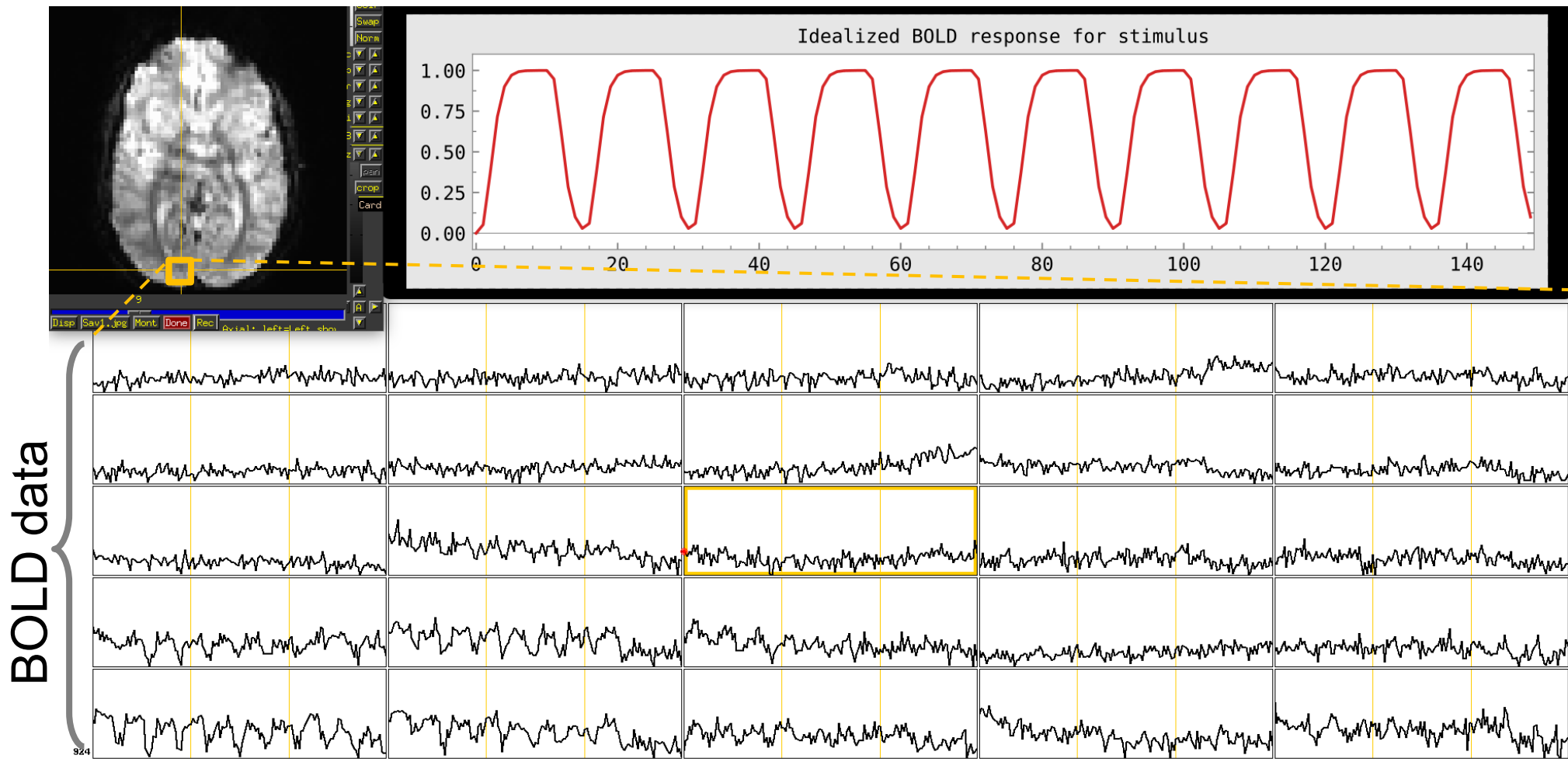
Task FMRI: search subject BOLD for ideal response

Some real BOLD time series in a FMRI dataset (NB: *noisy!*).



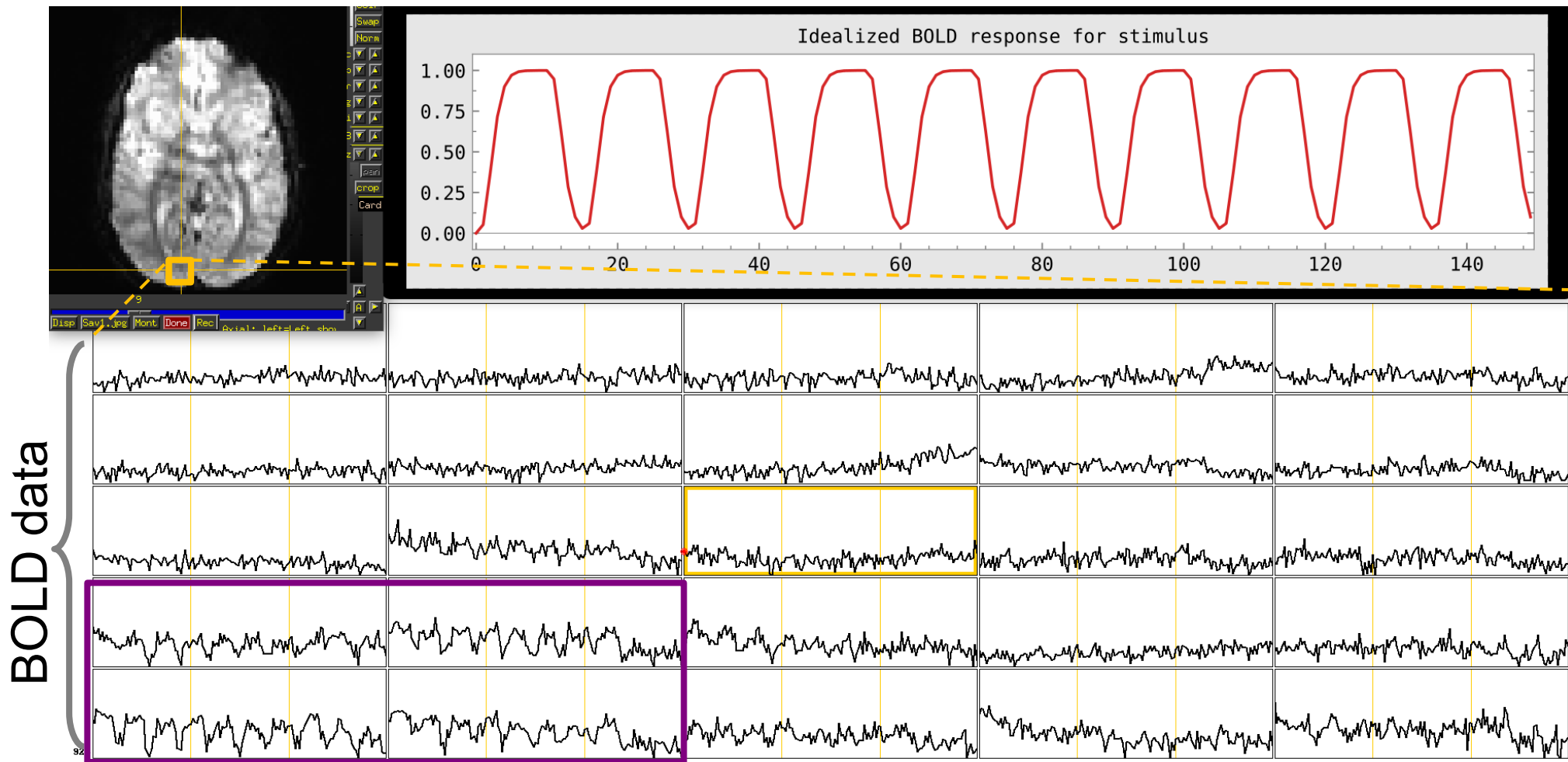
Task FMRI: search subject BOLD for ideal response

Which BOLD time series look like the “idealized” BOLD response?



