Multi-echo fMRI removes physiological noise during naturalistic viewing

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INTRODUCTION

Physiological noise from respiration during naturalistic viewing may induce artifacts in inter-subject correlation analyses (ISC). If participants are watching the same movie and their breathing and heart rate are synchronized with events in the movie, this will cause synchronized global artifacts. Multi-echo fMRI helps to remove head motion artifacts and rapid pulsatile respiratory and cardiac artifacts, but current denoising methods, such as tedana[4,7], may be less effective at removing changes in blood oxygenation due to slow T2* weighted changes in respiratory rates and depths.

We collected data to induce these artifacts and test the effectiveness of current multi-echo denoising methods at removing these noise sources. We additionally examined a method to directly measure and remove slow breathing artifacts as part of multi-echo denoising

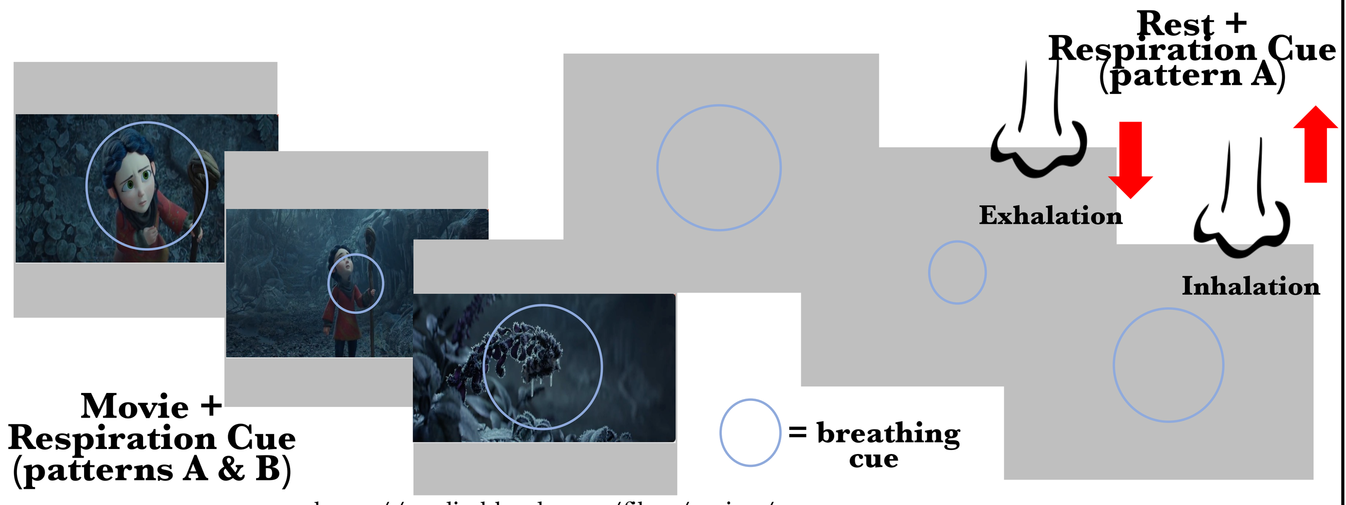
METHODS

Experimental Paradigm

24 participants completed runs where they watched a movie while doing a cued breathing task or just did the cued breathing task

