USING MULTI-ECHO CARDIAC GATED FMRI TO BETTER DENOISE BRAINSTEM DATA

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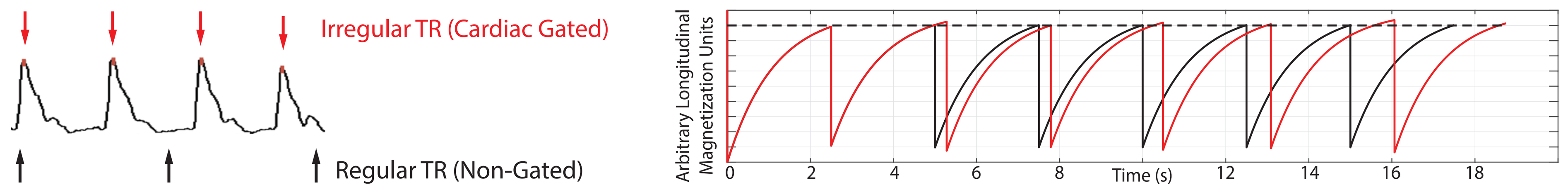
INTRODUCTION

BACKGROUND

Detecting activity in the brainstem using BOLD-fMRI (blood-oxygen-level dependent functional MRI) is difficult due to the pulsatile motion of blood flowing and the heart beating. One way to minimize pulsatile motion, is to acquire images always at the same point within the cardiac cycle (cardiac-gated imaging). Unfortunately, the irregular repetition time (TR) associated with cardiac-gated imaging produces artifactual baseline signal shifts of a T1 origin that ought to be accounted for. Guimaraes et al. (1998) previously proposed a model-driven approach to account for these artifactual baseline shifts. Here, we propose an alternative data-driven approach based on ME-ICA denoising. We evaluate this approach looking at patterns of activation in the Inferior Colliculus (IC) during a simple auditory stimulation block design.

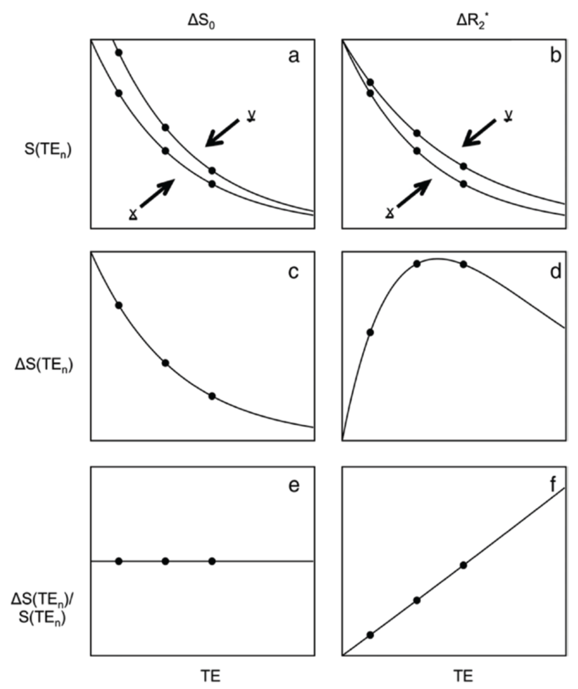
CARDIAC GATING

While standard fMRI measures at a fixed repetition time (TR), cardiac-gating (CG) triggers the measurements when the subject is at the peak of their cardiac cycle.

