Two is better than one (and many are better): Multi-echo fMRI methods and applications

How to decide if multi-echo fMRI can improve your study?

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Engaging Minds & Empowering Brain Science

Overview

- Multi-echo fMRI: One of many acquisition choices
- On example of how multi-echo fMRI can help
- Evaluating multi-echo fMRI with open eyes

Multi-echo fMRI: One of many acquisition choices

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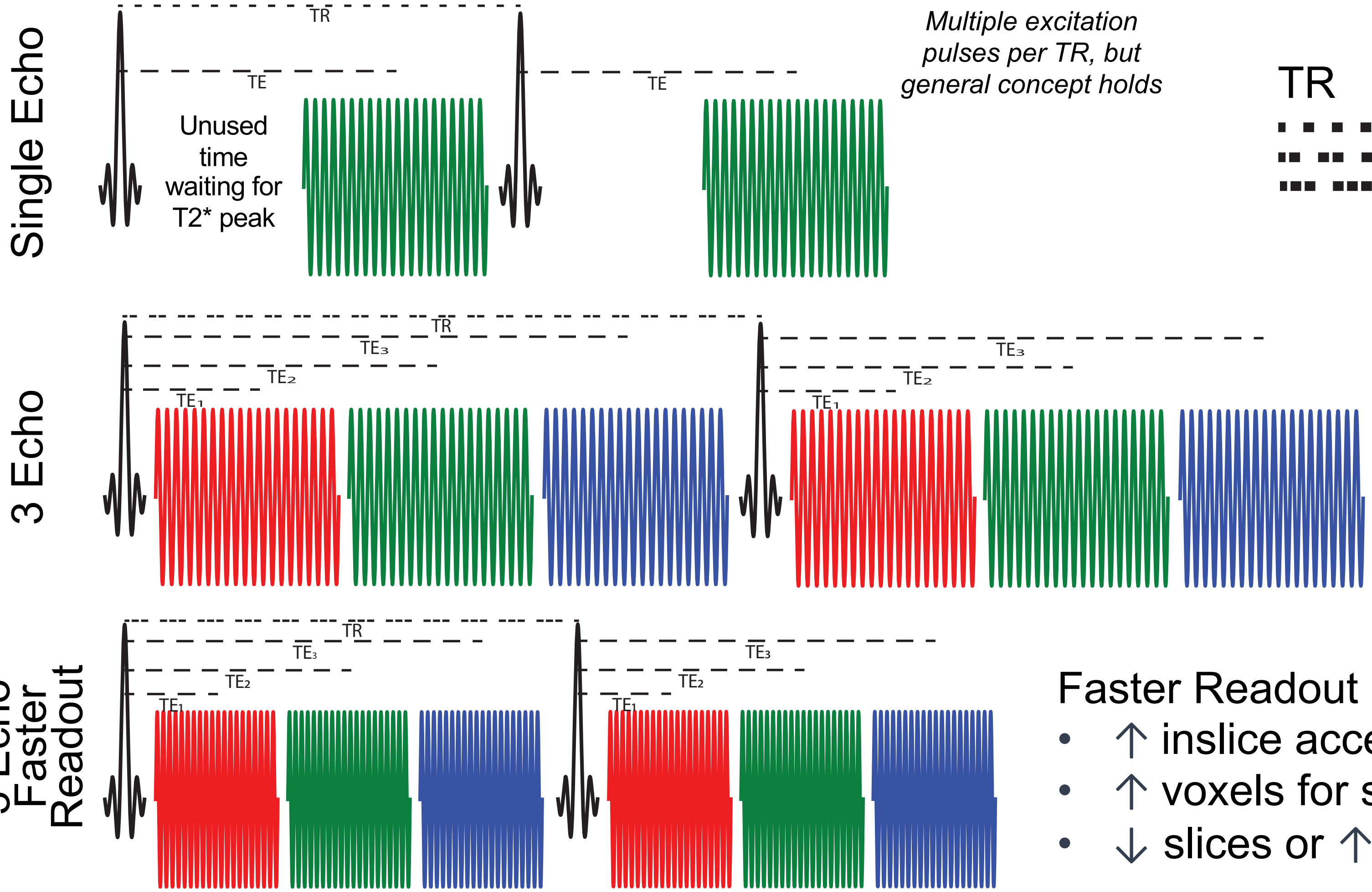
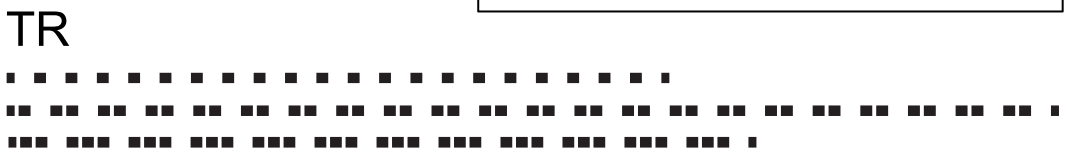
- Common question: Multi-echo fMRI or a short TR?
- Better question: How many echoes for how short a TR?

