

Improving BOLD sensitivity with real-time multi-echo echo-planar imaging - Towards a cleaner neurofeedback signal

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Improving BOLD sensitivity with real-time multi-echo echo-planar imaging

Towards a cleaner neurofeedback signal

S. Heunis^{1,2}, R. Lamerichs^{1,2,3}, G. Song¹, S. Zinger¹, B. Aldenkamp^{1,2}

1. Real-time fMRI and neurofeedback quality

Real-time fMRI suffers from known issues related to T_2^* -weighted single-echo echo-planar imaging (EPI). These include image dropout in areas with increased local magnetic susceptibility gradients¹; suboptimal whole-brain BOLD contrast due to average T_2^* -weighting²; and confounders like subject motion and physiology³. During fMRI neurofeedback a metric calculated from real-time brain activity is presented visually to the subject in the scanner⁴. To prevent sham feedback, new methods should focus on improving BOLD signal quality in real-time.

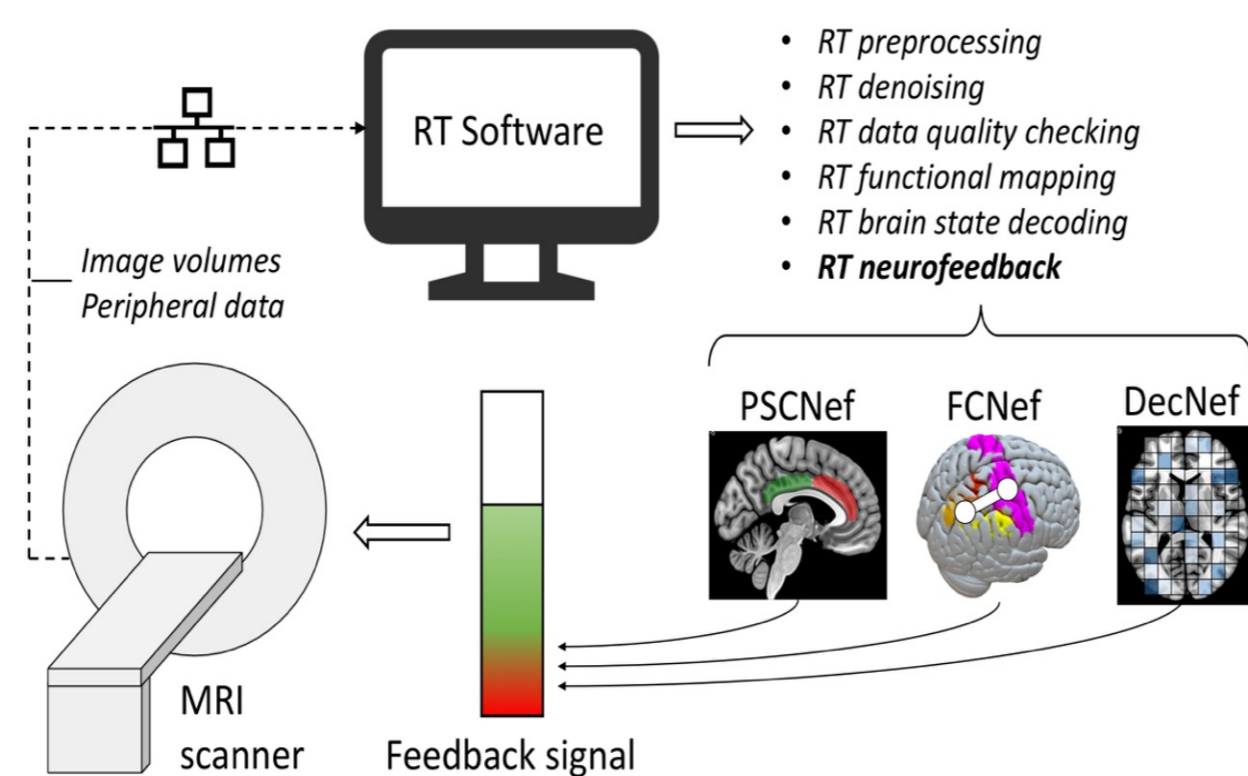


Fig. 1 - Real-time fMRI neurofeedback (image adapted⁴)

