Multimodal Neuroimaging Overview

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NIH Summer Neuroimaging Course
July 18, 2024

cmn.nimh.gov

Simultaneous EEG-fMRI

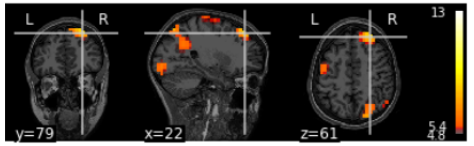
- Equipment
- Experiment Design
- Analysis
- Interpretation / Writeup

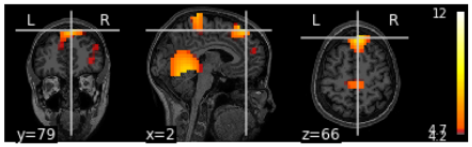
Workshops

- 2019 - Multimodal Neuroimaging
- 2021 - Naturalistic Stimuli & Individual Differences
- 2022 - Simultaneous PET-MRI
- 2024 - Eye Tracking
- 202X - Layer fMRI & Other Modalities

Multi-Modal

- Combine Data from multiple modalities
  - EEG, fMRI, DTI, EyeTracking, Behavior
- Refer folks to expert cores
  - AFNI, MEG, PET





Why This Talk?

13	Thursday	7/18/24	2:00PM	FAES B1C207	Multimodal Neuroimaging Overview	PDF	Pete Molfese
14	Tuesday	7/23/24	2:00PM	FAES B1C209	Electroencephalography (EEG) with and without simultaneous fMRI	PDF	Pete Molfese

- Two talks with potentially overlap
- Today: Mostly Theory
- Next week: More applications / Video Demos
  - How to do EEG/EEG-MRI at the NIH

Overview

- What is Multimodal Neuroimaging?
  - Definition
  - Motivation
- Doing this well is hard
- Doing this well is important

Multimodal Neuroimaging

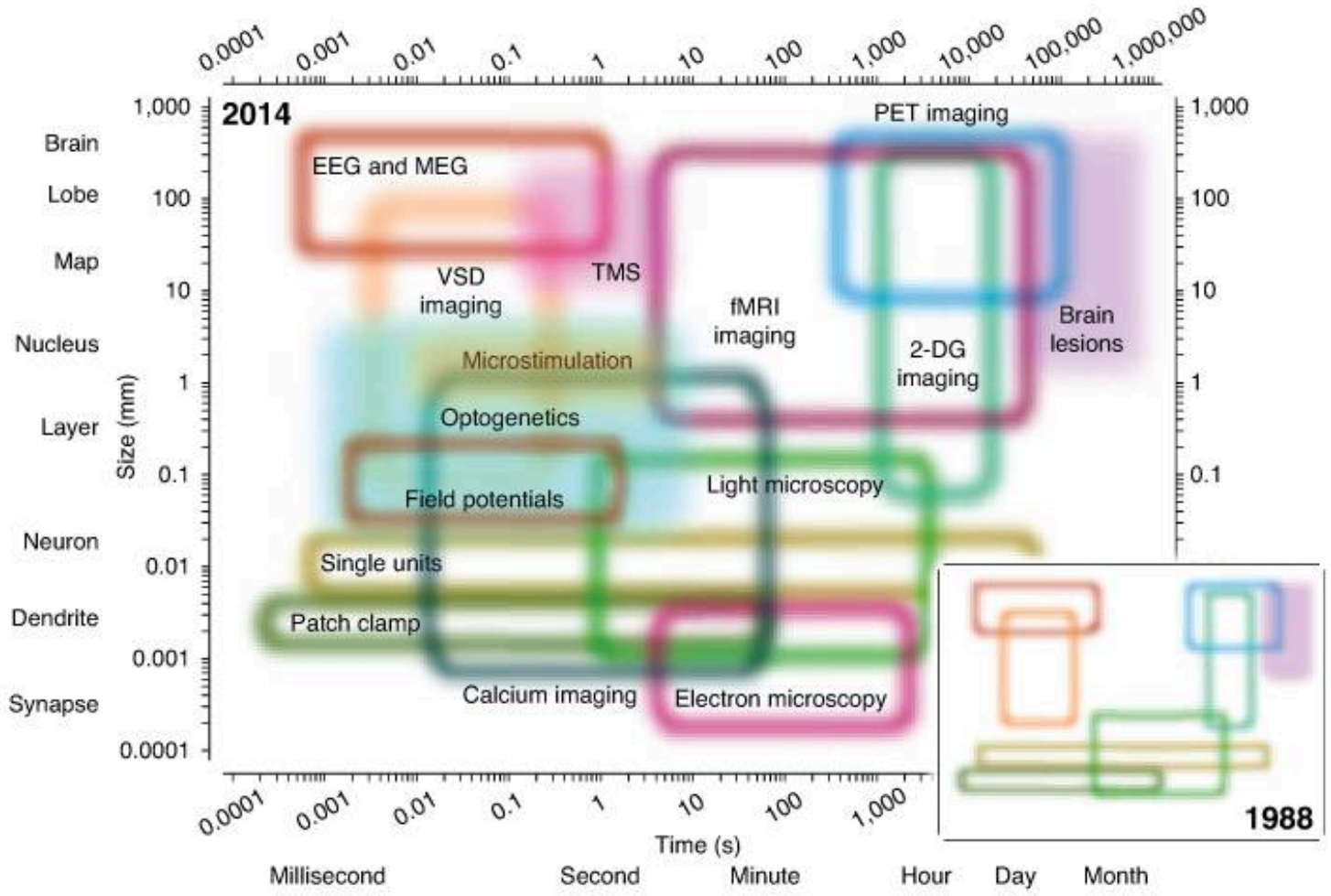
- Any neuroimaging that uses multiple (complimentary) methods