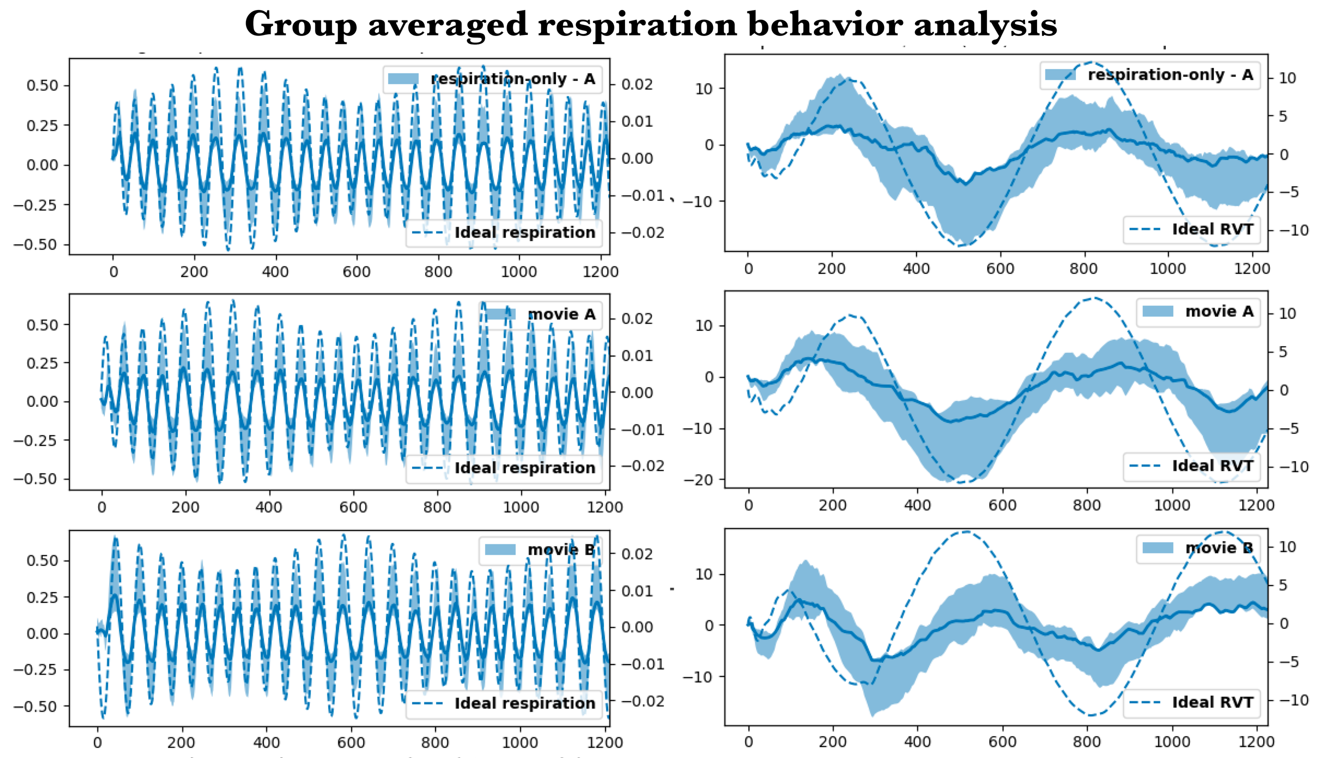
The breathing cue was task-locked and varied according to phase amplitude and frequency. The participants alternated between movie viewing sessions with phase-A and phase-B respiration patterns, and phase-A-only resting-state sessions.

The movie and breathing sessions lasted for the same duration (~ 8 minutes), with 2-3 runs completed per subject, and with the same movie being shown on subsequent runs.



https://studio.blender.org/films/spring/

Group averaged respiration behavior analysis



Shaded area is the 25th to 75th percentile range across all participants and runs. Participants followed the breathing cues. RVT=Respiratory Volume / Time

Acquisition

3T Siemens Prisma, Multi-echo fMRI (CMRR sequence, EPI, SMS=2, iPAT=2, TE=13.44, 31.7, & 49.96ms, 3.0mm^3 isotropic voxels)
Magnitude and phase scans were retained and 5 RF-off "noise" volumes were collected at the end of each sequence. (Phase and noise information were not used in these analyses)

Processing

Data was pre-processed with AFNI[3]. The respiration and cardiac traces for the design matrix were calculated using NiPhlem[9]. The within- and between-subject correlations were calculated using AFNI's *3dTcorrelate*, within-subject correlations were assessed at the group level with *3dttest*, and inter-subject BOLD synchronization was calculated with *3dISC*. Runs were compared across 3 conditions: 1) movie x movie with different respiration patterns, 2) movie x rest with same respiration patterns, and 3) rest x rest with same respiration patterns. Our denoising method involved 1) tedana's denoising pipeline or 2) a combined regressors model that combined tedana with fitting regressors based on respiratory and cardiac signals, head motion, and CSF and white matter regressors to the component time series.