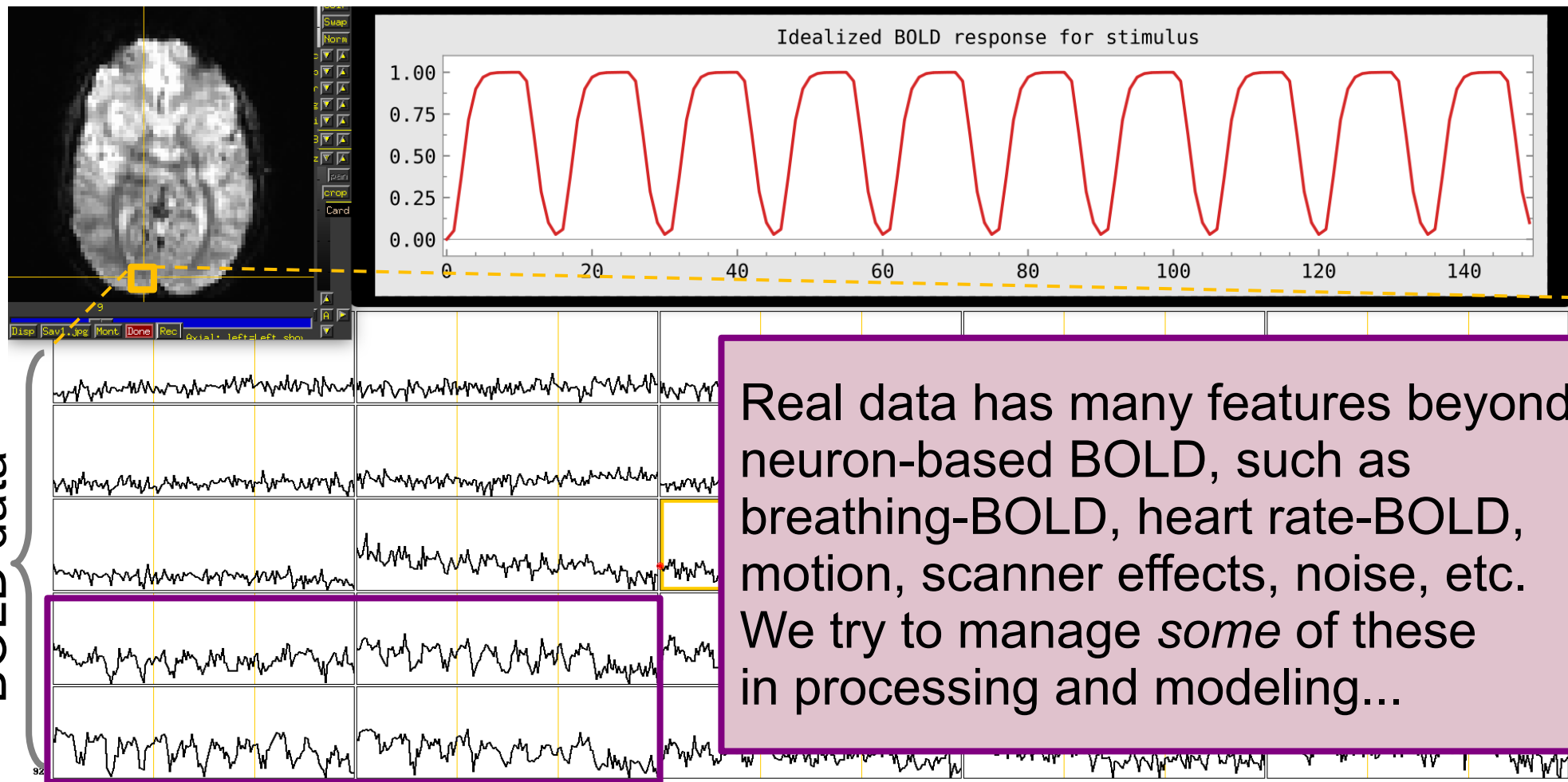
Task FMRI: search subject BOLD for ideal response

Which BOLD time series look like the “idealized” BOLD response?



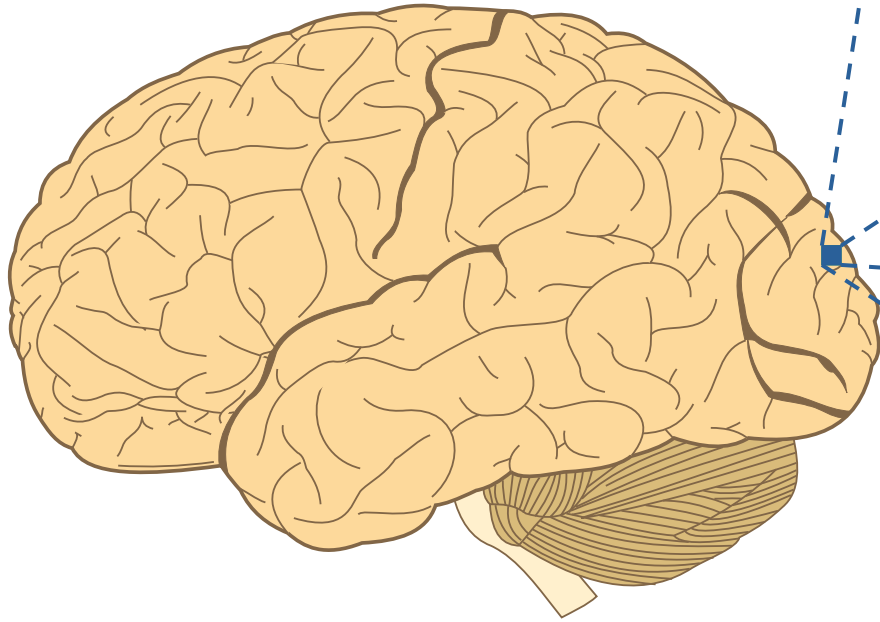
Task FMRI: search subject BOLD for ideal response

Which BOLD time series look like the “idealized” BOLD response?

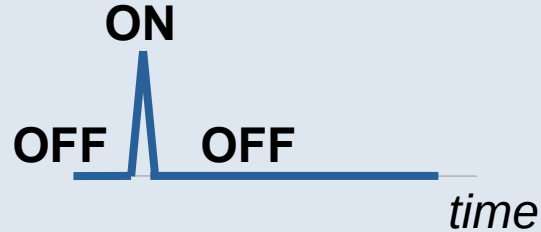


Real data has many features beyond neuron-based BOLD, such as breathing-BOLD, heart rate-BOLD, motion, scanner effects, noise, etc. We try to manage *some* of these in processing and modeling...

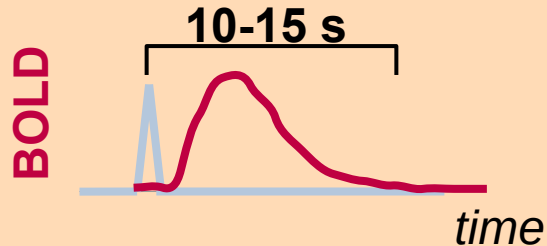
A cartoon picture of task-based fMRI



Brain activity:
some neurons fire
(e.g., brief stimulus)



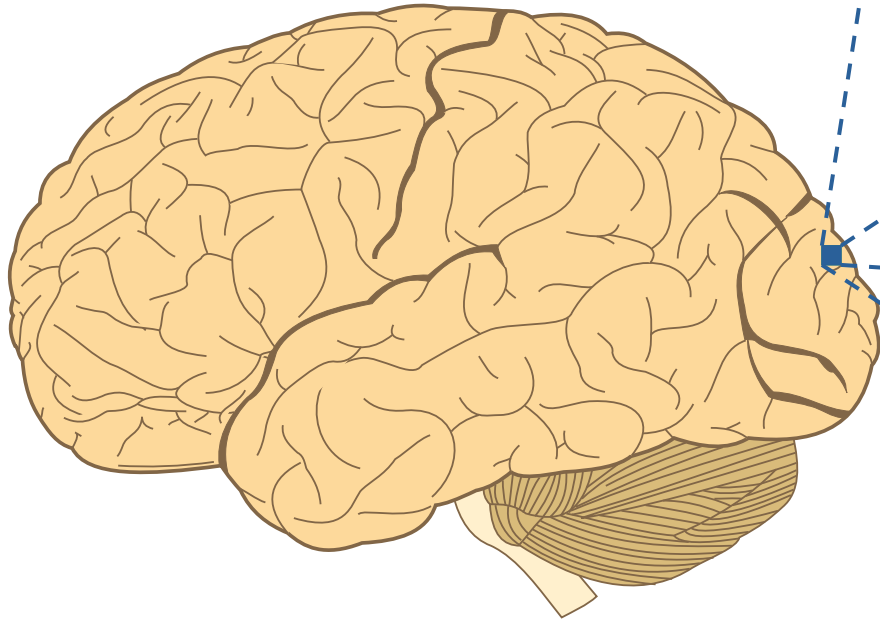
BOLD response:
blood oxygenation
changes locally



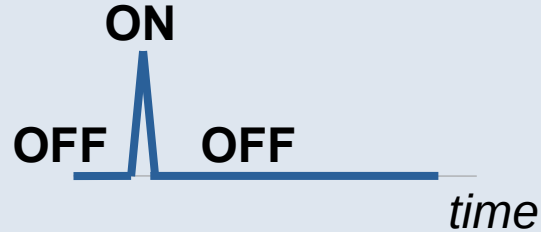
MRI measures:
BOLD changes
affect magnetic
field, which are
observed with
the MRI scanner

*BOLD = Blood Oxygen
Level-Dependent*

A cartoon picture of task-based fMRI

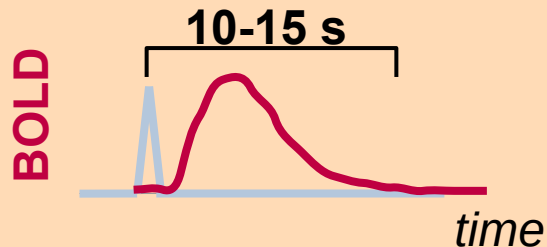


Brain activity:
some neurons fire
(e.g., brief stimulus)



Study function:
Provide stimuli,
measure BOLD
over time, &
find patterns that
match the stim
(= activity)

BOLD response:
blood oxygenation
changes locally



MRI measures:
BOLD changes
affect magnetic
field, which are
observed with
the MRI scanner