- fMRI + EEG*
- MEG + EEG*
- fMRI + MRI
- fMRI + DTI

- fMRI + MEG
- tDCS/tACS/TMS + EEG*
- TMS + fMRI*
- Etc…

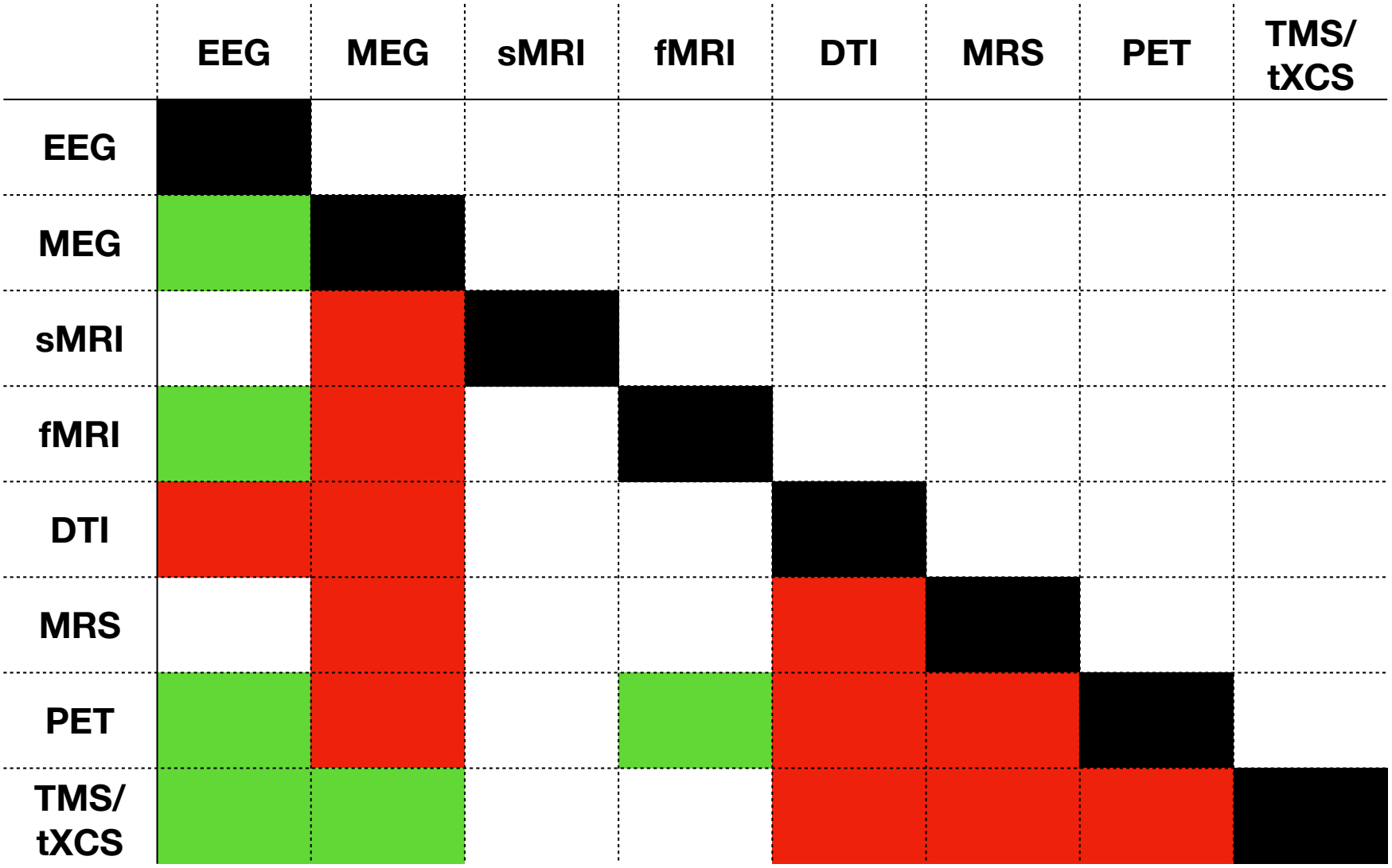
* Simultaneous Possible

Temporal-Spatial Tradeoffs

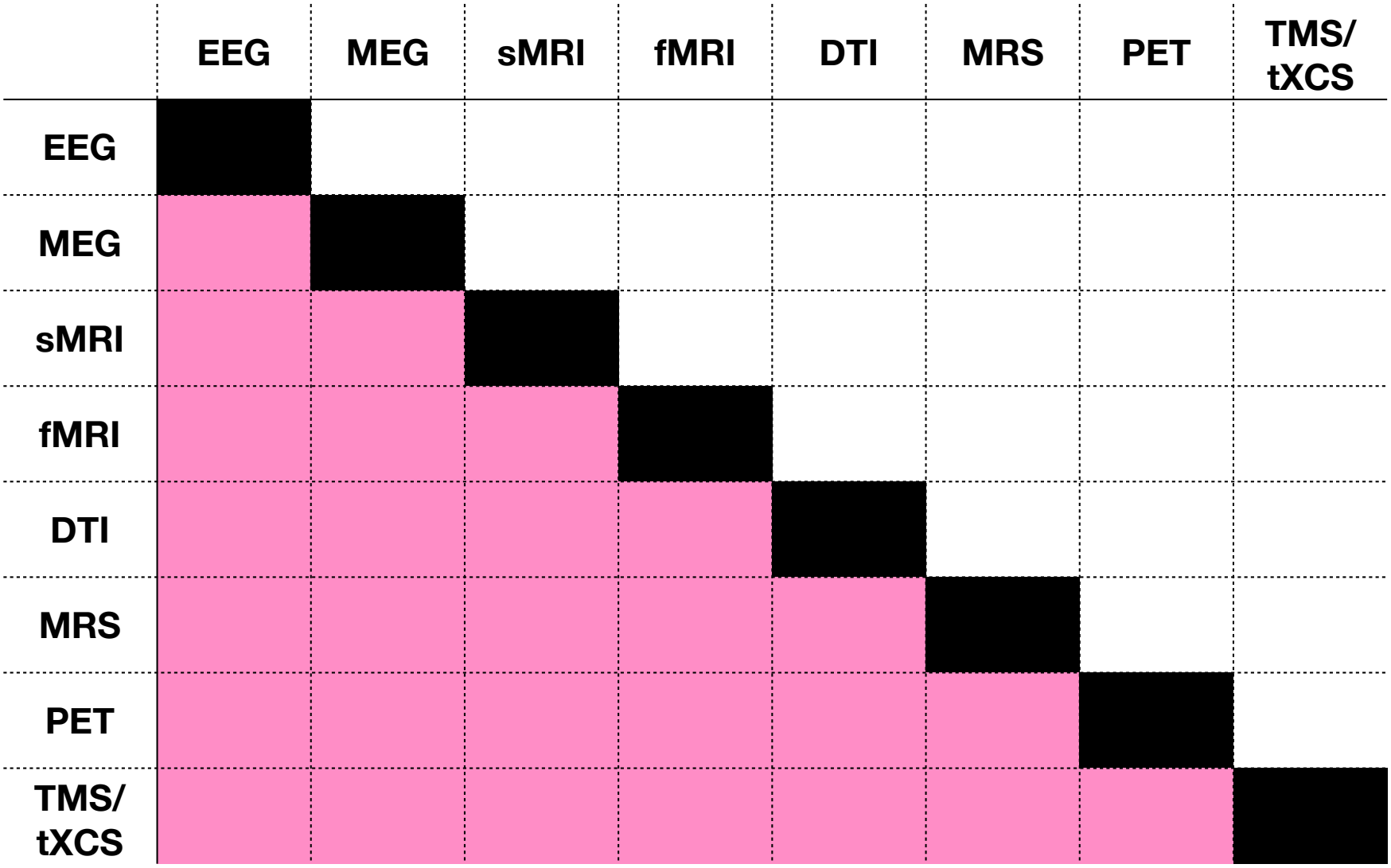


Sejnowski et al. (2014)

Multimodal Possibilities



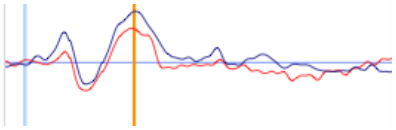
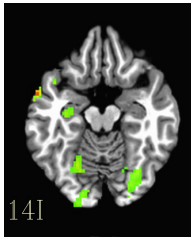
Doesn’t Have To Be Simultaneous