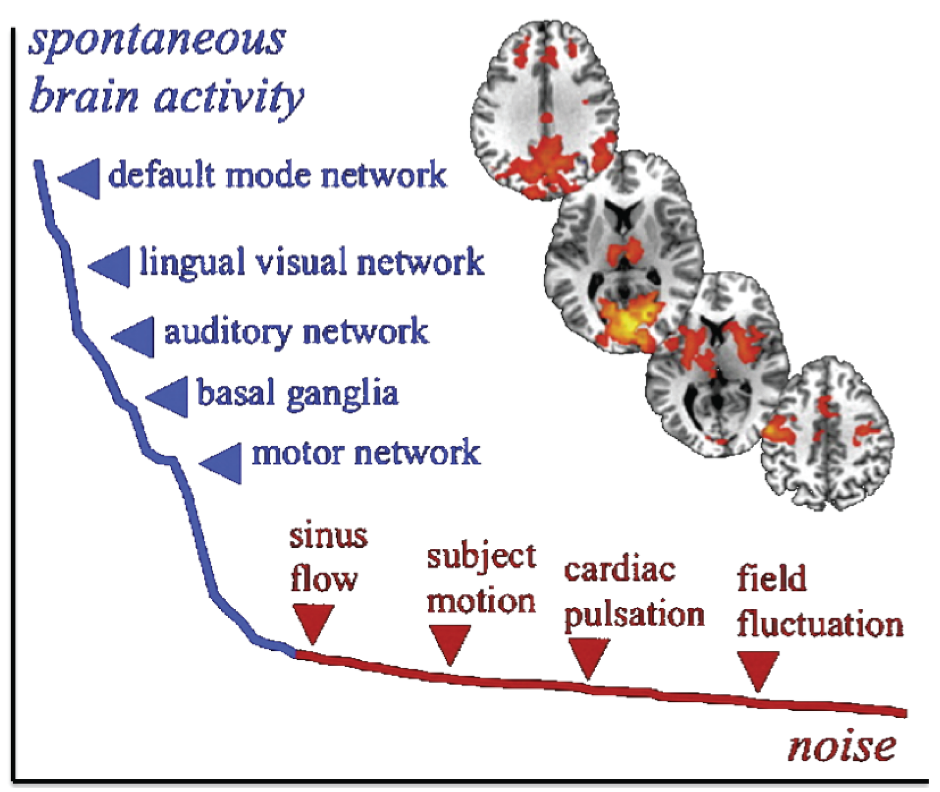


MULTI-ECHO ICA (ME-ICA) DENOISING

Multi-echo fMRI acquires several brain volumes per TR, each at a different echo time (TE). Echoes can then be combined (e.g., weighted average) to improve BOLD sensitivity (Posse et al. 1999) . However, this approach will not succeed when the nuisance signals of no-interest are common to all echoes (such as those due to the non-constant TR in cardiac-gated imaging). An alternative approach is ME-ICA denoising (Kundu et al, 2012, 2013), in which ICA is first used to detect signals in the data, and then the echo dependence profile of these signals is used to separate BOLD-like (e.g., task-related activity, intrinsic BOLD fluctuations) from non-BOLD-like (e.g. baseline variability, motion). Given the non-BOLD origin of the baseline shift in cardiac-gated imaging, ME-ICA should be successful at removing this artifact from the data.