*BOLD = Blood Oxygen
Level-Dependent*

Practical aspects of fMRI

Practical aspects of fMRI



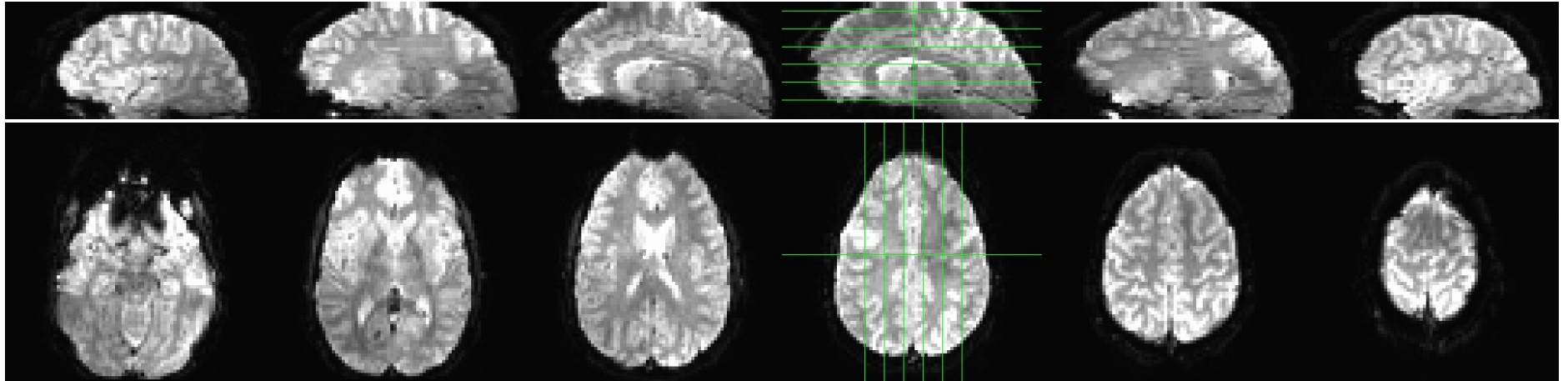
... of fMRI

Positive features of FMRI



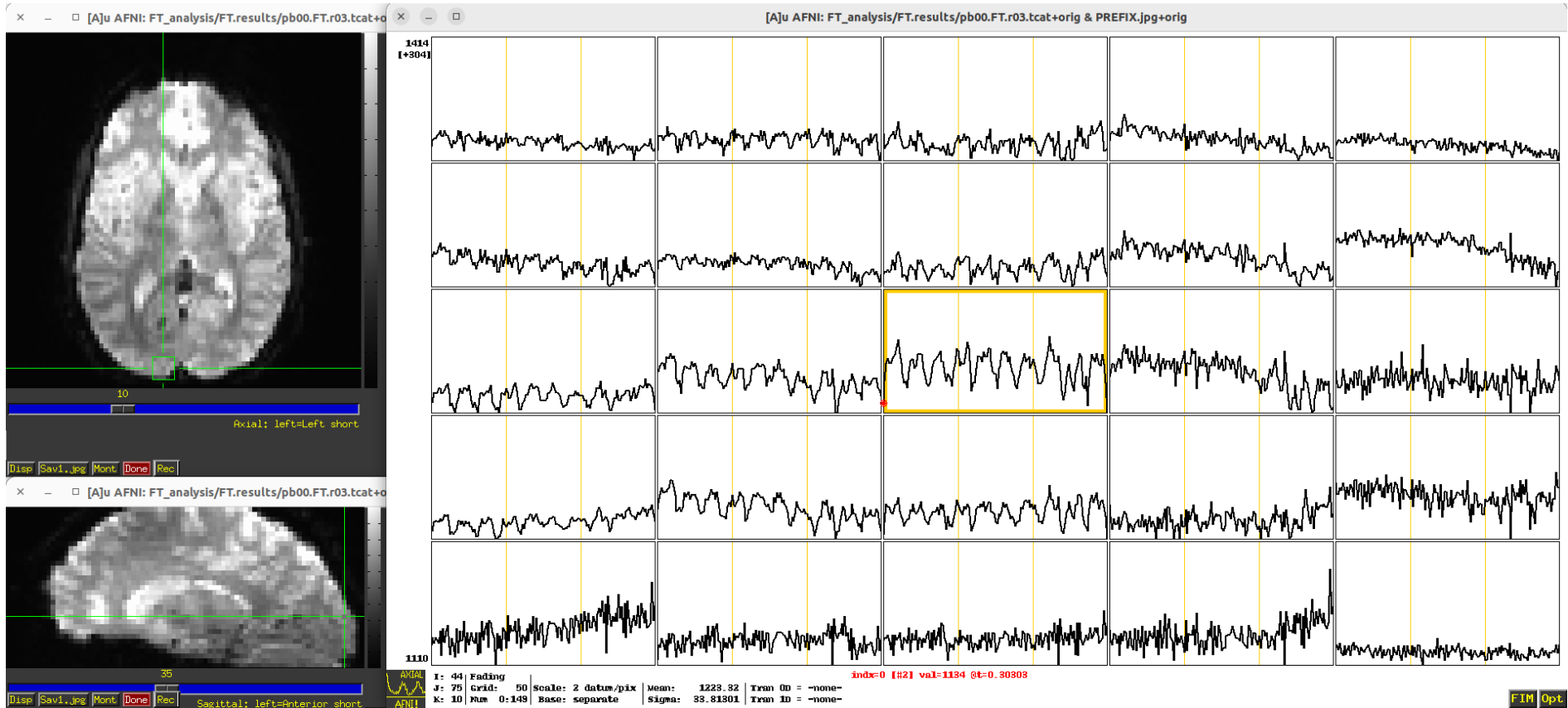
Positive features of fMRI

- Non-invasive and non-ionizing (just radio frequencies)
- Can have flexible task designs:
reading, viewing images, finger tapping/button pushing,
imagining, neurofeedback, movies, and much more
- Whole brain coverage, surface and interior:
 - 2-3 mm resolution (spatial specificity, $\approx$ cortical thickness)



Positive features of fMRI (cont'd)

- Reasonable temporal sampling --- whole volume every 1-2 s
- Data are noisy, but can still have useful signal-to-noise ratio (SNR)