Possible As Separate To Combine Data

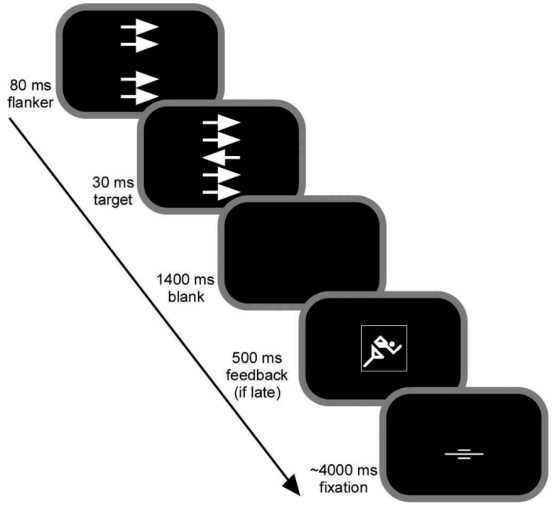
Tradeoffs

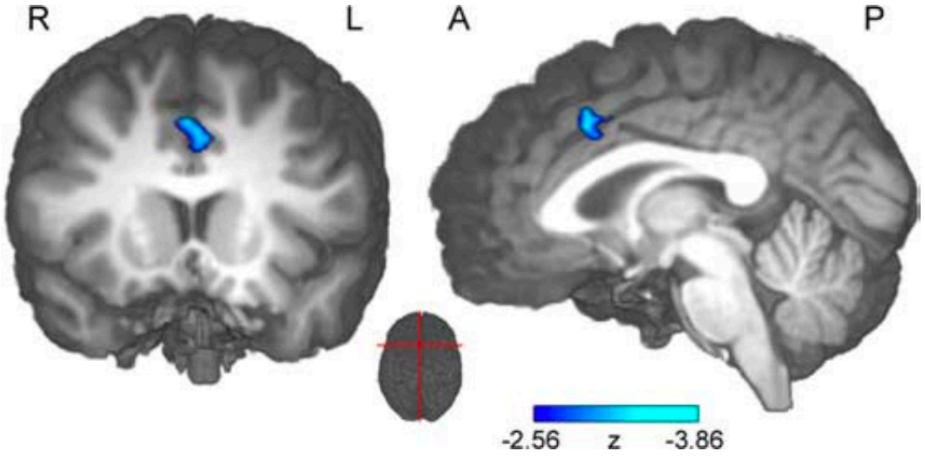
Information Tradeoffs

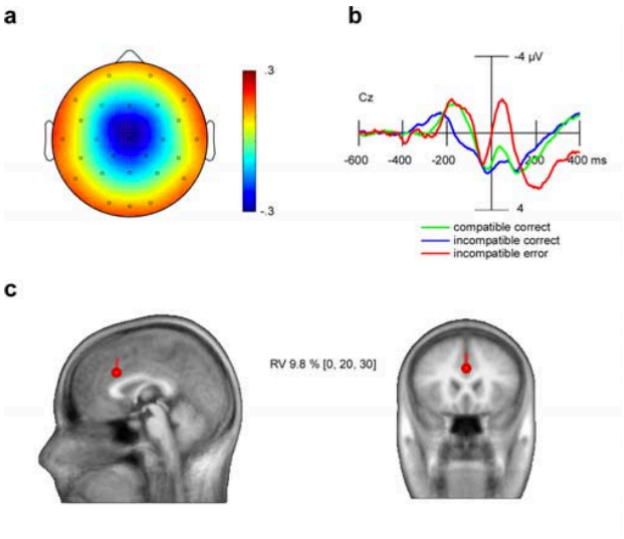
- "When in the brain" 
- "Where in the brain" 

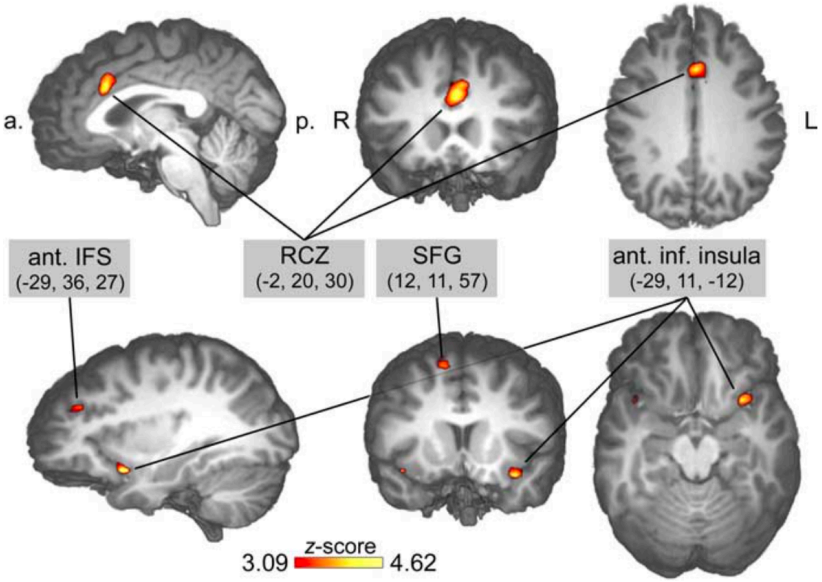
- "What happens to a process when X area is disrupted?"
  - Is there a fallback network?
- "What happens to a process when disrupted at Y time?"
  - How does the brain compensate?

EEG-fMRI Example









EEG-MEG

- EEG & MEG have different sensitivity profiles
  - EEG picks up on “all” sources (including radial), lower SNR, source “smearing”
  - MEG <u>most</u> sensitive to tangential sources, higher SNR
  - These complimentary profiles allow improved source localization accuracy (Sharon, et al. 2007; Aydin et al. 2015)

Flanker Task

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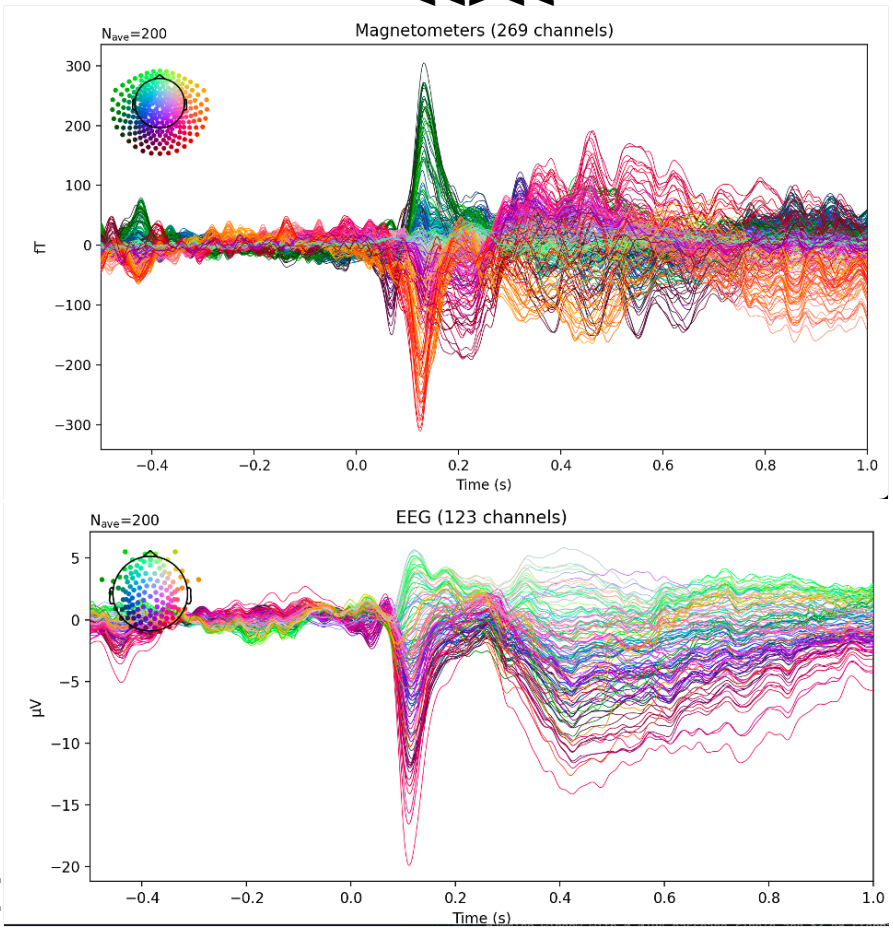