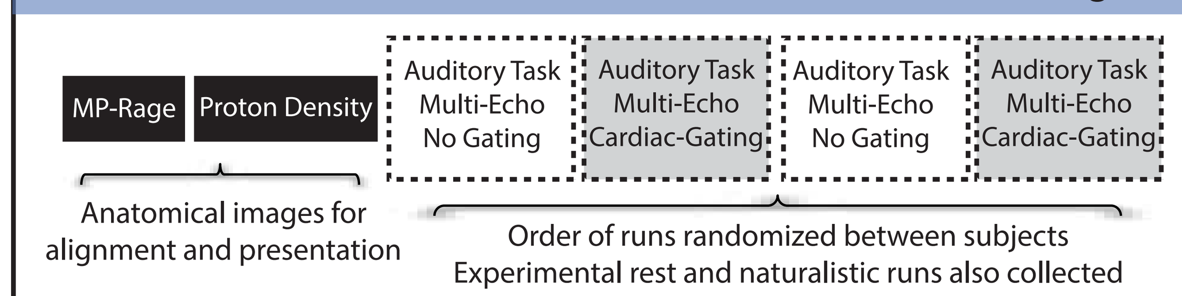


Echo Dependence Model for BOLD (right) and Non-BOLD (left) signals



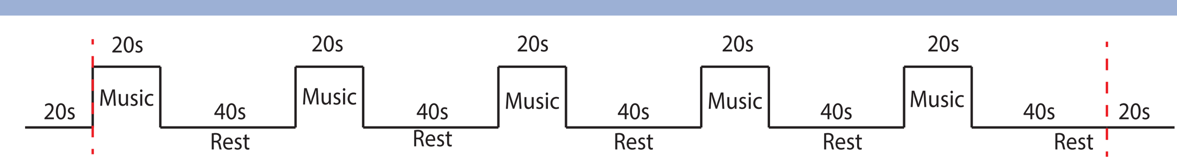
Components sorted by kappa (i.e., a statistic that captures how BOLD-like a component is).

DATA ACQUISITION



5 subjects, 3T GE Scanner, 32-Channel head coil.
3x3x3mm, #Slices = 33, FA = 60°, #Acquisitions = 136.
Multi-echo with TEs=13.9ms/31.7ms/49.5ms, nominal TR=2.5s.
2 runs were acquired with constant TR
&
2 runs were acquired with cardiac-gating.

EXPERIMENTAL PARADIGM



Subjects listened to the same 20s block of music 5 times, with 40s breaks in between.

PRE-PROCESSING PIPELINES/ANALYSES

H0 & H1 - Single Echo
Use only the middle echo
Pre-processing: Discard 10s, slice-time correction, head motion estimation, transformation to MRI, spatial smoothing.

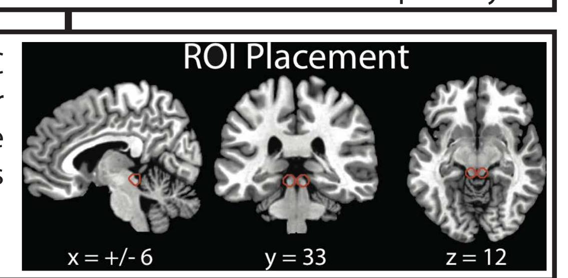
H2 - T1 Correction
Use only the middle echo
Model-driven T1-correction laid out in Guimaraes et al. (1998).
Same Pre-processing as H1

H3 & H4 - Optimal Combin.
Use all echoes
Same Pre-processing as H1
Optimal combination of echoes to maximize voxel-wise BOLD-contrast (Posse, 1999)

H5 & H6 - ME-ICA Denoise
Use all echoes
Same Pre-processing as H1
ME-ICA denoising using methods previously described by Kundu et al. (2012)

Compute activation maps for Gated and Non-Gated data separately.

For anatomically defined IC ROIs, we compute the number of active voxels, and the average T-stat for the different analysis pipelines.



RESULTS

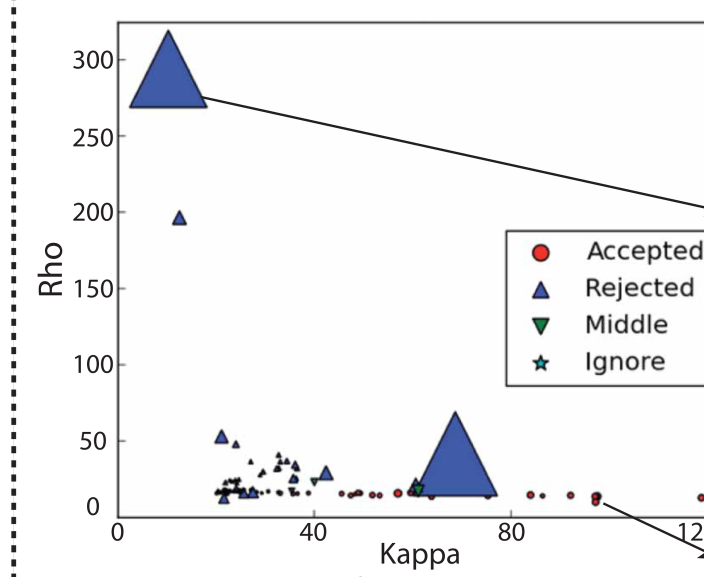
HYPOTHESIS / EXPERIMENTAL QUESITONS

	Type of Data		
	No Gating	Gating	Gating + T1Correction
Single Echo	**"Standard fMRI" Baseline (H0)**	*Hypothesis 1 (H1):* Below Baseline ↓	*Hypothesis 2 (H2):* Above Baseline ↑
Optimally Combined	*Hypothesis 3 (H3):* Above Baseline ↑	*Hypothesis 4 (H4):* Below Baseline ↓	
ME-ICA Denoised	*Hypothesis 5 (H5):* Well Above Baseline ↑↑	*Hypothesis 6 (H6):* Best Activation Detection ↑↑↑	