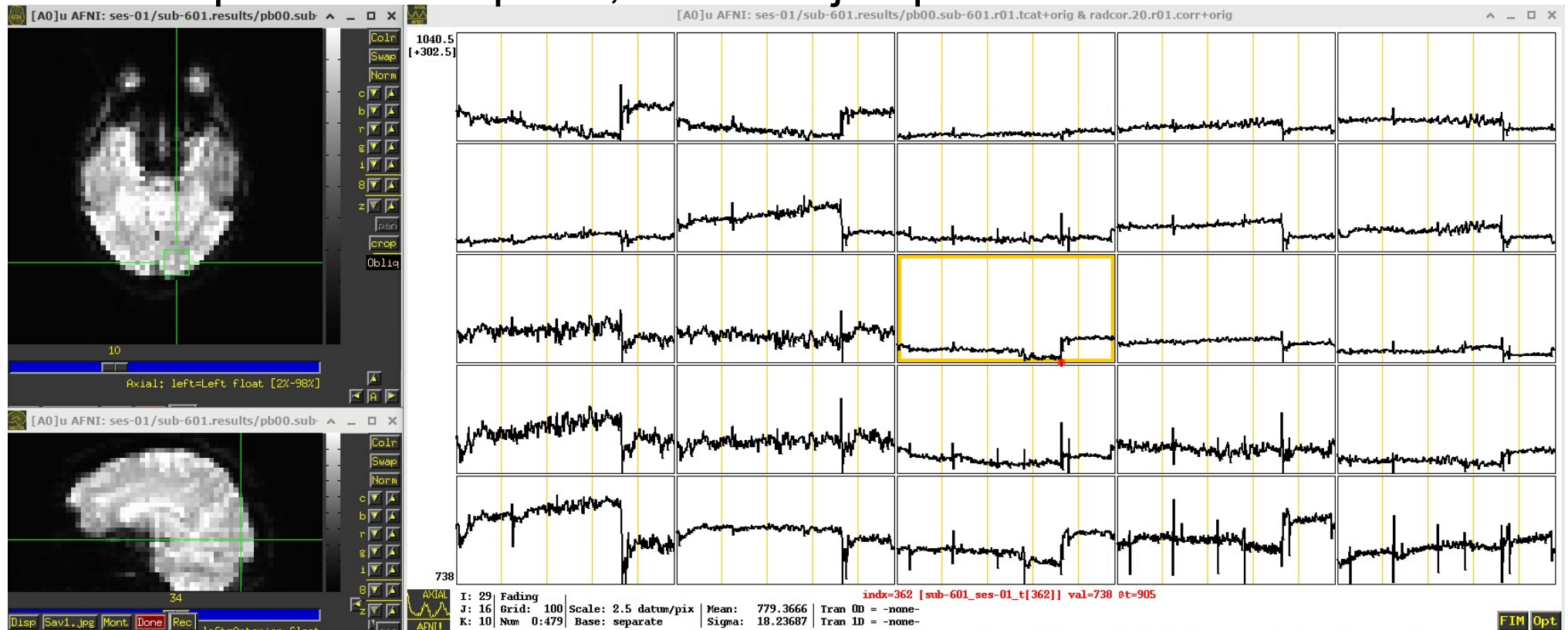


Challenging features of fMRI



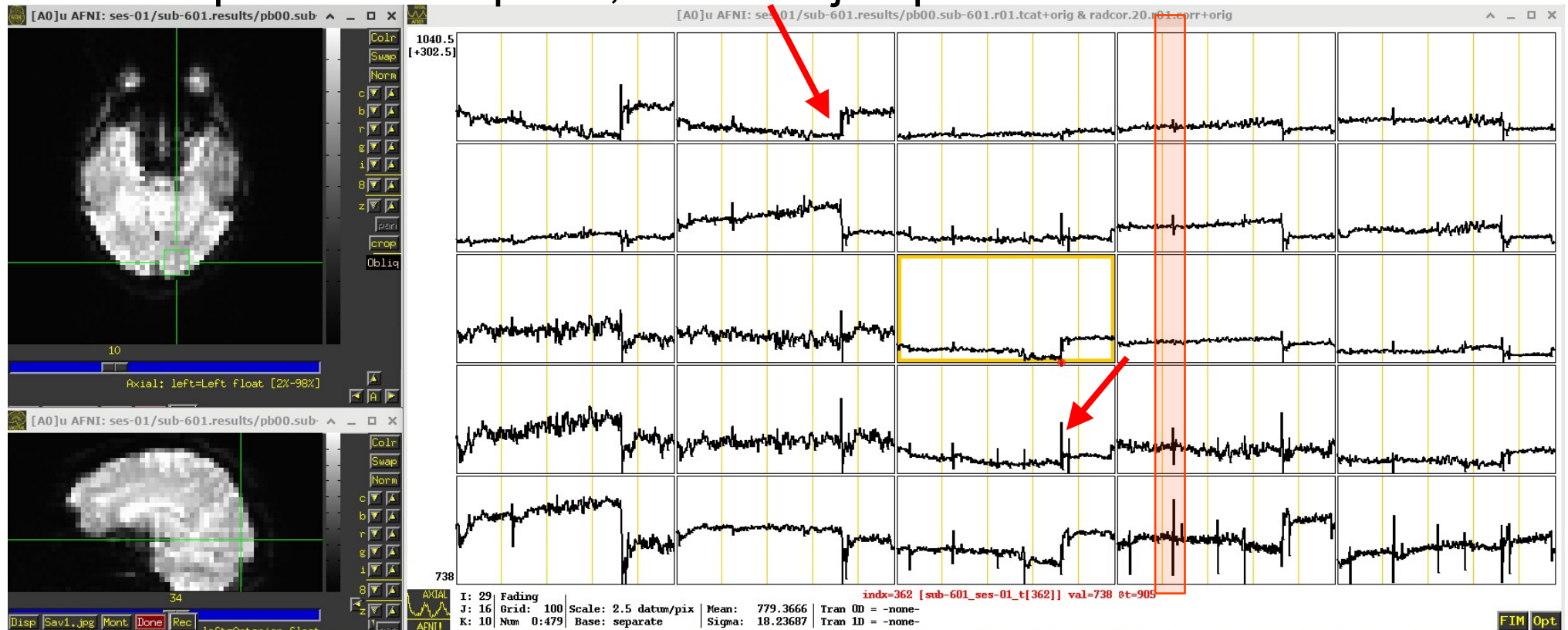
Challenging features of FMRI

- Time series are very sensitive to participant motion (even <1 mm!)
- Unpredictable spikes, baseline jumps and more



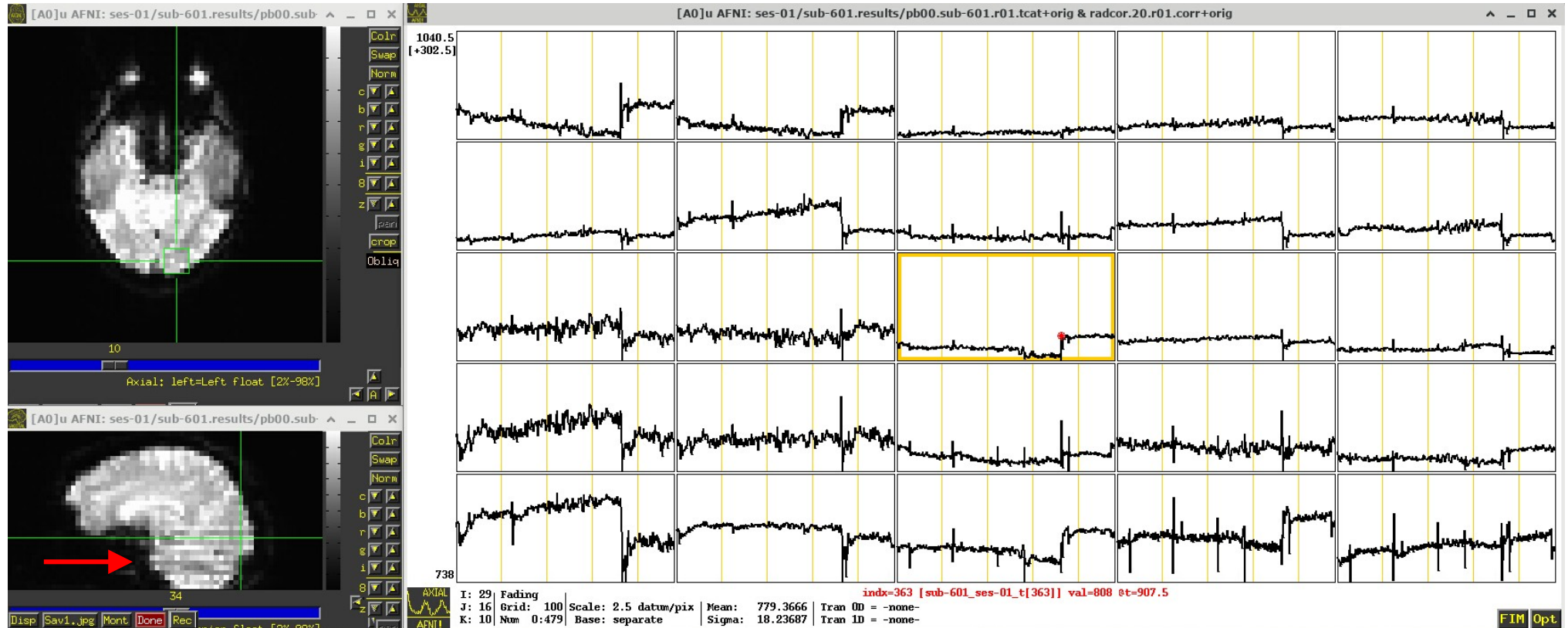
Challenging features of fMRI

- Time series are very sensitive to participant motion (even <1 mm!)
- Unpredictable spikes, baseline jumps and more



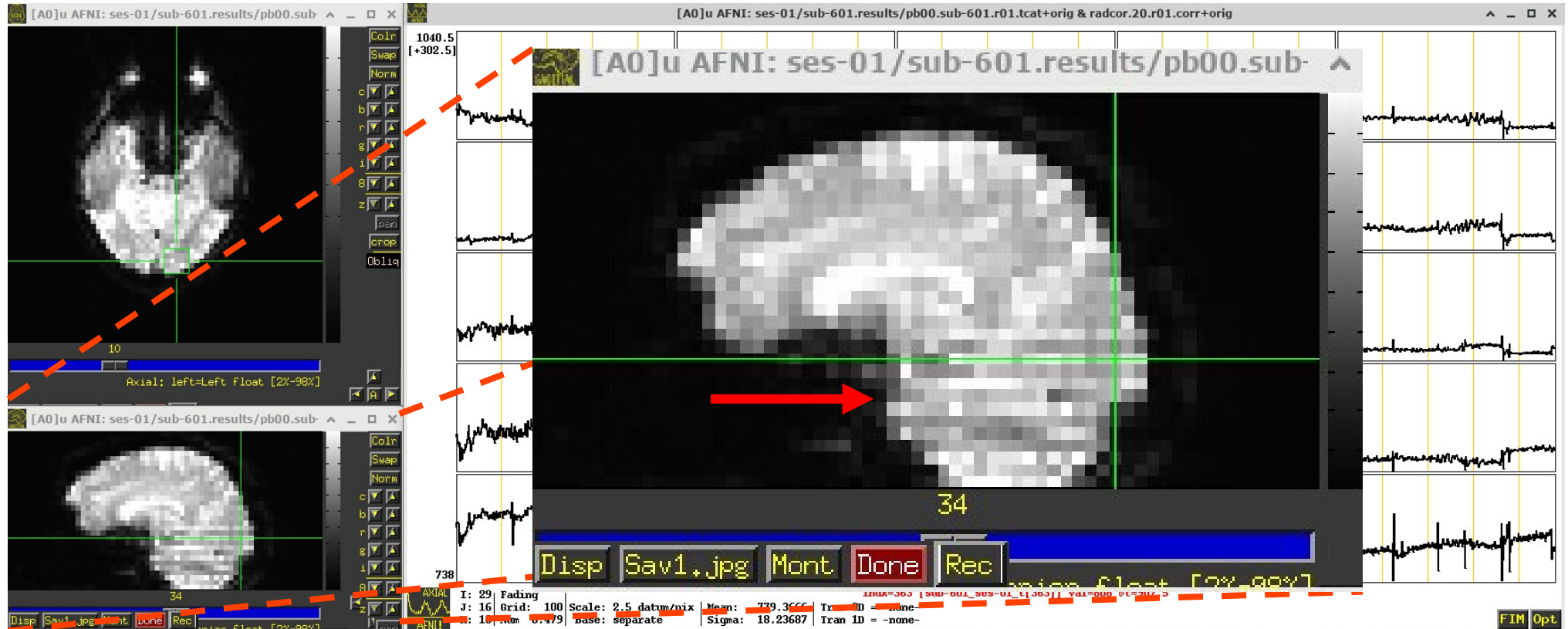
Challenging features of FMRI

- Spatial volumes are very sensitive to participant motion (<1 mm!)
- Altered geometry during motion event (slice-based)