Dual-echo methods
Helpful for motion correction & physiological artifact removal
Bright *NeuroImage* 2013; 62;526
Buur *NMR Biomed* 2009; 22:551



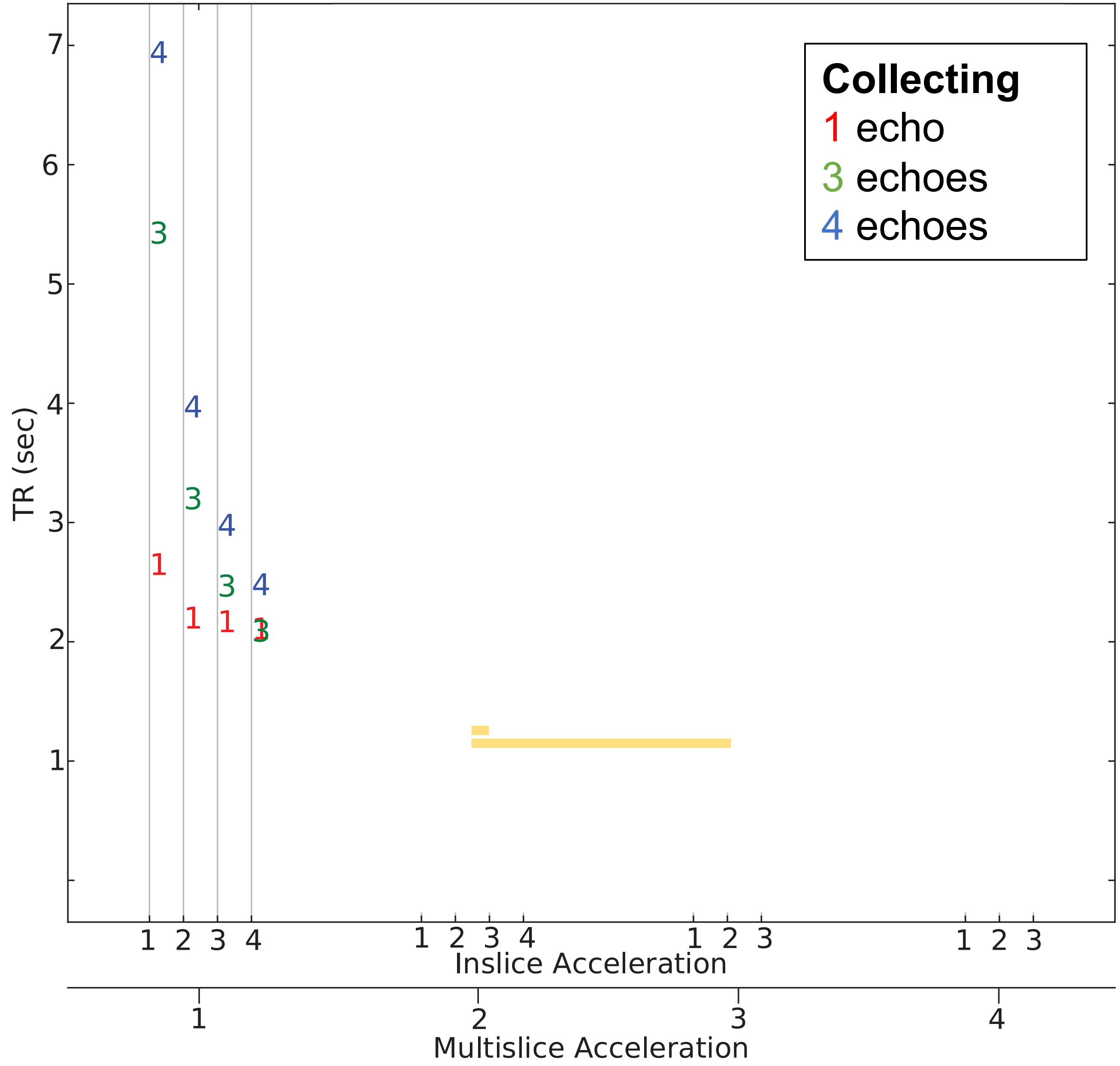


Optimize many acquisition parameters based on study goals, just like any other fMRI study

Faster Readout

- ↑ inslice acceleration (GRAPPA, ASSET, etc)
- ↑ voxels for same field-of-view
- ↓ slices or ↑ multislice or multiband acceleration