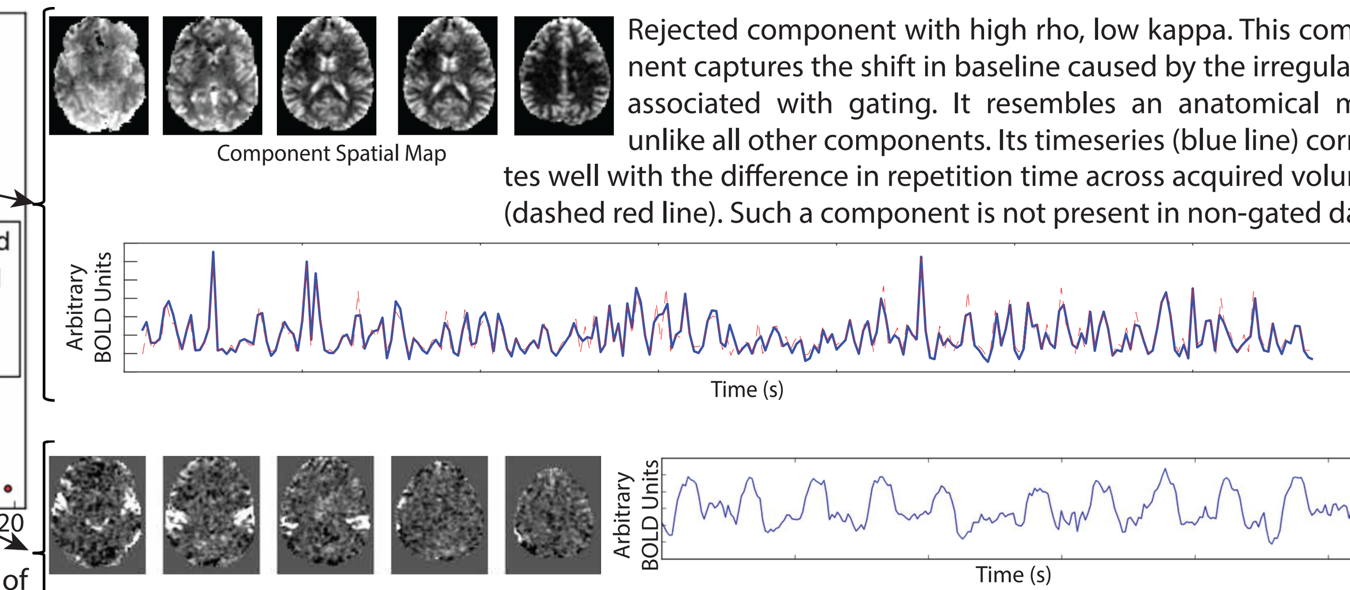
(1) Can gated fMRI combined with ME-ICA provide supieror detection of activity at the single-run/single-subject level in a region heavily affected by pulsatile motion?

(2) Can ME-ICA detect and reliably remove artifactual fluctuations in baseline signal levels associated with non-constant repetition time?