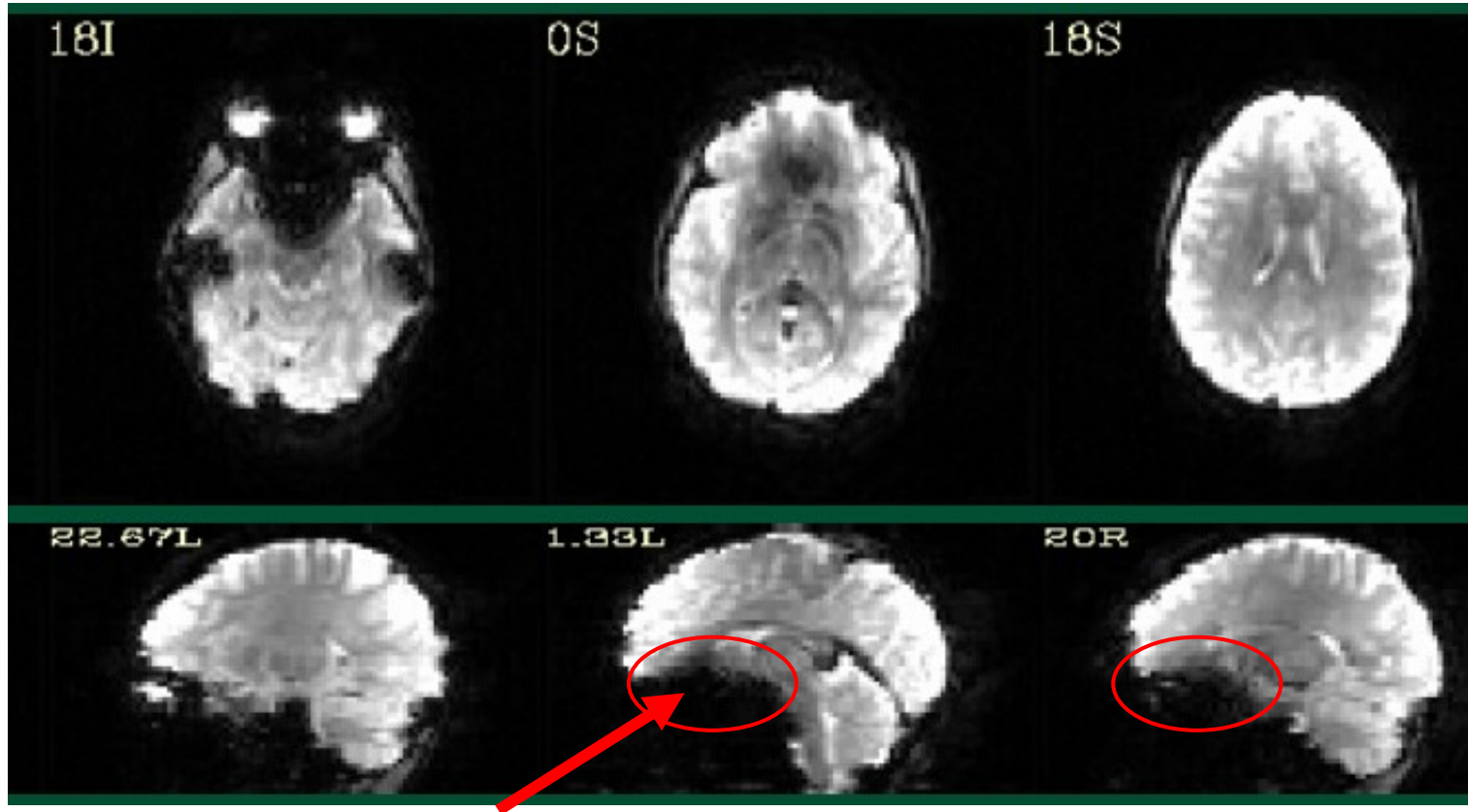
Challenging features of FMRI

- Spatial volumes are very sensitive to participant motion (<1 mm!)
- Altered geometry during motion event (slice-based)



Challenging features of fMRI (cont'd)

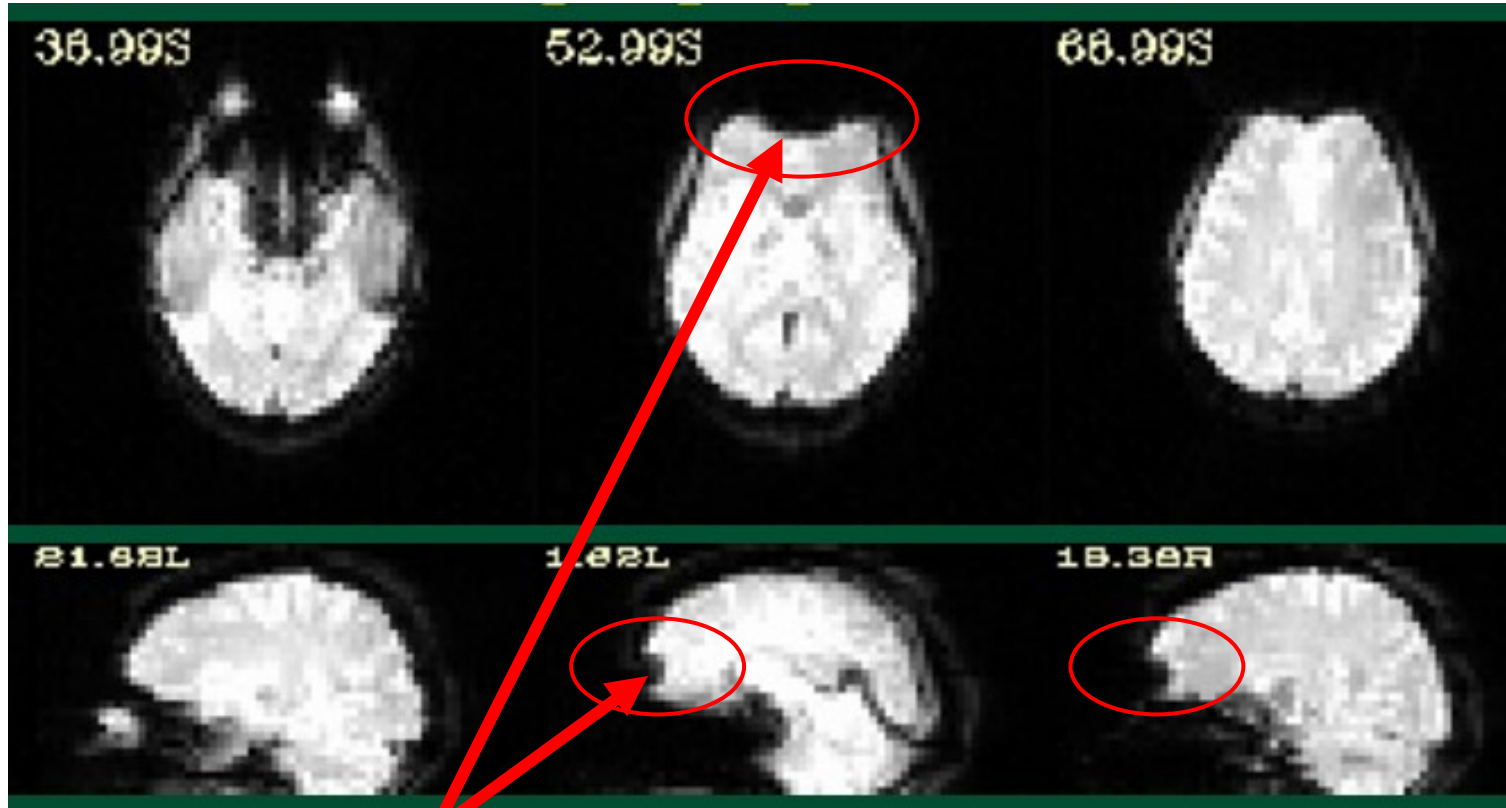
- Magnetic field effects can lead to signal loss:



There is brain here...