Courtesy Lucrezia Liuzzi (SDAN)

fMRI + Diffusion

- Can use fMRI activation (resting state or task) as seeds for diffusion tensor imaging
- Memory scores correlated with global and local "efficiency" in DMN
    - Anxiety negatively correlated

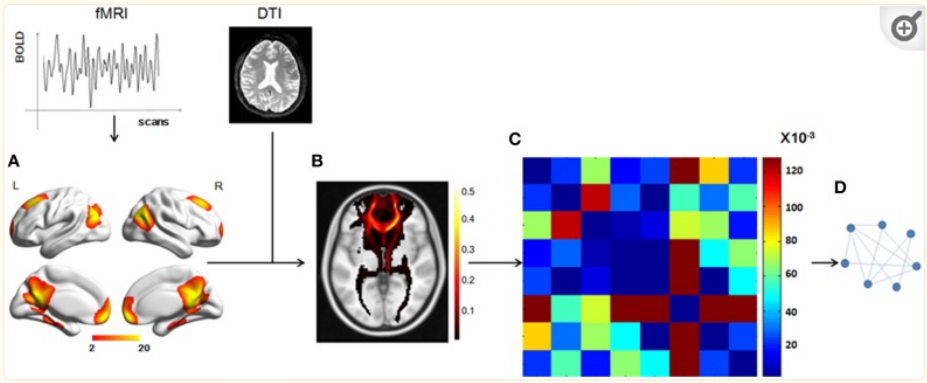
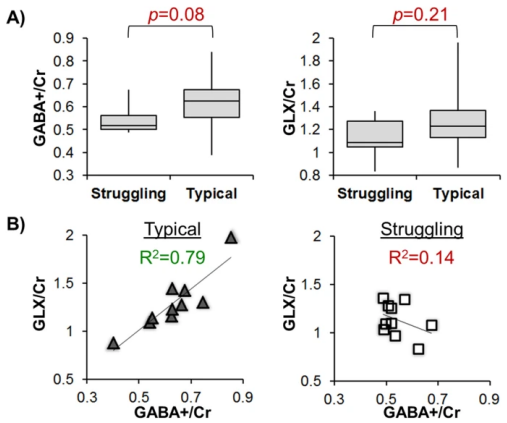


Figure 1

Total workflow before the statistical analysis. (A) The DMN mask was extracted from fMRI data using group ICA, with a threshold of $z = 2$. **(B)** A probabilistic fiber tractography method was used to track the fibers from each ROI and the connectivity probability between any two ROIs was calculated to get the matrix **(C)**. **(D)** A graph theory method, in which the nodes represented the ROIs and the weighted edges reflected the connectivity probabilities between any two nodes, was used to analyze the DMN structural network.

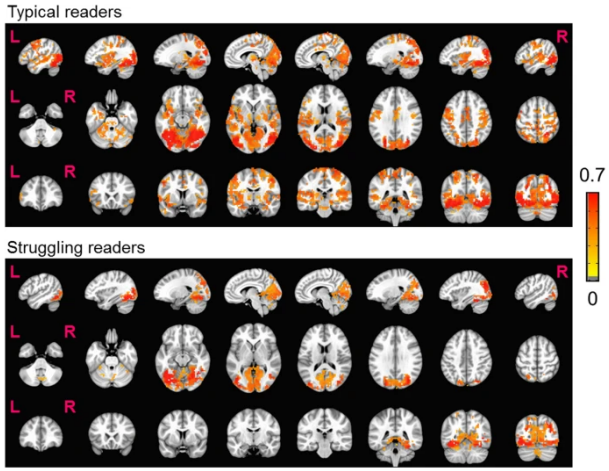
fMRI + MRS

Figure 2



The age-corrected neurotransmitter concentrations for both typical and struggling reader groups. (**A**) Though not significant, the struggling readers have lower GABA+/Cr and GLX/Cr concentrations in the frontal regions. (**B**) The typical readers show a strong relationship between GABA+/Cr and GLX/Cr, whereas struggling readers may have a neurotransmitter imbalance in their frontal system.

Figure 3



Functional connectivity maps in typical and struggling readers (p = 0.001, cluster size 100, FWE corrected) when seeded from L-FG. Color bar indicates the Z(CC). Note: L = left, R = right.