TR variation for multi-echo vs single-echo



Collected on a Siemens Prisma 3T MRI
Siemens OS VD11

CMRR Multiband pulse sequence
64 channel head coil

$3mm^3$ voxels 42-44 slices
cortex & cerebellum coverage

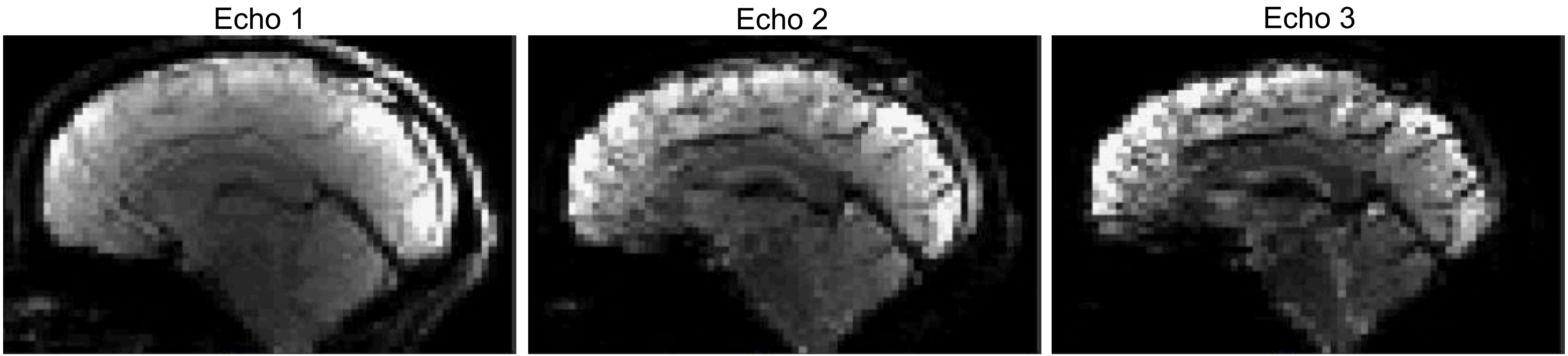
3 vs 1 echo for:

Inslice Acceleration = 2: 40-50% TR cost

Inslice Acceleration = 3: ~14% TR cost

Inslice Acceleration = 4: ~-1% TR cost

Multi-echo fMRI data with a 1 sec TR



- Collected on a Siemens Prisma 3T MRI, 64 channel head coil, Siemens OS VD11
- CMRR Multiband pulse sequence, Multi-slice acceleration=4, in-slice acceleration=2, $3mm^3$ voxels
- TEs=13.6, 31.86, 50.12ms
- Data from an ongoing study led by Emily Finn

How multi-echo fMRI can help

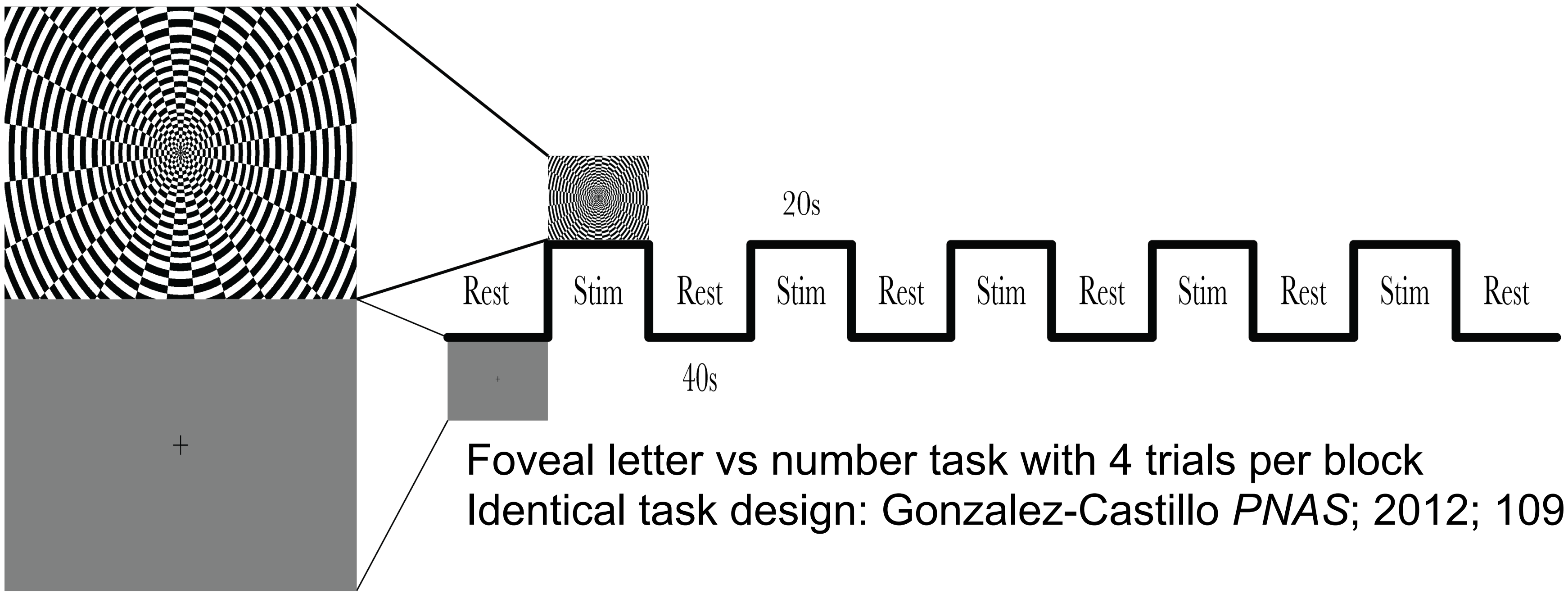
- ”Optimal Combination” of echoes: Weighted average (Posse 1999, Poser 2006)
  - Weighted average of echoes based on voxel-wise T2* estimates
  - Straightforward math
  - Automatically calculated in AFNI, fMRIPrep, and tedana
- Denoising
  - Removal of non T2* weighted signal based on models of signal change across echoes (Kundu 2012 & 2013)
  - Uses empirical models of noise to get away from assumptions of what ”looks like noise”
  - Potential for bigger gains, such as separating slow drift of fMRI signal from slow neural changes (Evans 2015)