2. Multi-echo combination

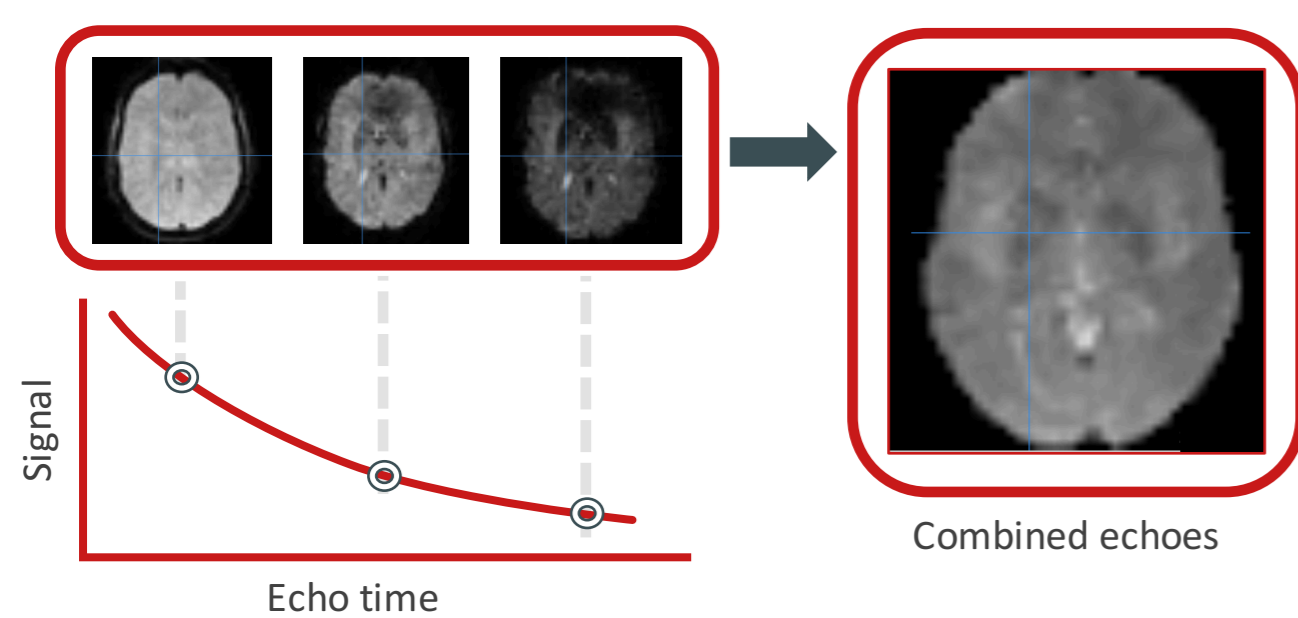


Fig. 2 - Multi-echo combination

Efforts to reduce noise have extended to multi-echo EPI (ME-EPI)⁵, which allows the estimation of brain-wide magnetic relaxation parameters (T_2^* , S_0) according to the standard decay equation⁶. Multiple echoes can be combined using various weighting schemes to increase BOLD sensitivity and decrease dropout^{6,7} (Fig. 2). This work investigates its use in real-time fMRI.

3. Methods, Data and Code

We introduce a novel real-time multi-echo fMRI processing pipeline. To quantify potential improvements, we investigate the influence of 3 real-time multi-echo combination schemes⁷ on resulting time series temporal signal-to-noise ratio (tSNR).

- pre-calculated $tSNR$ -weighted combination;
- pre-estimated T_2^* -weighted combination;
- real-time estimated T_2^* -weighted combination.

Data - We used publicly available data from OpenNeuro⁸. A single resting state multi-echo fMRI run (scan time 10m06s) was collected for 31 subjects.

Preprocessing - Data were preprocessed to ensure anatomical/functional alignment. $tSNR$ maps were calculated per echo time series and T_2^* maps were estimated from the temporal average of all echoes, using log-linear regression of the standard decay equation. These $tSNR$ and T_2^* maps provided the weighting combination schemes (i) and (ii) above.