Challenging features of fMRI (cont'd)

- Magnetic field effects can lead to geometric distortion:



Brain appears to be “squashed in” here

Processing FMRI



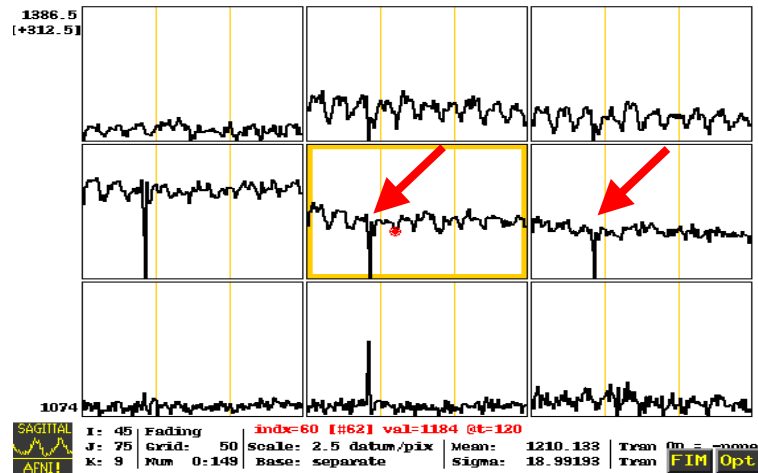
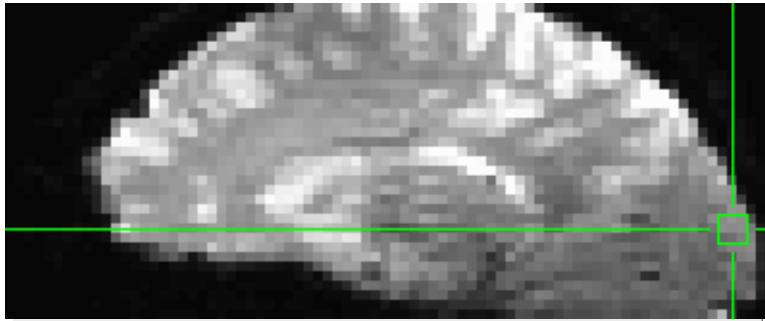
Processing FMRI



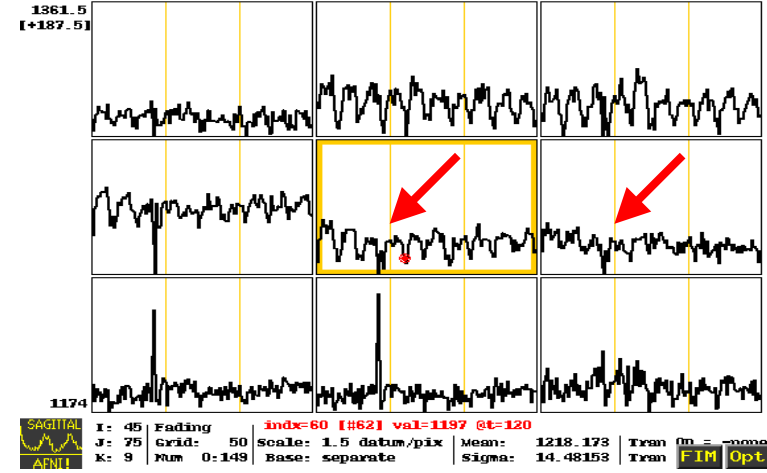
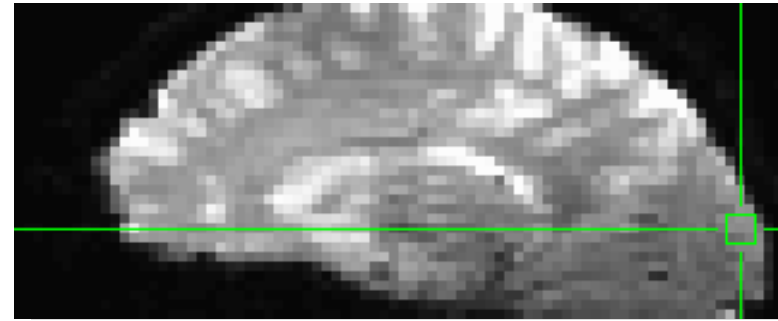
Processing steps FMRI

- **Motion correction** → align/register volumes across time
 - Estimate motion history, reduce spikes, reduce baseline changes

Before correction



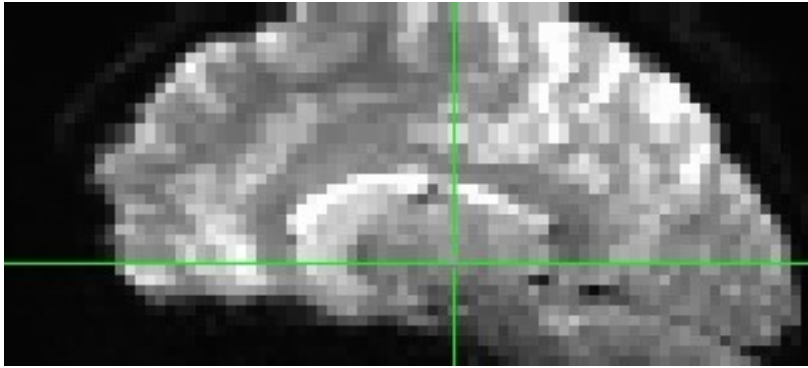
After correction



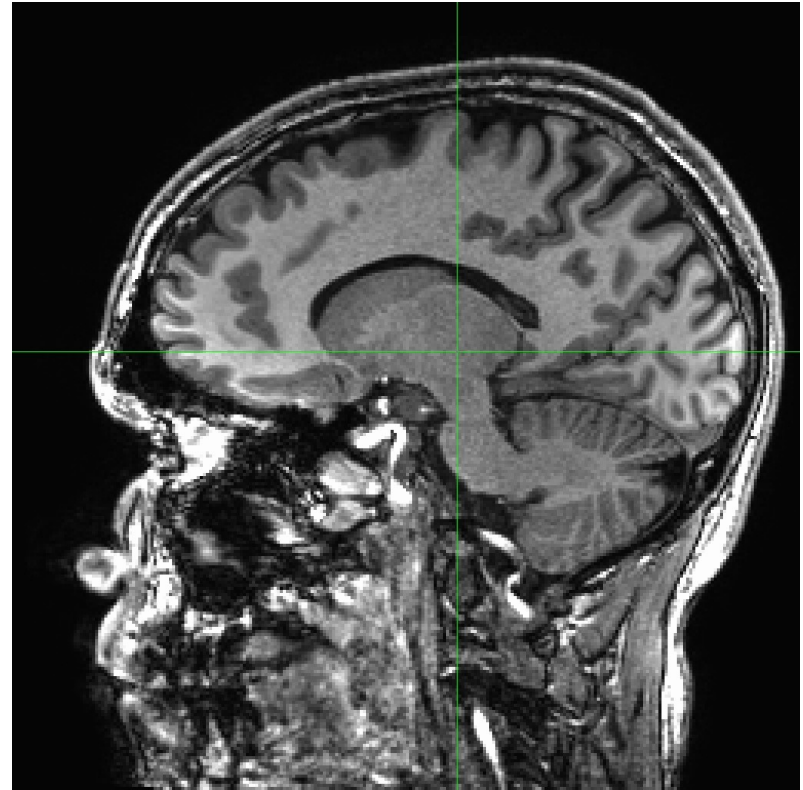
Processing steps FMRI

- **Align FMRI to anatomical** → spatial specificity and clarity
 - Reduce distortion, identify anatomy

FMRI



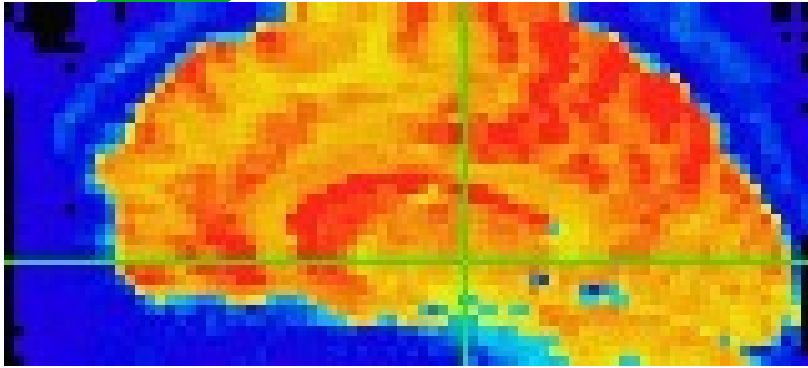
T1w anatomical



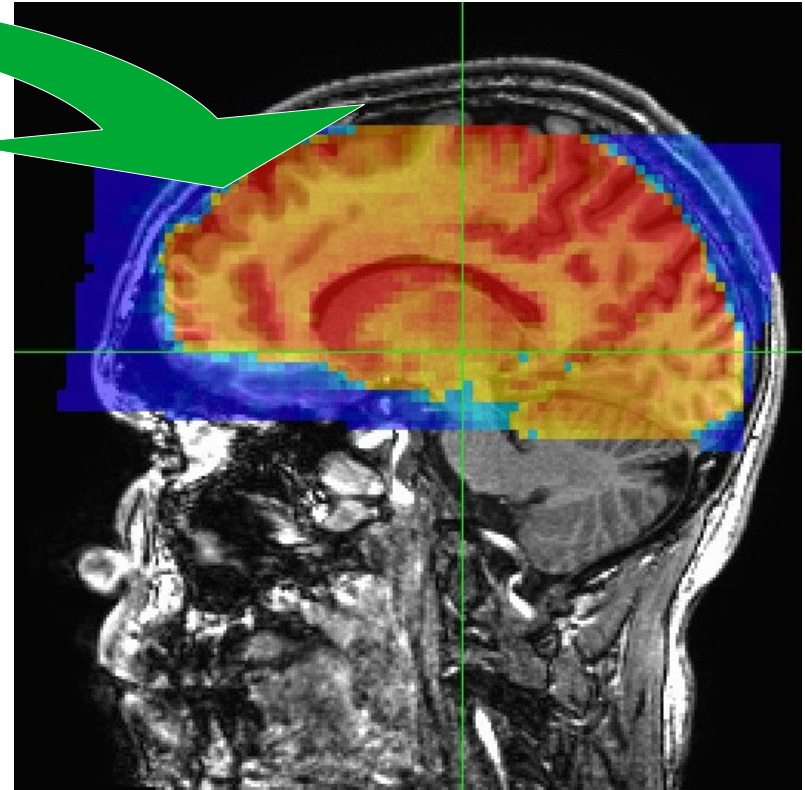
Processing steps FMRI

- **Align FMRI to anatomical** → spatial specificity and clarity
 - Reduce distortion, identify anatomy