More details at
https://tedana.readthedocs.io/en/latest/resources.html
https://tedana.readthedocs.io/en/latest/approach.html

Evans *NeuroImage* 2015; 105:189; Kundu *NeuroImage* 2012; 60:1759; Kundu *PNAS* 2013; 110:16187
Poser, *MRM* 2006; 55:1227; Posse *MRM* 1999; 42;87

Experimental Design

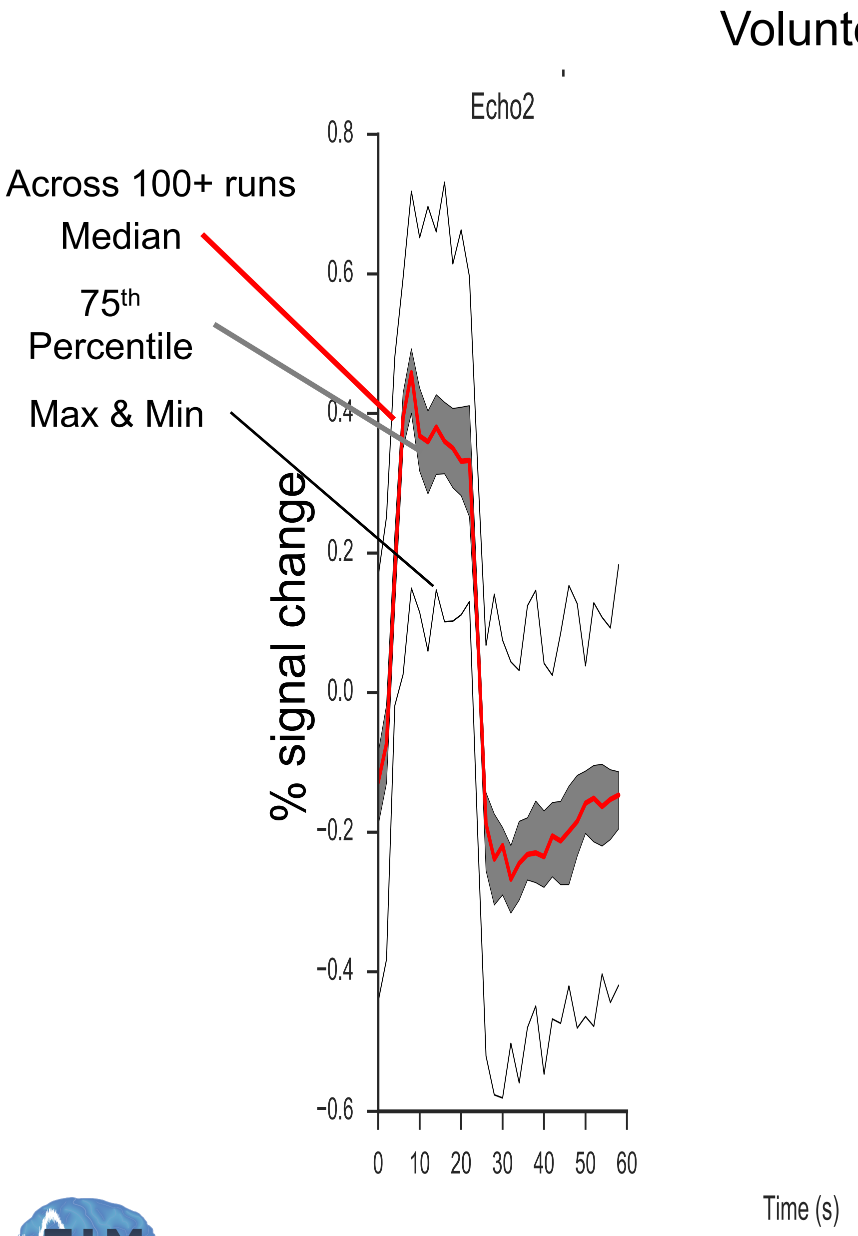
- 2 Volunteers, 9 sessions, 103 runs each, 9 hours of data per subject
- GE MR750, 3T, 32 channel coil
- EPI: 3.5mm^3, **3 echoes, TE=15.4, 29.7, & 44.0ms** FA=75°, TR = 2s, 33 slices
- 5.5 minutes, 161 volumes (150 volumes used in each run)