PROCESSING CODE

https://github.com/nimh-sfim/ComplexMultiEcho1

ACKNOWLEDGEMENTS

This work utilized the computational resource of the NIH HPC Biowulf cluster: hpc.nih.gov

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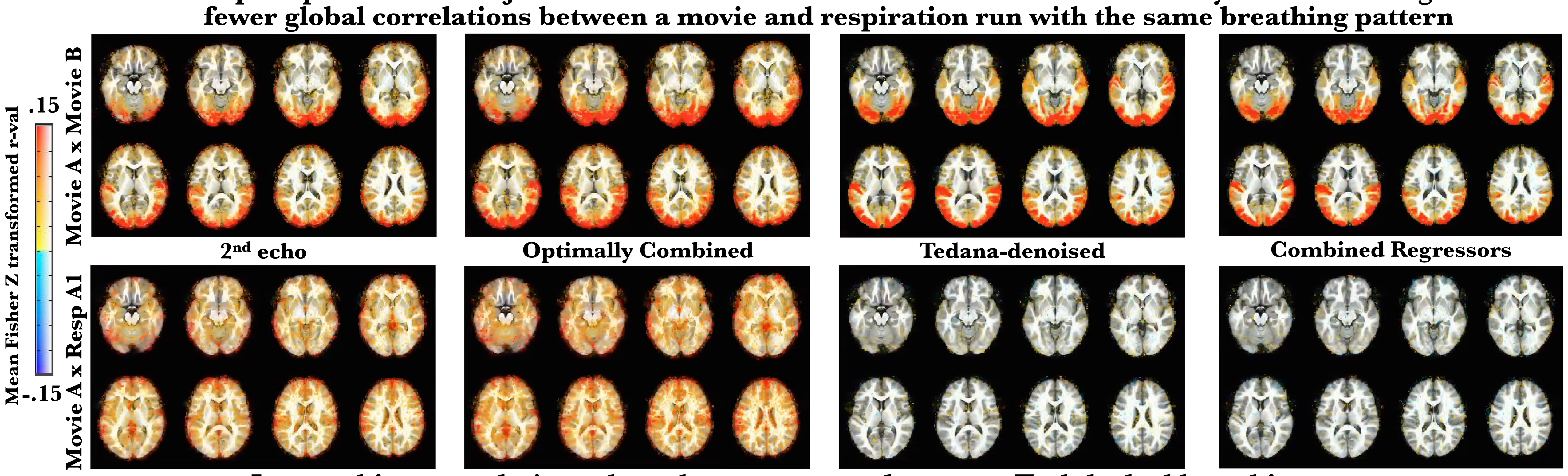
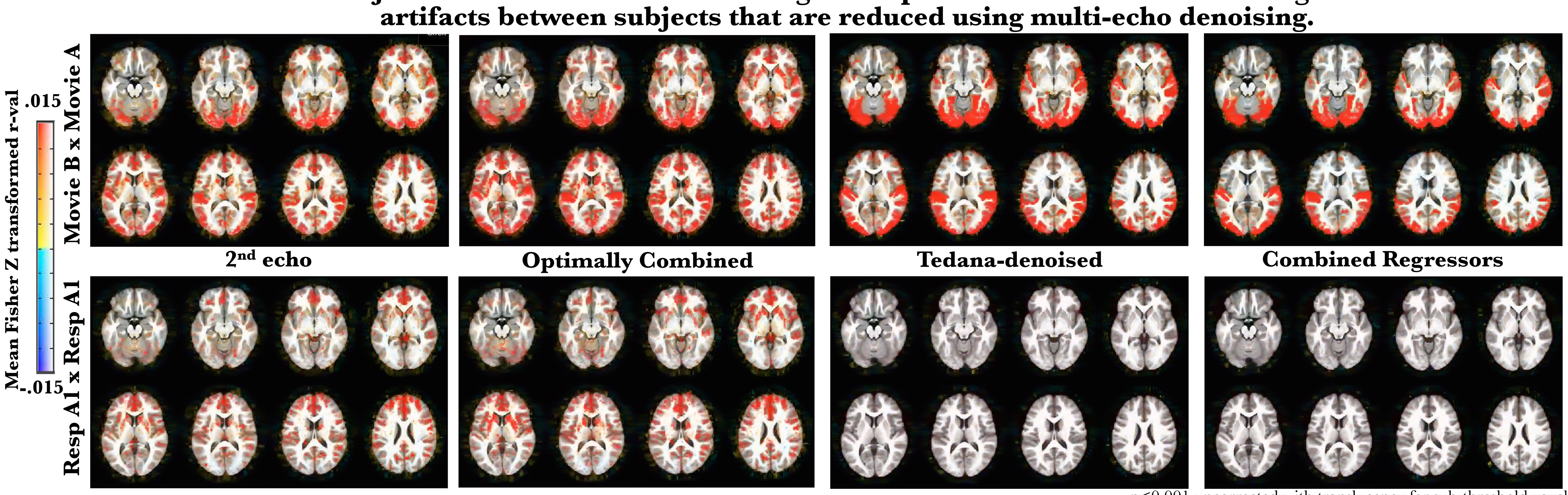
RESULTS