Real-time processing - Using the newly developed real-time ME-EPI processing pipeline all echoes were realigned, followed by per-time-point estimation of T_2^* and S_0 maps and real-time combination using methods (i), (ii) and (iii).

All processing was done with MATLAB 2016b and SPM12. Code is available on Github for reproducibility purposes⁹

4. Results Figures 3 and 4 show brain slice montages of group-averaged $tSNR$ and percentage difference in $tSNR$, respectively. These data were used to fit the probability density curves and box plots (termed raincloud plots¹⁰) displayed in Figures 5 and 6. Fig. 3 A, B and C indicate that combination leads to a brain-wide increase in $tSNR$ (typically ~50-100%) for all 3 methods, although both pre- T_2^* and pre- $tSNR$ show particularly large increases (~200-250%) in the medial temporal regions. Figures 5 and 6 support this through increases in peak values of the combined data vs echo 2.

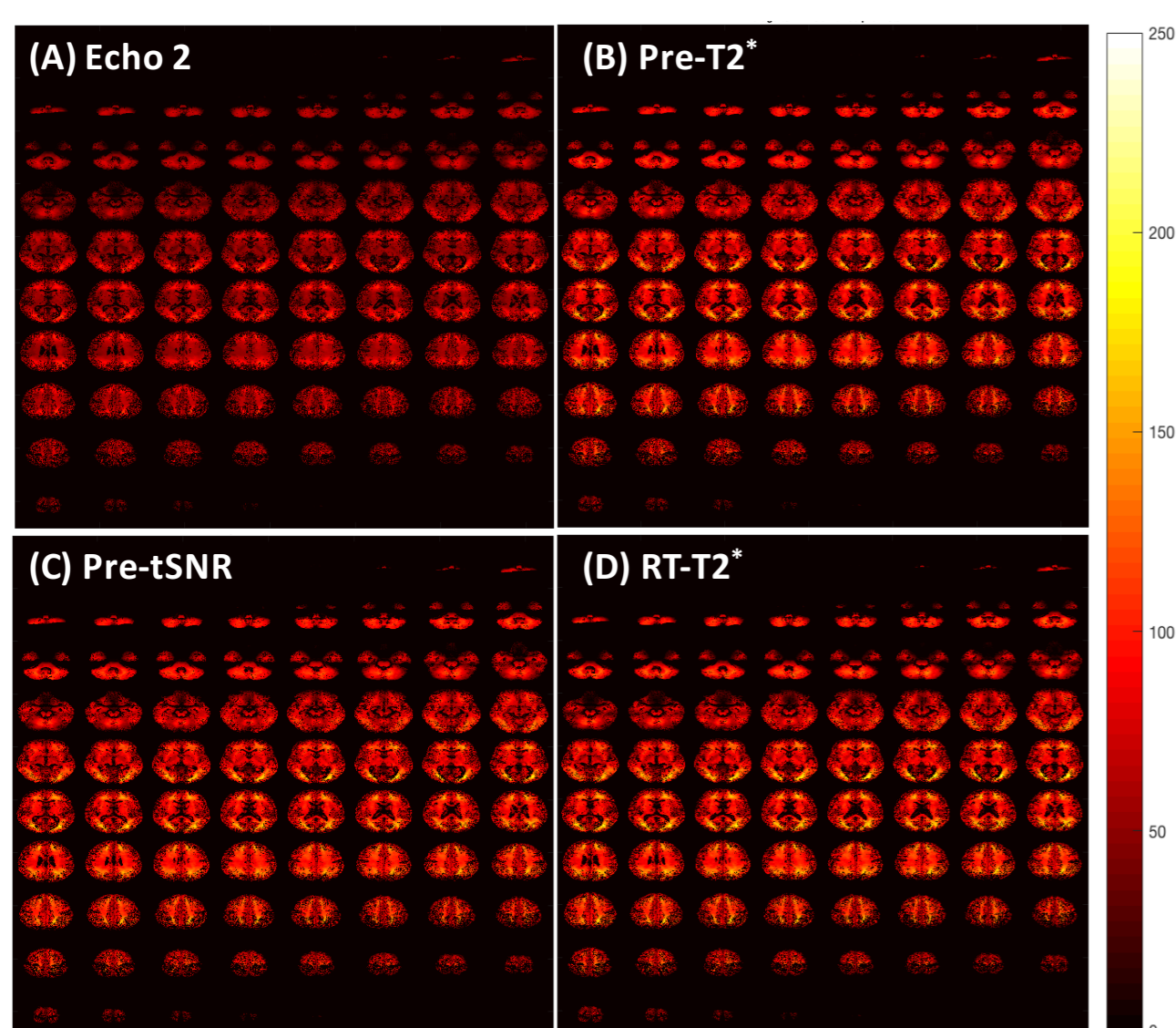


Fig. 3 - Montage of group averaged $tSNR$ maps for echo 2 and the three combination methods

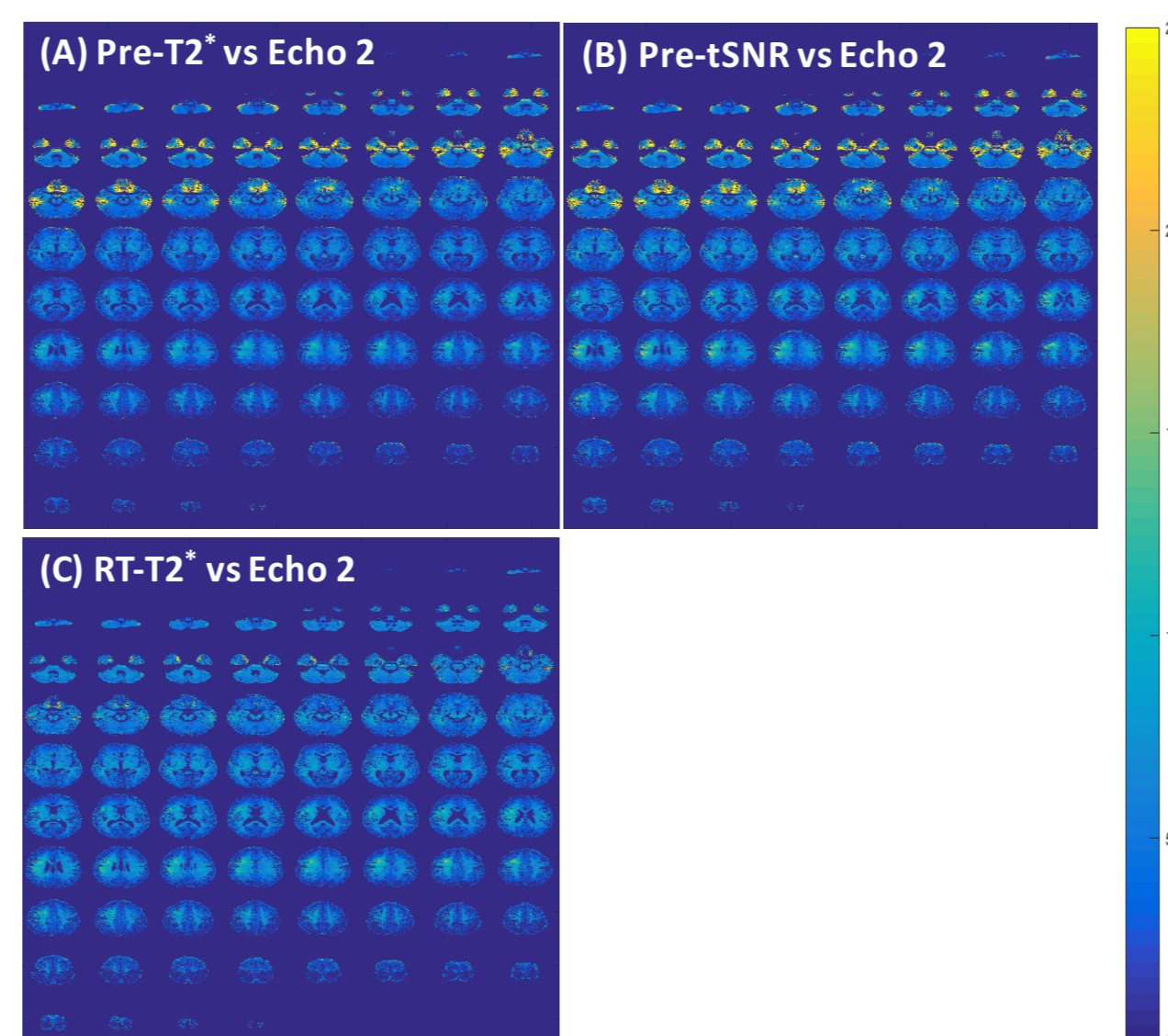


Fig. 4 - Montage of group averaged percentage difference maps of the three combination methods vs echo 2.