FMRI



T1w anatomical



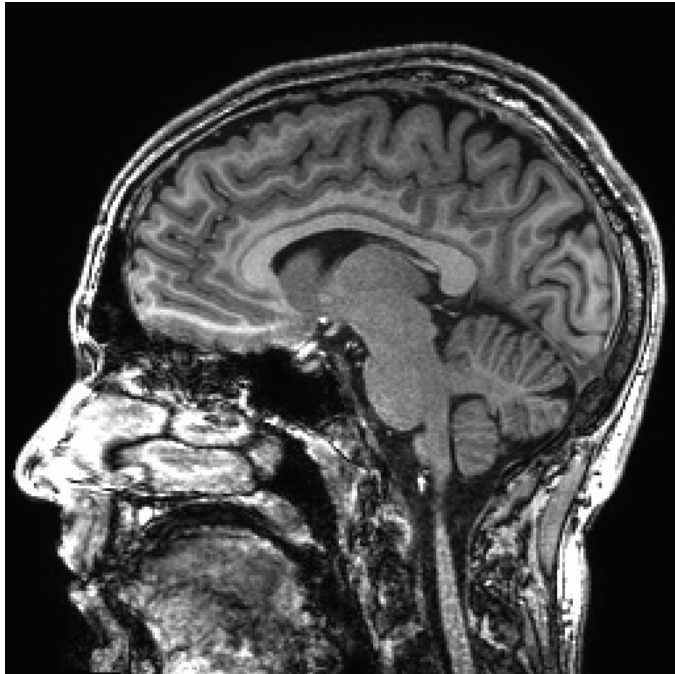
Sidenote about anatomical datasets (pre-processing and privacy)

*NB: the participant here shared data
without requiring anonymization.*

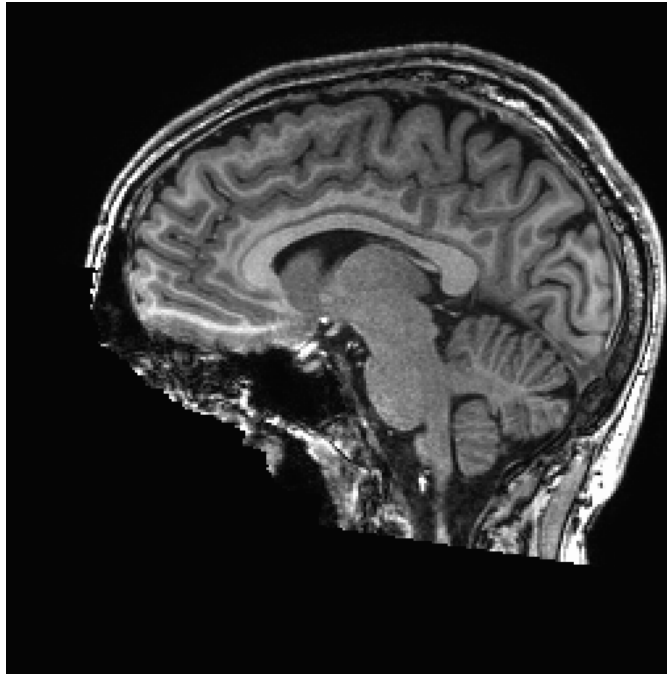
Anatomical data pre-processing

- **Defacing or refacing** → remove identifying face and ears
 - Help anonymize anatomical dataset

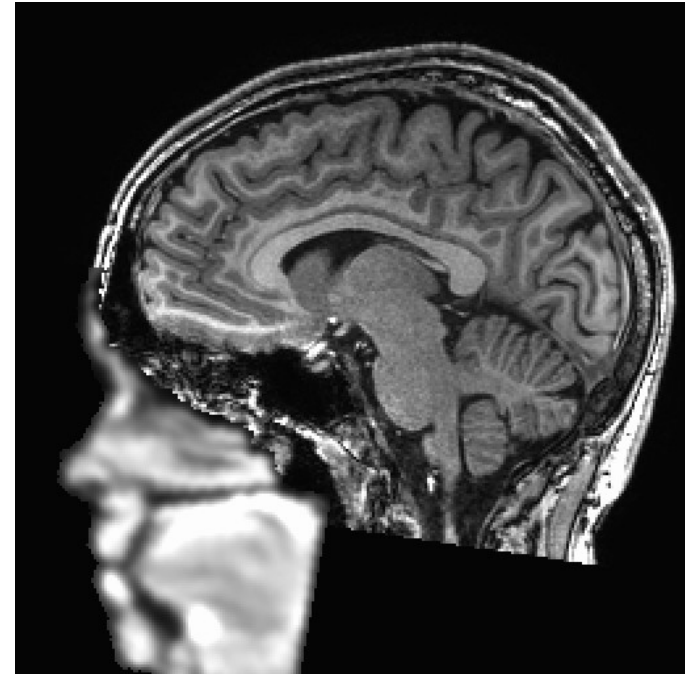
Original anatomical



Defaced anatomical



Refaced anatomical

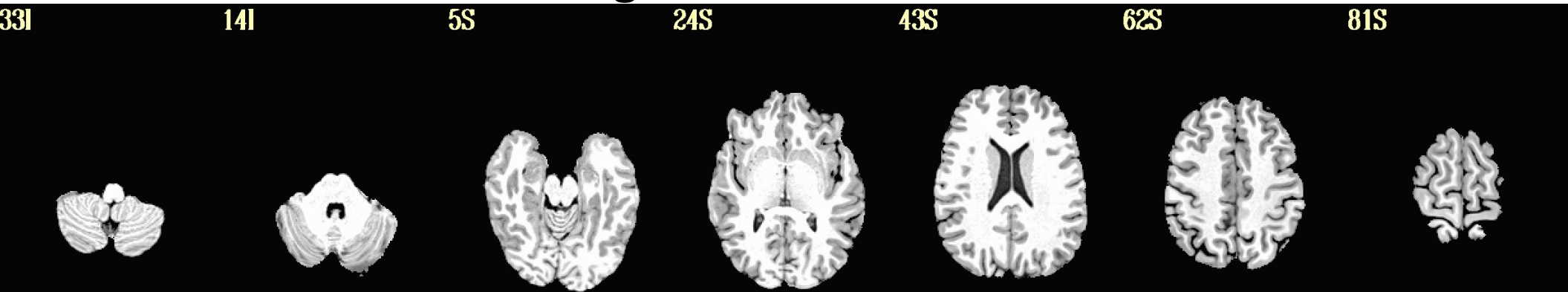


De/refacing in AFNI: @afni_refacer_run

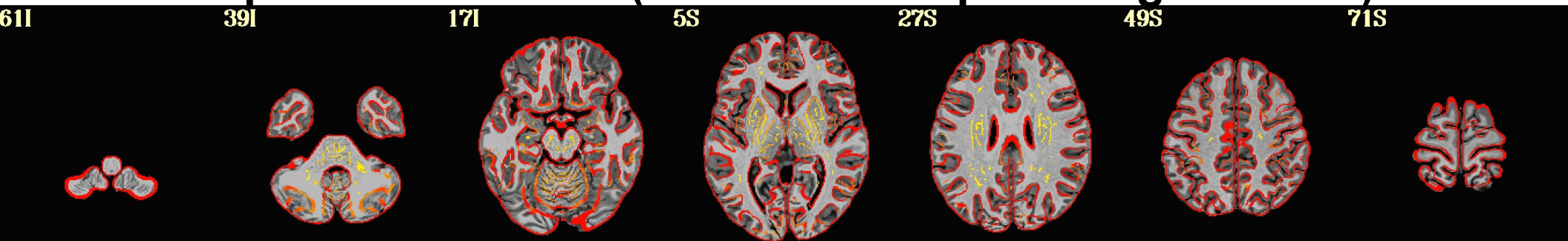
Processing steps FMRI

- **Align to standard space** → nonlinear warp to a reference template
 - All brains have anatomical variability: shape, size, gyral patterns, etc.