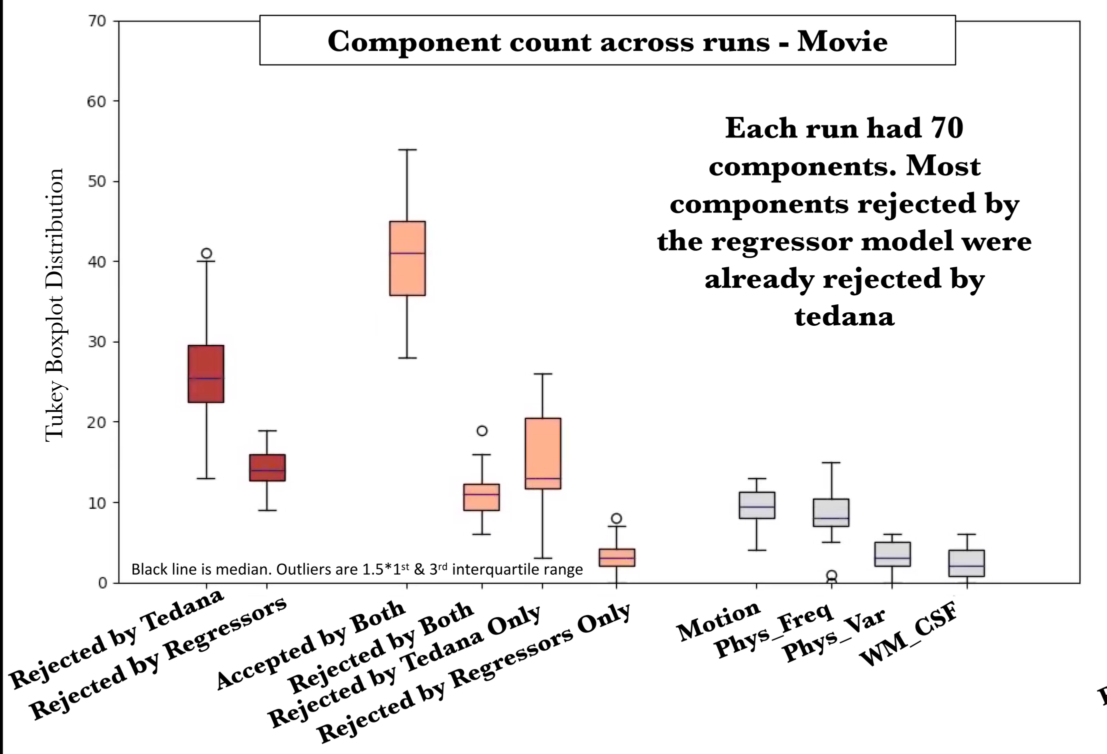
Group Maps of intra-subject correlations between runs show more focal activity after denoising and fewer global correlations between a movie and respiration run with the same breathing pattern