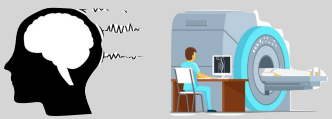
- Typical and struggling adult readers
- GABA in L IFG predicts real word reading behavior, but only if there is significant rsFC between fusiform and higher-order reading areas
- rsFC between L Fusiform and other language systems predicts oral reading of real words, irrespective of GABA

Technique Tradeoffs

	Pro	Con
EEG	High Temporal Resolution Comparable Across Lifespan Inexpensive	Low (Source) Spatial Resolution Source Analysis Difficult
MEG	High Temporal Resolution Less Difficult Source Analysis	Expensive Difficult to use with Children Limited Signal from Deep Tissue
fMRI	Excellent Spatial Resolution	Expensive Difficult to use with Children Low Temporal Resolution (HRF)

Doing Multimodal is Hard

Design



- Knowledge of the domain or topic
- Knowledge of component parts (e.g. MRI + EEG)
- Technical Knowledge to carry out some portion of the experiment

Data Analysis

Interpretation

More Design Questions

- Do you have the equipment?
- Do you have the expertise to operate the equipment?
- Is it worthwhile?
  - More data isn't always better.
- Can you do this well?

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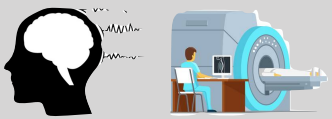
Design



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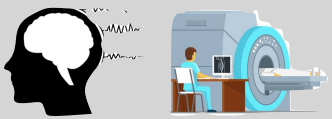

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- Technical Knowledge to carry out some portion of the experiment
- What's the value added?
- Does it have to be simultaneous?

Data Analysis

Interpretation

Simultaneous? Really?

- Quite a bit of information can be gathered from separate sessions of EEG and MRI
- The benefits of simultaneous are:
  - Same environment in both cases (inside an MRI)
  - Looking at individual trial modulation of either ERP/ BOLD
  - Looking at coherence and resting state relationship at the same time

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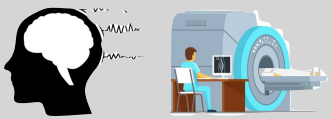

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- Important choice points: Simultaneous vs. Separate
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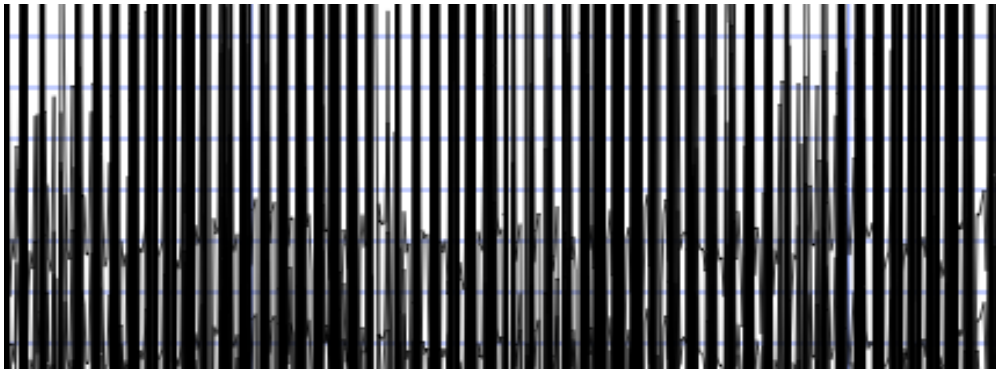
Data Analysis

- Are there artifacts from multimodal imaging?
  - Can you fix them?

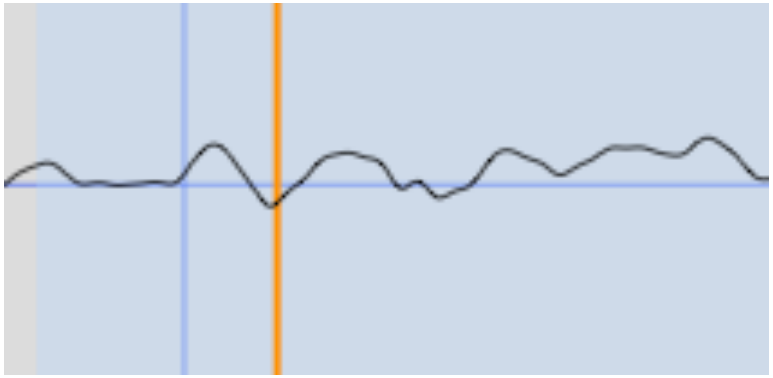
Interpretation

Artifacts

- MR Artifacts
  - Caused by the gradients



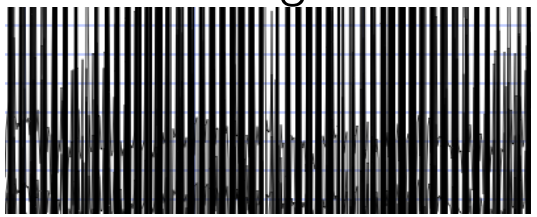
- Ballistocardiogram (BCG)
  - Caused by movement of the electrode within the magnetic field



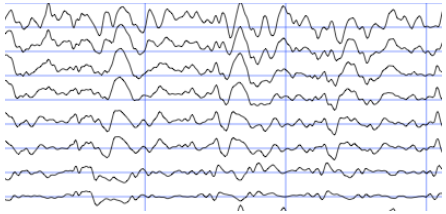
Artifact Removal

- Gradient Artifacts
  - Fairly straightforward to remove
  - Template subtraction
- BCG Artifacts
  - More prominent on the facial electrodes
  - Follows the heartbeat by ~250 ms
  - PCA to model the artifact, remove, reconstruct