ME-ICA DENOISING



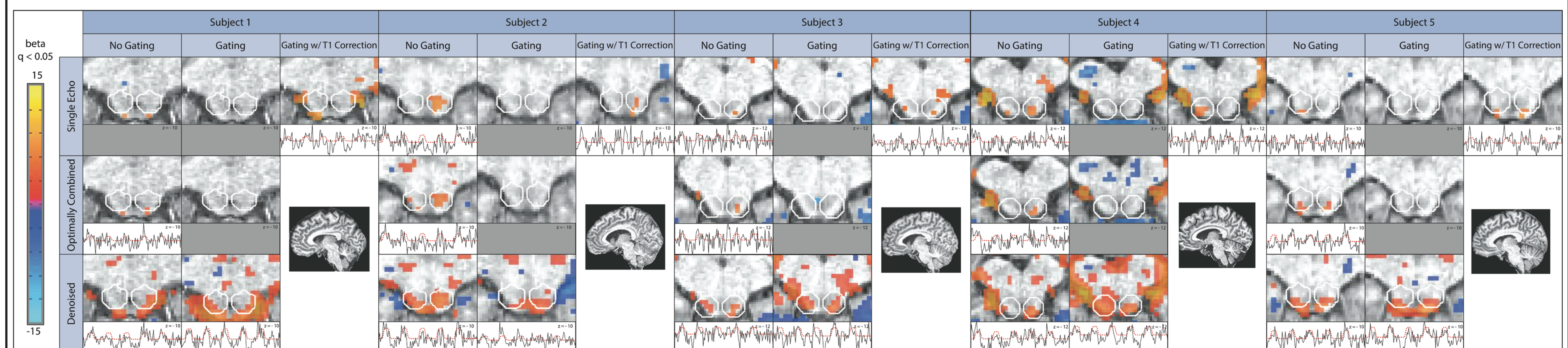
Kappa vs. Rho spectrum for the ICA decomposition of the gated data for one representative subject. Details about two components of interest on the right.



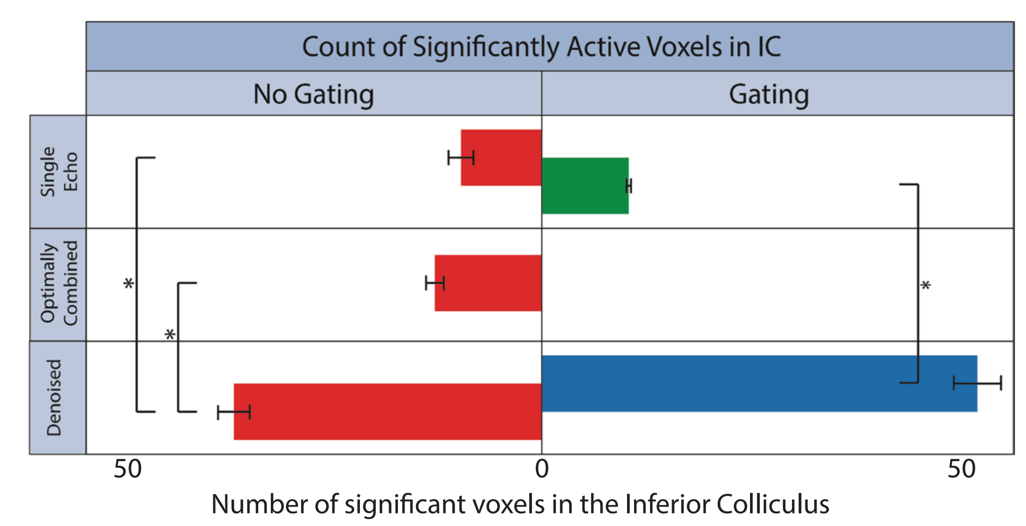
Rejected component with high rho, low kappa. This component captures the shift in baseline caused by the irregular TR associated with gating. It resembles an anatomical map, unlike all other components. Its timeseries (blue line) correlates well with the difference in repetition time across acquired volumes (dashed red line). Such a component is not present in non-gated data.

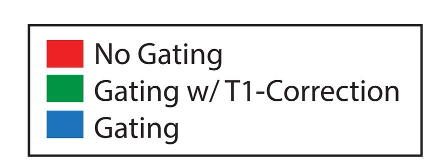
Accepted component with high kappa and low rho. Its timeseries corresponds to the task block design. Its spatial map includes regions such as the primary auditory cortex and the inferior colliculus.