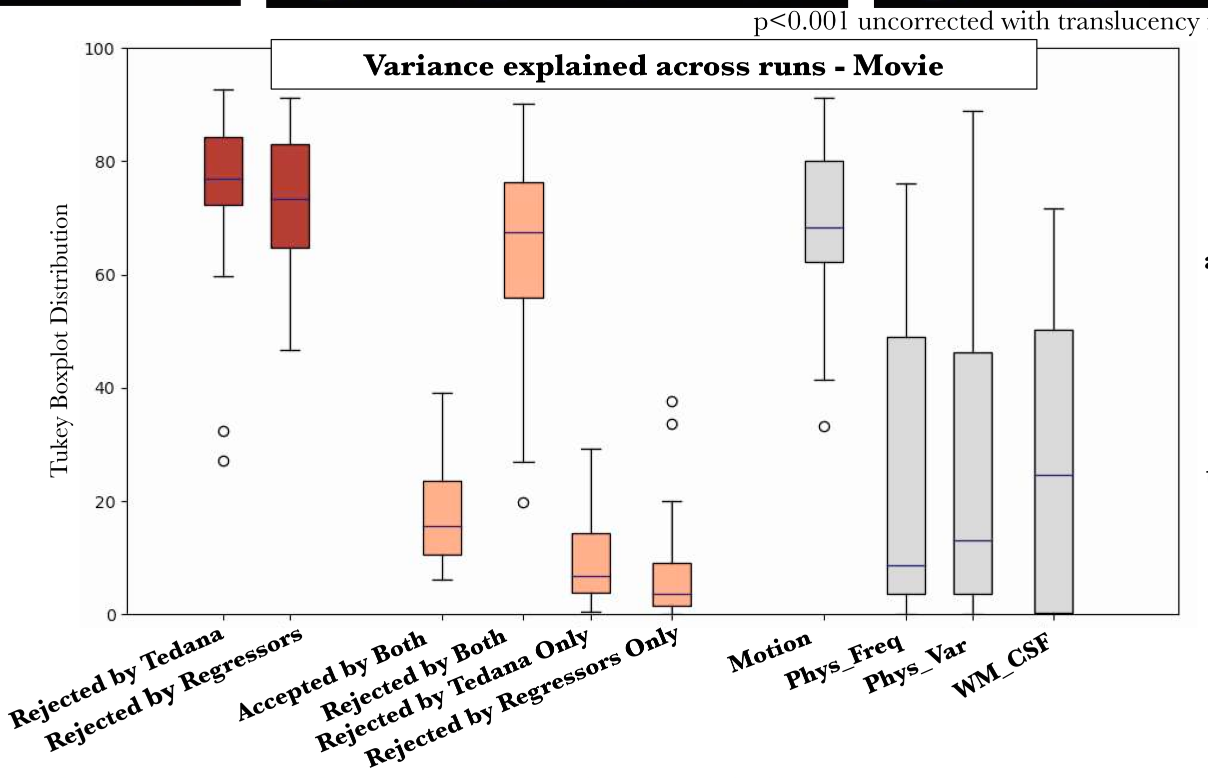


Inter-subject correlations show the same general pattern. Task-locked breathing can cause artifacts between subjects that are reduced using multi-echo denoising.



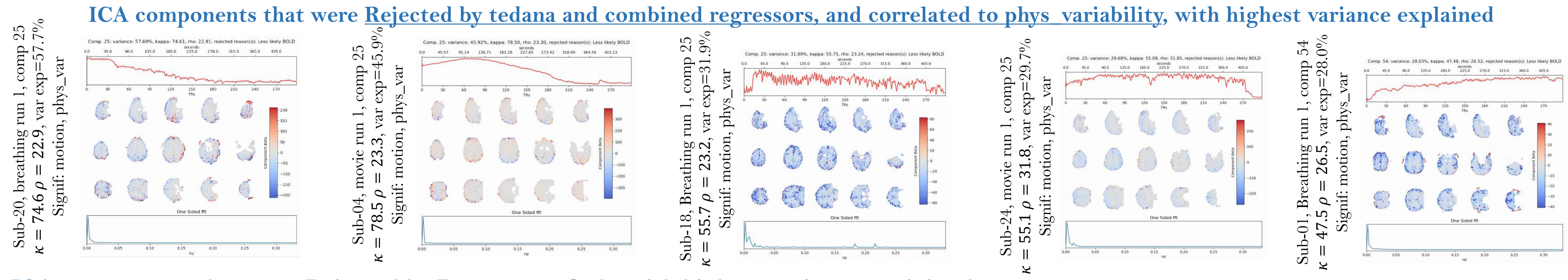
p<0.001 uncorrected with translucency for sub-threshold voxels