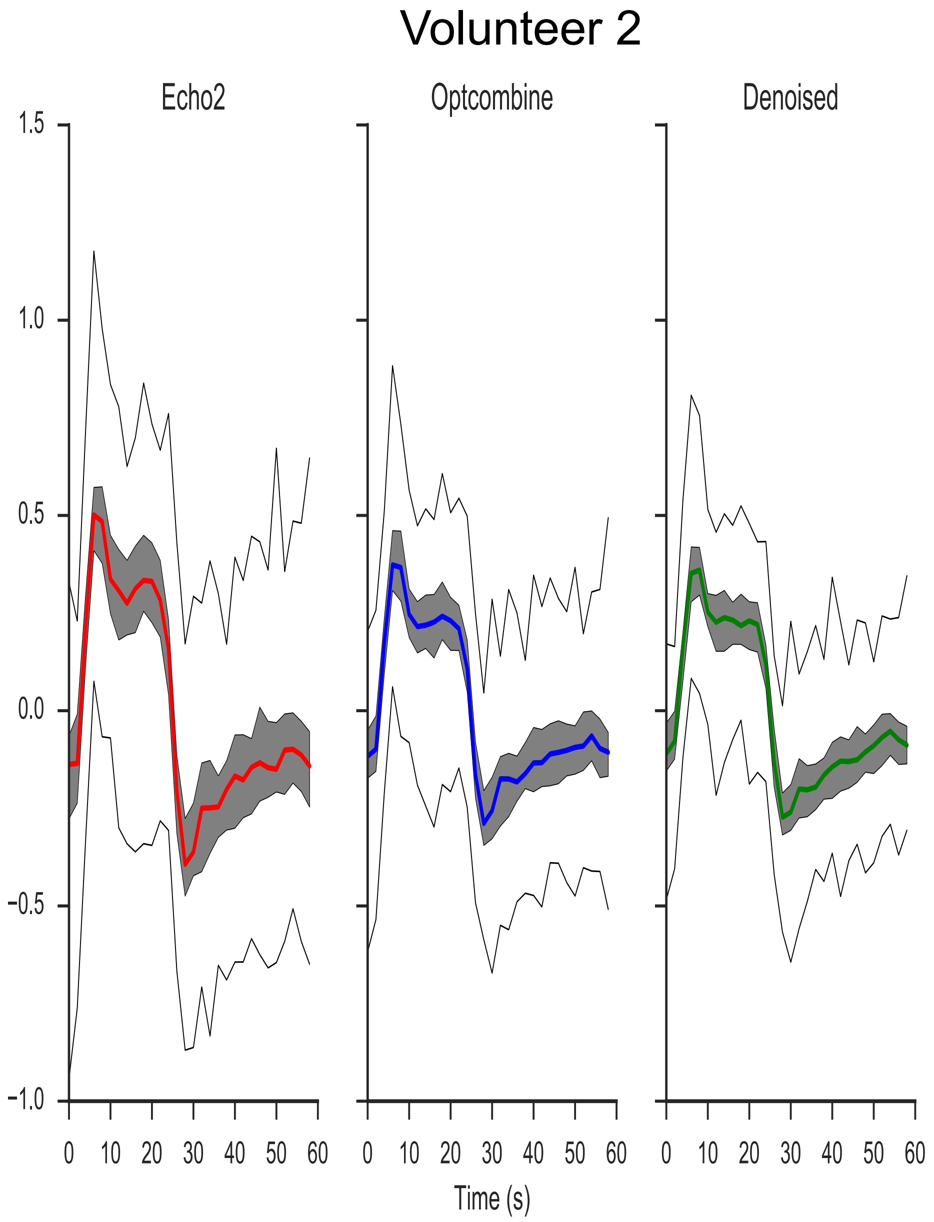


Foveal letter vs number task with 4 trials per block
Identical task design: Gonzalez-Castillo *PNAS*; 2012; 109;5487