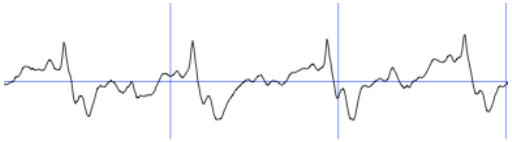
Raw Signal



Artifact Removed



BCG Detection



Doing Multimodal is Hard

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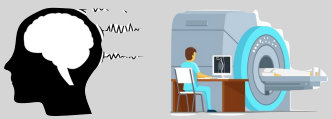

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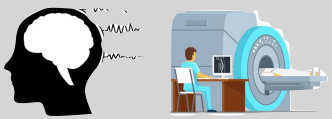

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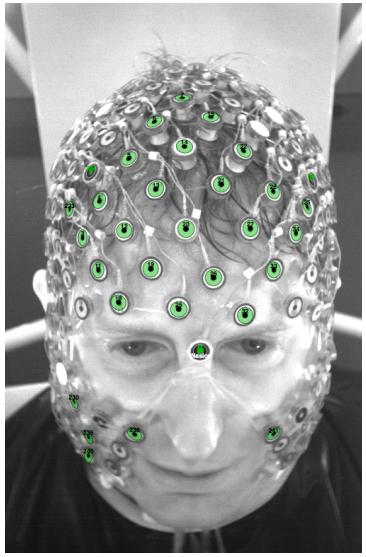
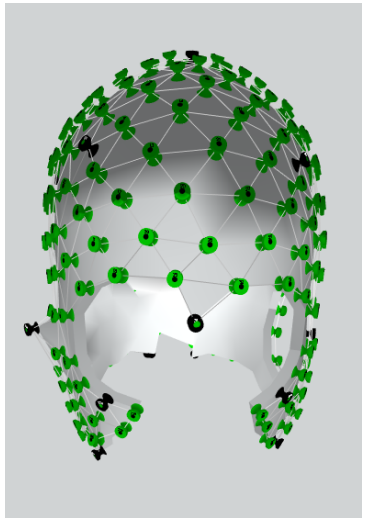
  - Co-register data across modalities
  - Head Models / Single Subject vs. Group
  - EEG Sources