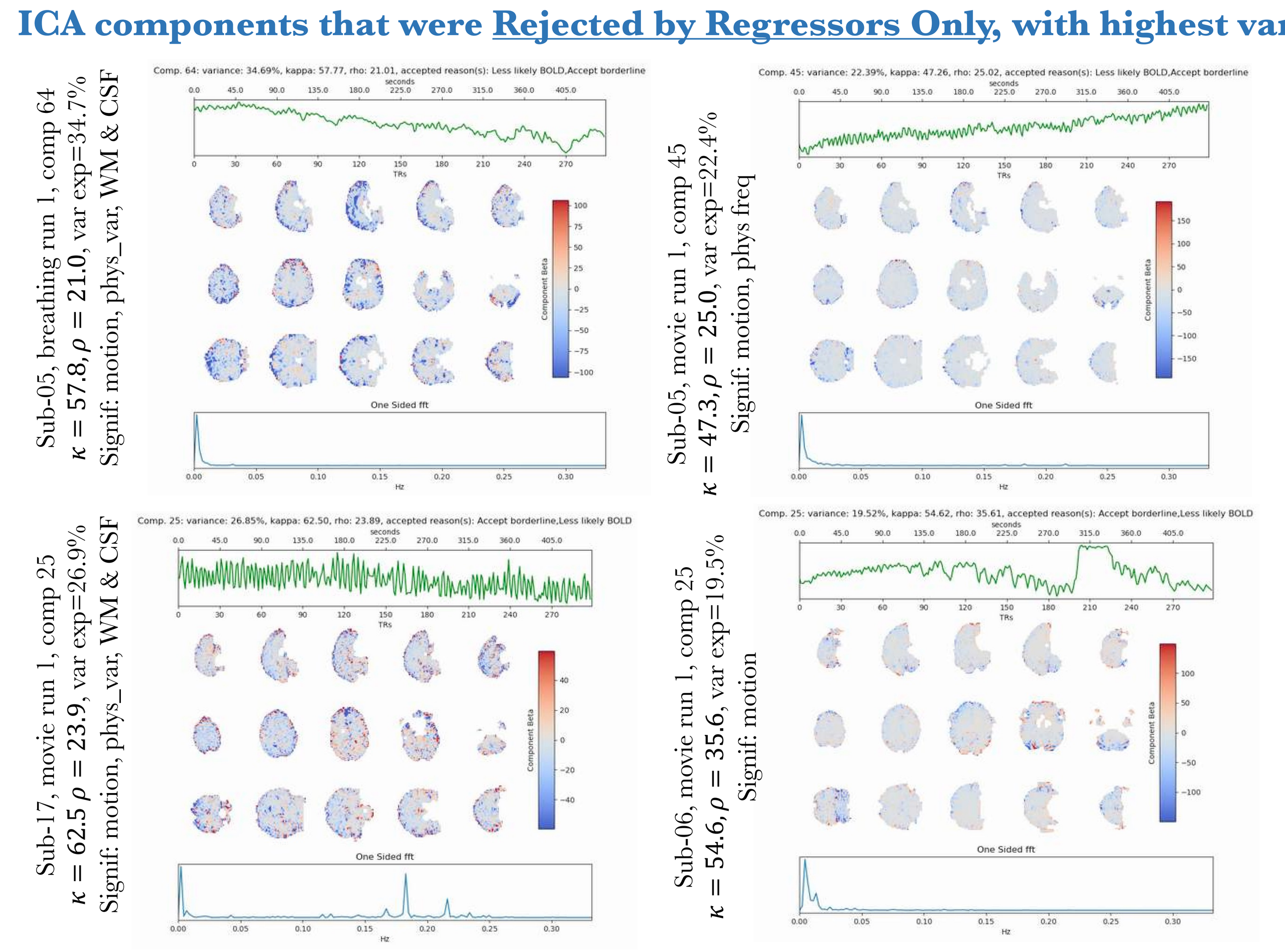


Similarly, most of the rejected variance in components was already rejected by just tedana. Some high variance components fit to slow respiratory fluctuations, but those were already rejected by tedana

ICA components that were Rejected by tedana and combined regressors, and correlated to phys_variability, with highest variance explained



ICA components that were Rejected by Regressors Only, with highest variance explained