Optimal Combination & Denoising processed with: bitbucket.org/BenGutierrez/me-ica

Lateral Geniculate Nucleus (LGN) Responses





Contrast-to-Noise By Run

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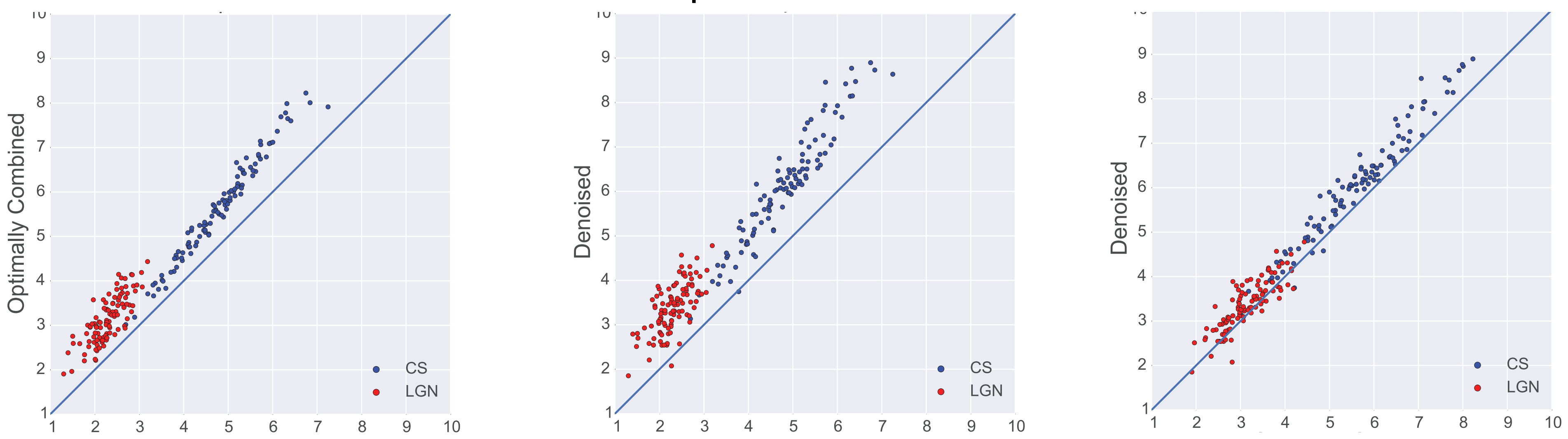
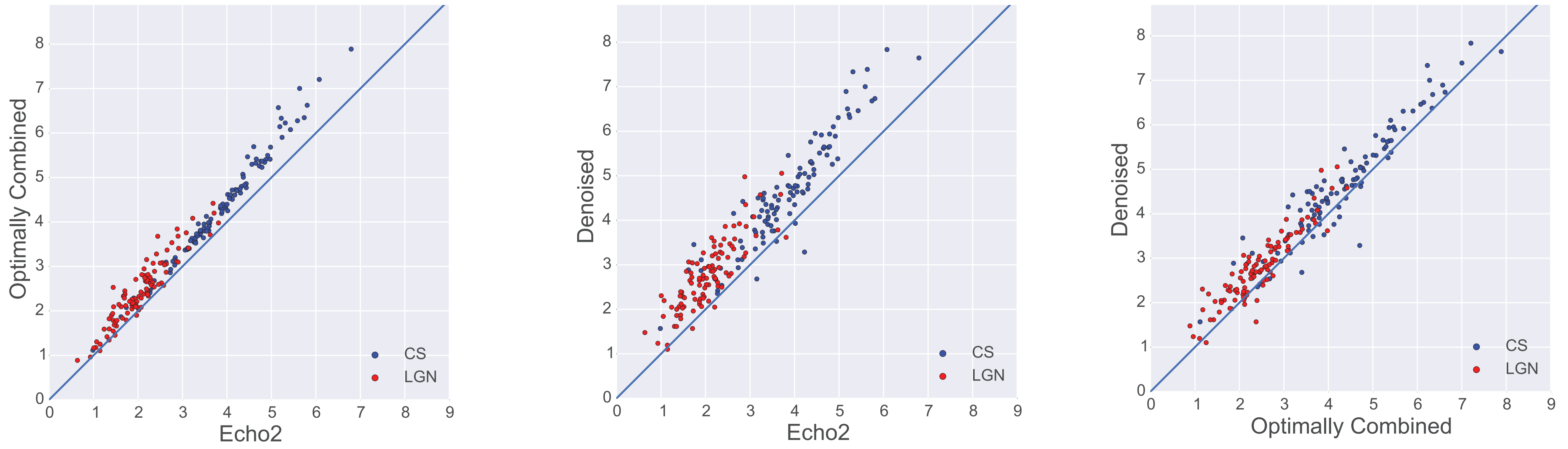
CNR Comparison for Volunteer 1