Interpretation

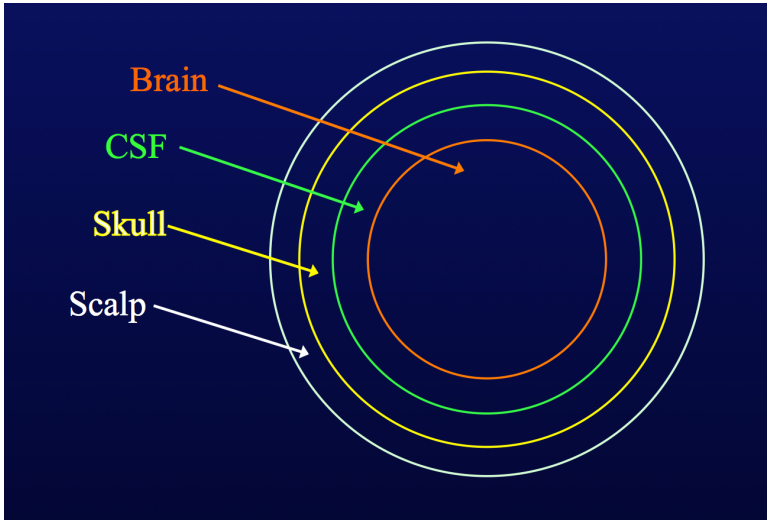
Electrode Coordinates



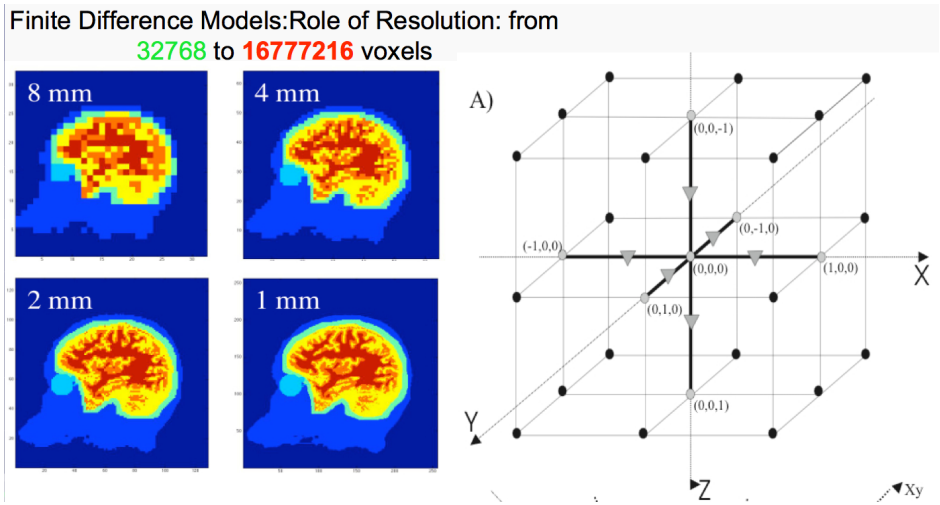


Head Models

Shell Models

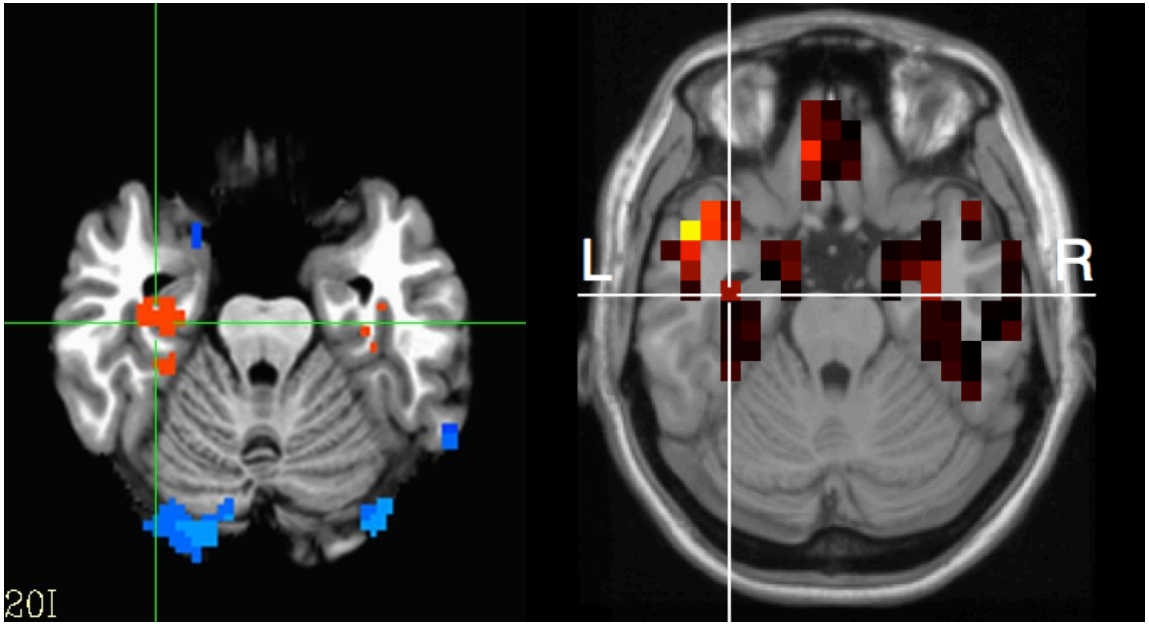


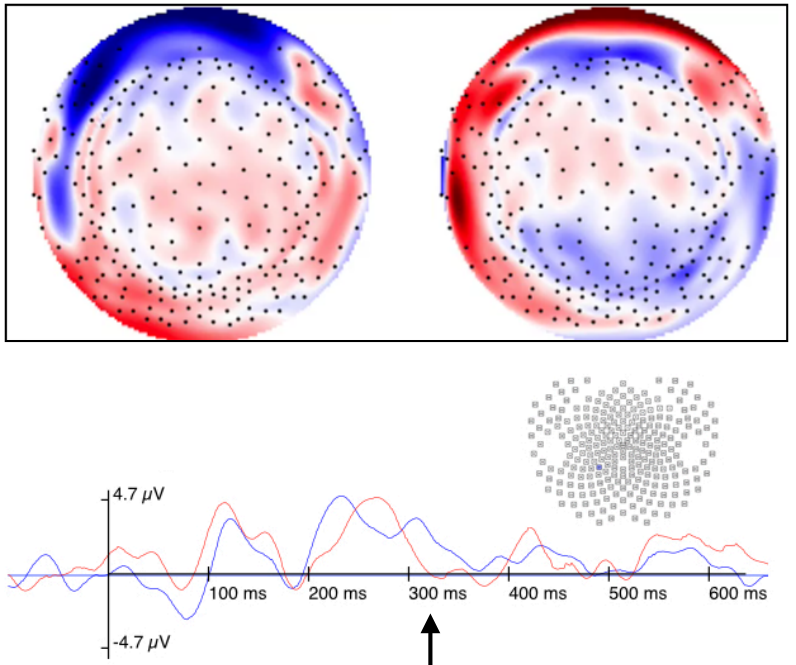
Finite Difference/Element Models



Difficulty Combining Very Different Measures

fMRI **EEG**

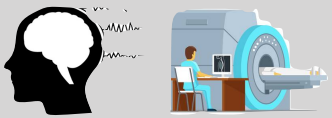




Parahippocampal Activation to P300

Doing Multimodal is Hard

Design



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Interpretation

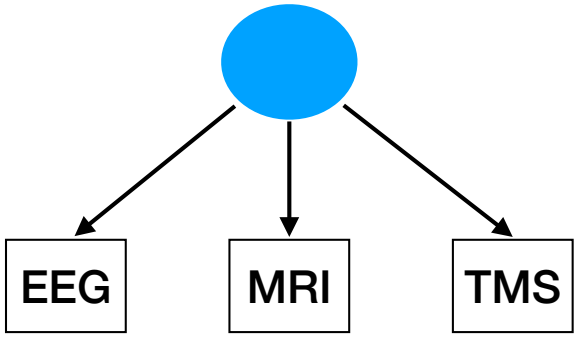
- How to interpret findings?
  - Do the analyses of you data let you make certain generalizations?
- What does it really mean?

Good News

- We’re making great progress on integrating Multi-modal techniques
  - Simultaneous methods have improved noise and artifact reduction
  - Non-concurrent methods continue to improve integration and comparison of results

Multimodal is Important

- Provides (hopefully) complimentary and (possibly) overlapping information
- May facilitate better studies of individual differences
  - May be used as a control within subject!
  - Allow for creation of multi-measure latent variable models
- Improve reliability/replication



Open Questions

- Design: What Questions best lend themselves to multi-modal imaging?

- Analysis: How should analyses be standardized to best make use of multimodal imaging?

- Interpretation: What will be the scientific/statistical level of rigor to support multimodal imaging conclusions

Questions?

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