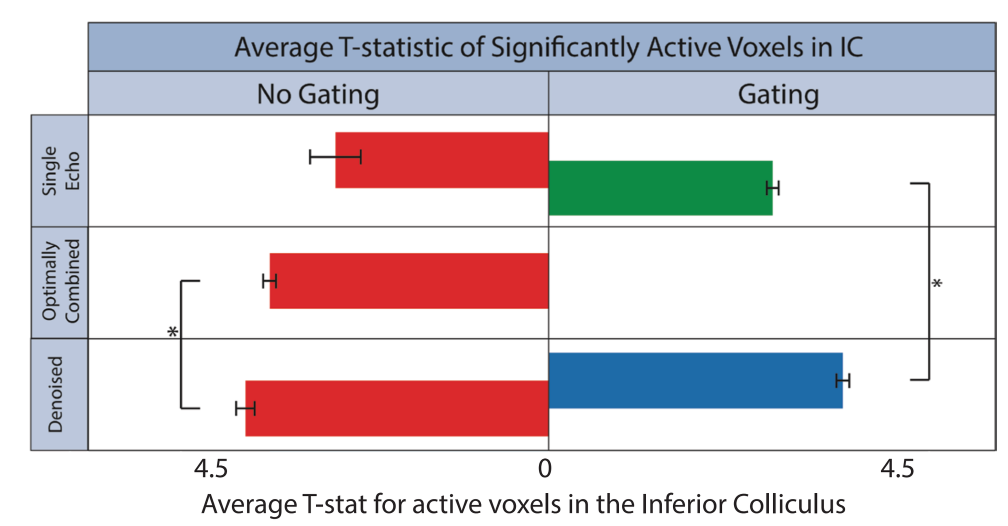
ACTIVATION MAPS



The results for each subject's 7 analysis inputs are shown, with statistical maps and average timeseries of significantly active voxels. Activation maps correspond to a threshold of $p_{FDR} < 0.05$. The anatomical image to the left of each subject's data shows a saggital view of where the IC ROI was placed in that subject. In the first row is the single echo data, with the non-gated, gated, and gated with T1-correction results. Generally, the gated case performs worse than the non-gated case, as predicted. Additionally, when the T1-Correction is applied to the gated data, we recover some of the activation that is never present on gated data without any correction. In the second row, the results for the non-gated and gated optimally combined data are shown. The non-gated OC cases appear to perform better than the non-gated single echo cases, as expected. There is still no significant activation in the OC gated cases, also as expected. In the thrid row, there is improved activation in both the non-gated and gated denoised cases in all subjects. It appears that the denoised gated data shows superior activation to the non-gated denoised data. Additionally, the average timeseries of the denoised data in both cases better tracks of the model of the task timing convolved with the expected hymodynamic response.







Across-subjects average of significant voxels in the IC for the different analyses. Significant differences (p<0.05) are denoted with an *. For gated data, in the single echo and optimally cobined cases, there are no significant voxels in any subjects. No significant difference was found in the number of active voxels between single-echo Gated+T1Correction and single-echo Non-Gated data. ME-ICA lead to a significantly larger number of active voxels than any other analysis for both Gated and Non-Gated data. No significant difference was found between Gated and Non-Gated analysis with ME-ICA.

Across subject average T-statistic value for significant voxels in the IC for all analyses. Significant differences (p<0.05) are denoted with an *. For both Gated and Non-Gated data, ME-ICA outperformed the results obtained for the Optimally Combined or T1-Correction methods respectively. There was no significant difference between the average T-statistic value for the denoised data in the gated and non-gated cases.

CONCLUSIONS

(1) T1-corrected gated data performed as well or better than non-gated single echo data, and permitted recovery of otherwise non-significant activation in the gated single echo data. This is in agreement with the original report by Guimaraes et al. (1998)

(2) ME-ICA improved detection of activaty in the IC for all subjects irrespective of gating.

(3) ME-ICA was able to reliably detect and remove baseline signal fluctuations due the non-constant TR associated with cardiac-gated acquisitions.

(4) ICA components associated with non-constant TR resemble anatomical maps. Evaluation of the potential value of these "*T1-like*" maps requires further investigation.

REFERENCES

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