CNR Comparison for Volunteer 2



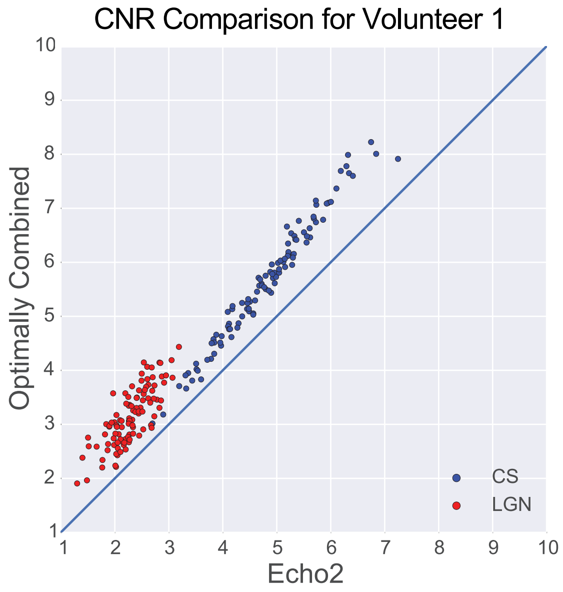
Regions of Interest

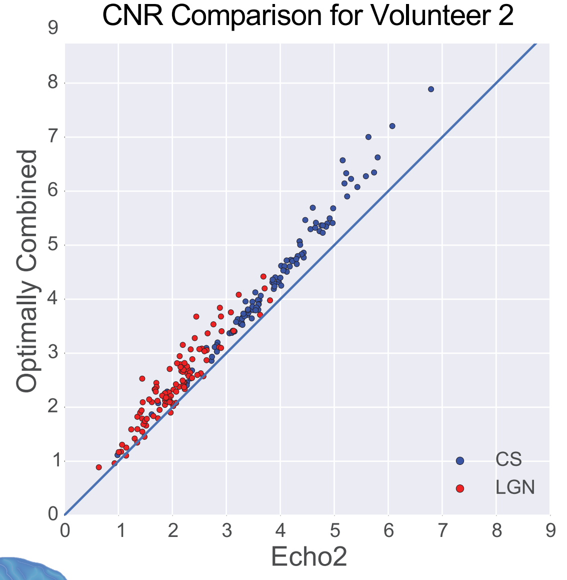
CS
Calcarine Sulcus

LGN
Lateral Geniculate Nucleus

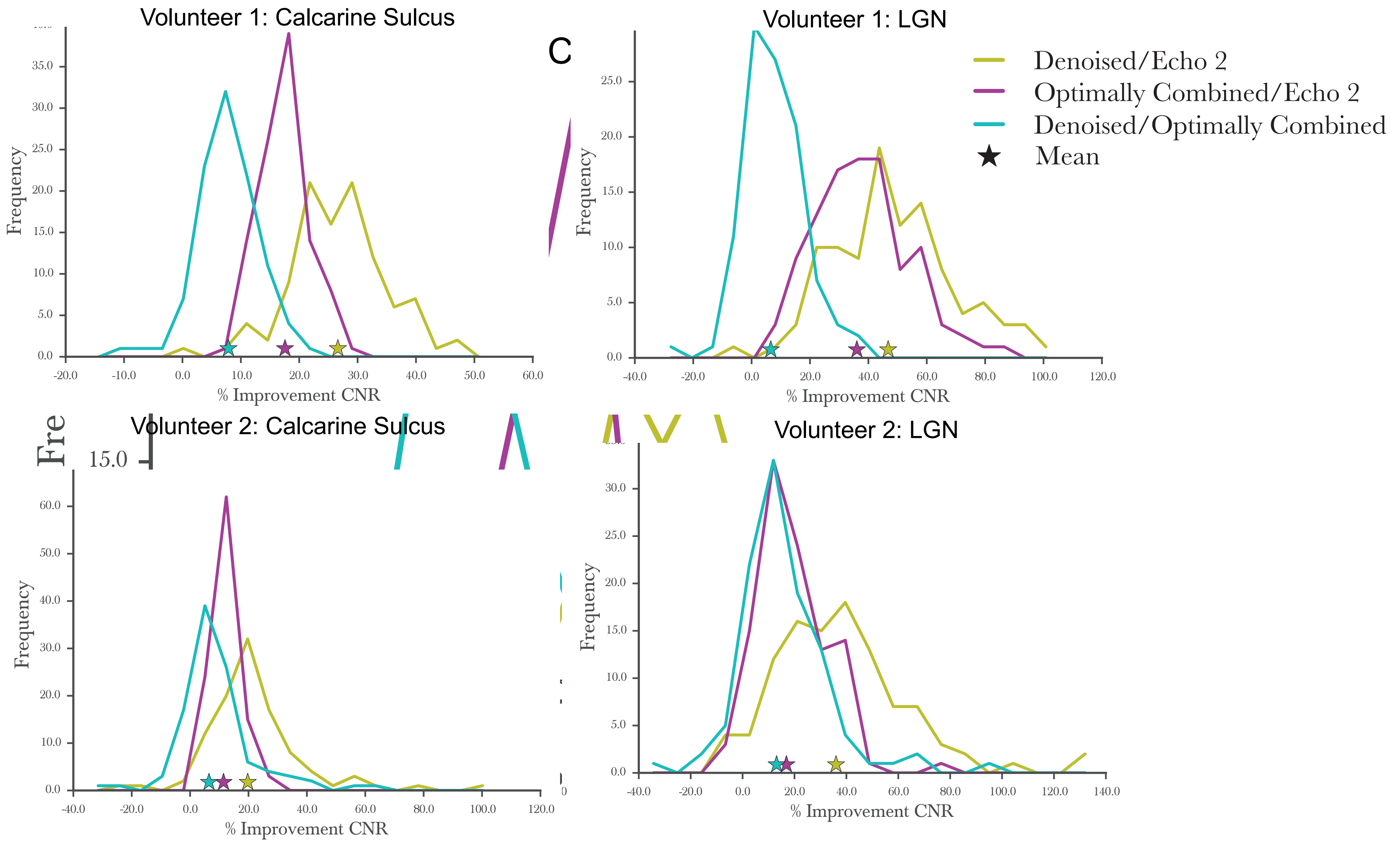
Each dot is the CNR values from 1 run

Contrast-to-Noise By Run





CNR % Improvement Between Preprocessing Methods



Evaluating multi-echo fMRI with open eyes

- Optimal Combination reliably improves CNR over single echo
- Denoising can be similar, much better, or worse than the optimal combination
  - More to understand & improve on methods of defining noise to remove
  - Use denoising, but don’t assume everything worked perfectly
- Limits of presented data
  - Awesome volunteers: <1.5mm max head motion in all but 2/206 runs
  - Single, stable scanner with a regular Quality Assurance testing
  - Benefits of denoising may be greater with more noise to potentially remove

Summary and Recommendations

- Acquiring multi-echo can be balanced with a combination of acceleration↑, slices↓, & TR ↑
- More CNR from "optimal combination" of echoes **should** balance lower SNR from acceleration↑
- With multi-echo data, you can empirically identify and remove non-T2* weighted noise
  - Algorithms still under development & should not be blindly used
  - These methods will get better: **tedana.readthedocs.io & Elizabeth DuPre's talk**
- **Recommendations**
  - Planning to go from acquisition to publication in a couple of years: Consider multi-echo