Original anatomicals



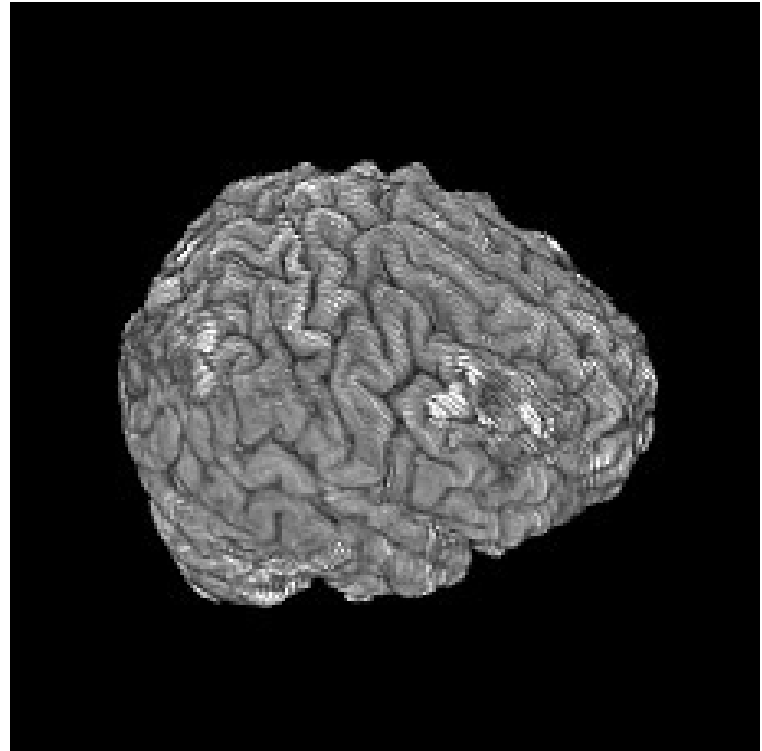
Warped anatomicals (reference template edges in red)



Processing steps FMRI

- **Align to standard space** → nonlinear warp to a reference template
 - All brains have anatomical variability: shape, size, gyral patterns, etc.

Nonlinear (diffeomorphic) warping starts with bulk alignment, and then refines locally. Primary goal is to match sulcal and gyral features.



Summary

- BOLD fMRI is a useful way to see and study the brain as it works
- We have to process the data to extract desired information

Summary

- BOLD fMRI is a useful way to see and study the brain as it works
- We have to process the data to extract desired information
- Processing steps are chosen based on:
 - Our understanding of brain biology
 - The physics of MRI scanners
 - Necessary approximations and assumptions
 - General strengths and challenges of EPI/fMRI
 - Specific characteristics of the data in hand
 - The goal of our study

Summary

- BOLD FMRI is a useful way to see and study the brain as it works
- We have to process the data to extract desired information
- Processing steps are chosen based on:
 - Our understanding of brain biology
 - The physics of MRI scanners
 - Necessary approximations and assumptions
 - General strengths and challenges of EPI/fMRI
 - Specific characteristics of the data in hand
 - The goal of our study



Summary

- BOLD fMRI is a useful way to see and study the brain as it works
- We have to process the data to extract desired information
- Processing steps are chosen based on:
 - Our understanding of brain biology
 - The physics of MRI scanners
 - Necessary approximations and assumptions
 - General strengths and challenges of EPI/fMRI
 - Specific characteristics of the data in hand
 - The goal of our study
- We incorporate all this in our processing pipelines (via `afni_proc.py`)



Summary

- BOLD FMRI is a useful way to see and study the brain as it works
- We have to process the data to extract desired information
- Processing steps are chosen based on:
 - Our understanding of brain biology
 - The physics of MRI scanners
 - Necessary approximations and assumptions
 - General strengths and challenges of EPI/FMRI
 - Specific characteristics of the data in hand
 - The goal of our study
- We incorporate all this in our processing pipelines (via afni_proc.py)
- ... *but it is as just as important to keep visualizing, checking, evaluating and understanding our data throughout all its stages*



Acknowledgments

Scientific and Statistical Computing Core (SSCC), NIMH

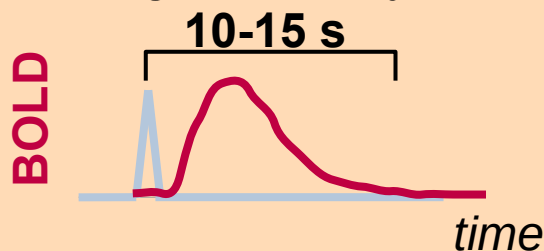


Gang Chen · Peter Lauren · Daniel Glen · Portia Devenish-Harris · Paul Taylor
· Yamuna Narayana Swamy · Brian Pittman · Rick Reynolds · Justin Rajendra

So, what is left to know about FMRI?

- Even though useful, there are many areas FMRI can be improved
- **Improving modeling** is one major area of investigation
 - Recall from the start, we assumed one BOLD response shape

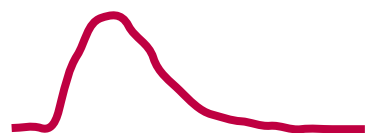
BOLD response:
blood oxygenation
changes locally



Q: Is this really constant across:
the whole brain,
for all tasks,
across all people,
across all ages
and conditions?(???)

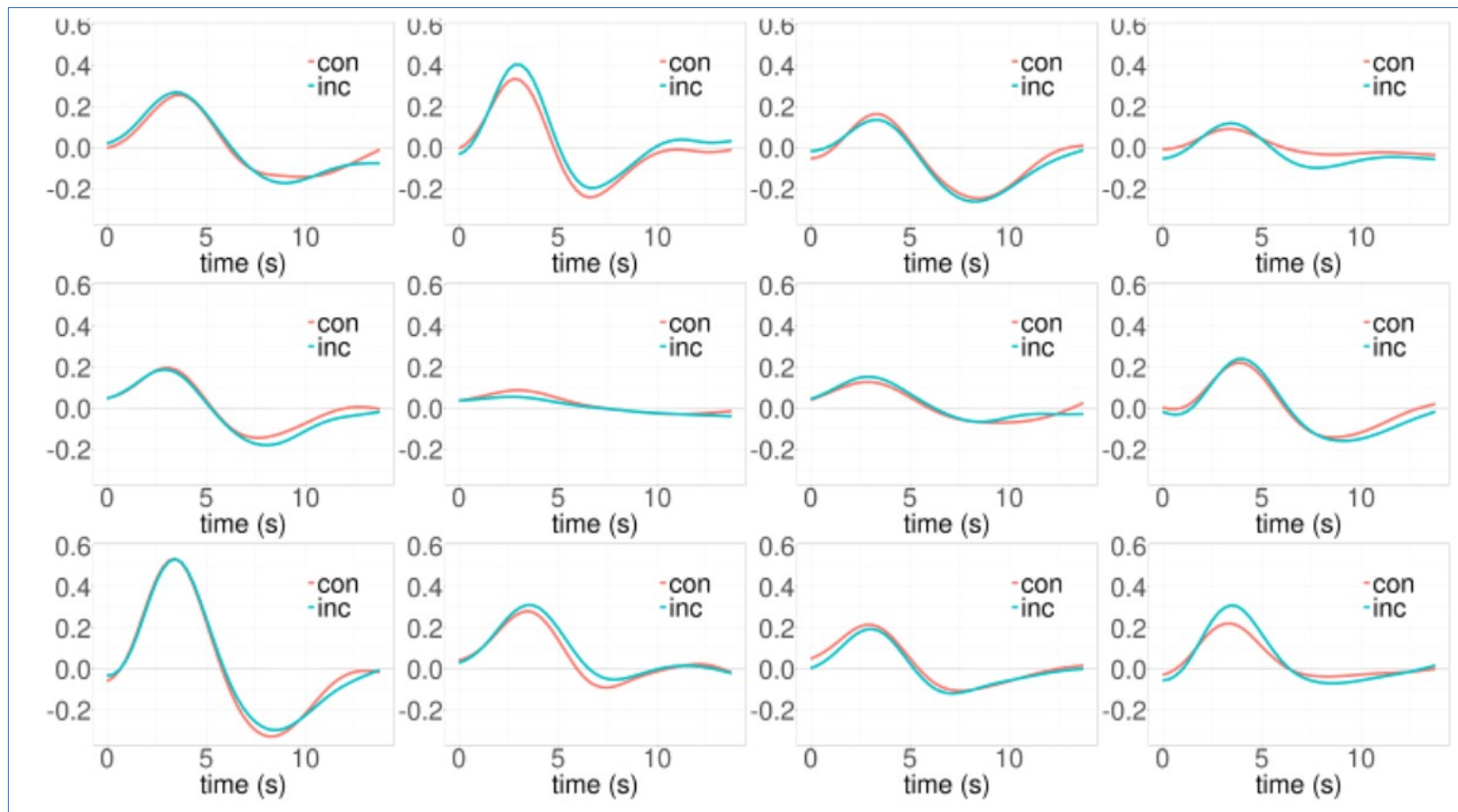
So, what is left to know about fMRI?

- ... No, BOLD response is not constant, even in one brain's gray matter



vs

One can estimate the BOLD shape from the data, but takes more data and careful study design.



from Chen et al. (2023)

So, what is left to know about fMRI?

- In the end, there are many fMRI considerations that are active domains of research:
 - How to acquire data (how much, best signal, least distortion...)
 - How to process (what parameters, what confounders)
 - How to evaluate/check data (quality control and reducing artifacts)
 - How to report results (digestible vs important information loss)
 - How to combine/compare studies (meta-analysis)
 - How to improve algorithms (faster, less time, more reliable)
 - How to combine with other modalities (synergize strengths)
 - ... and many other areas.
- All this contributes (hopefully!) toward better understanding the brain, from daily functioning to disorders and clinical applications.