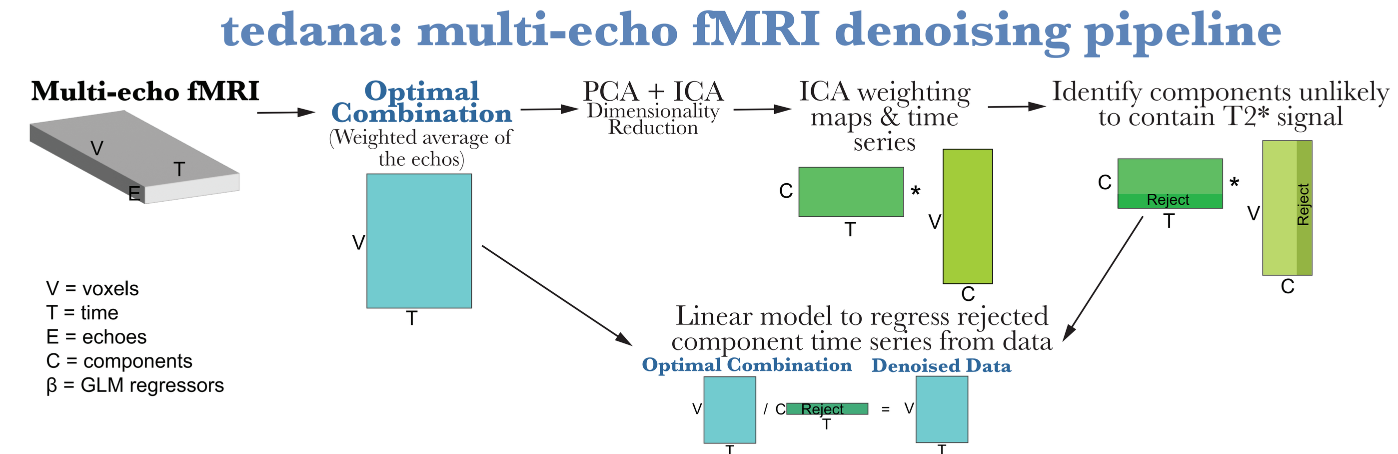


CONCLUSIONS

- Even with a naturalistic task with intentional slow-respiratory T2* artifacts, tedana removes a large portion of the observed noise
- A regressor that modeled slow respiratory changes was expected to remove more noise components, but many of these components were already removed by tedana
  - These components also contained motion, which is S0-weighted noise & typically removed by tedana.
- Future plans
  - Improve tedana's selection method to more reliably remove all clear noise components
  - Test other regressor models that might identify noise sources missed by tedana

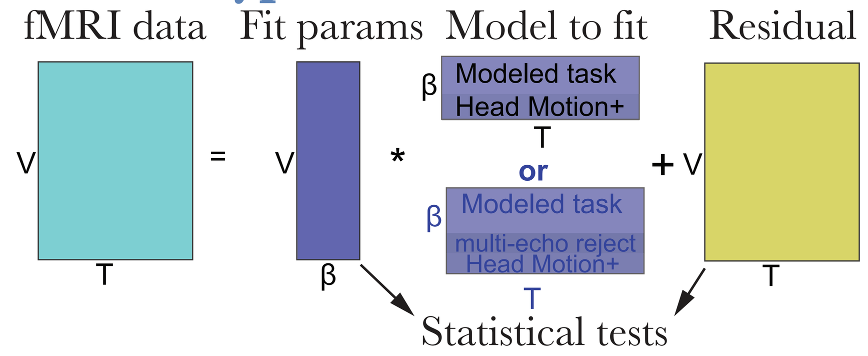
DENOISING METHODS

tedana: multi-echo fMRI denoising pipeline



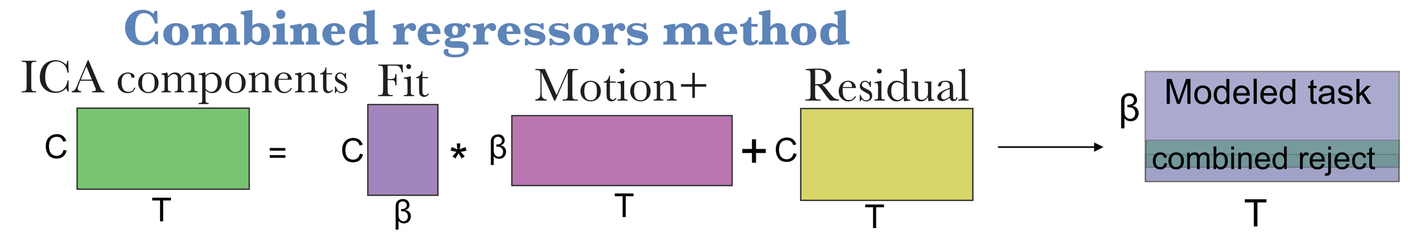
Identify non-T_2^* ICA components to reject & linearly regress the component time series

Typical fMRI GLM



Data are fit to a model that contains both expected behavioral responses & nuisance regressors
Tedana denoising adds the time series from rejected components

Combined regressors method



Find ICA components that are significantly modeled by motion, respiratory, and cardiac frequencies (phys_freq)[6], respiratory volume[1], and heart rate variability[8] over time (phys_var), and white matter & CSF ROI time series. Using $p<0.05_{bonf}$ & $R^2>0.5$ as the threshold. This is conceptually similar to AROMA[8], and adds multi-echo information