    - You may see modest benefits with optimal combination
  - Planning a longer-term project with goals of data re-use: Strongly consider multi-echo
    - Immediate, modest benefits, and larger longer-term benefits are likely
    - Development of additional ways to use multi-echo fMRI is likely (**see César Caballero-Gaudes' talk**)

Other talks in session

Introduction to Multi-Echo

Stefano Moia

Multi-echo is a simple concept that opens up many possibilities

tedana software and community

Elizabeth Dupre

A community based, open source software development to improve method and application together

Multi-Echo beyond preprocessing

César Caballero-Gaudes

With Multi-Echo we can estimate the activity-inducing neural signal better

Multi-Echo fMRI in practice

Angela Laird

Setting up a Multi-echo study for the first time will be challenging, but worth the effort

Acknowledgements

- 100-runs multi-echo study:
  - The volunteers!
  - Peter Bandettini
  - Javier Gonzalez-Castillo
  - Ben Gutierrez
  - Vinai Roopchansingh
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  - Colin Hoy
  - NIH Biowulf computing cluster: hpc.nih.gov
- tedana developers including:
  - Elizabeth DuPre
  - Logan Dowdle
  - César Caballero-Gaudes
  - Javier Gonzalez-Castillo
  - Ross Markello
  - Stefano Moia
  - Taylor Salo
  - Joshua Teves
  - Eneko Uruñuela
  - Kirstie Whitaker
  - **You?**