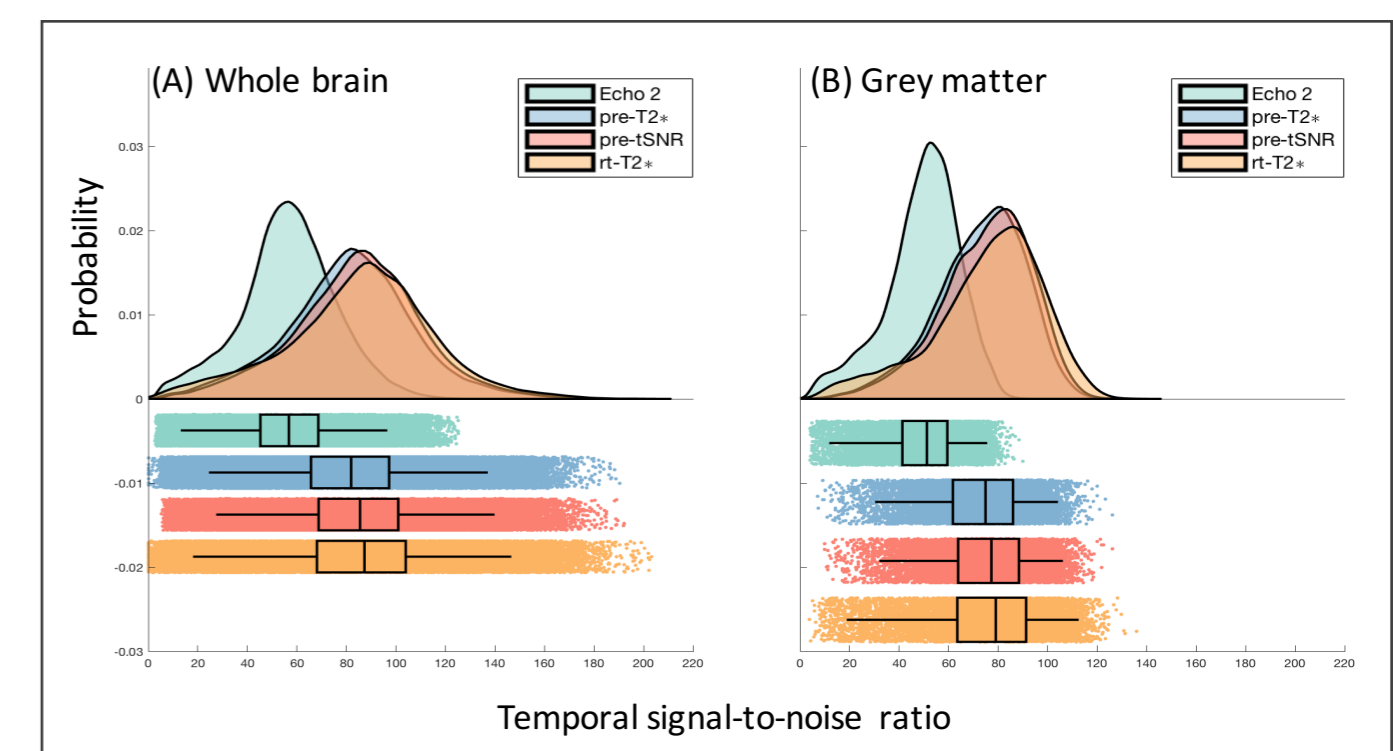


Fig. 5 - Raincloud plots fit to the group averaged $tSNR$ maps (from Fig 3) for echo 2 and all combination methods.

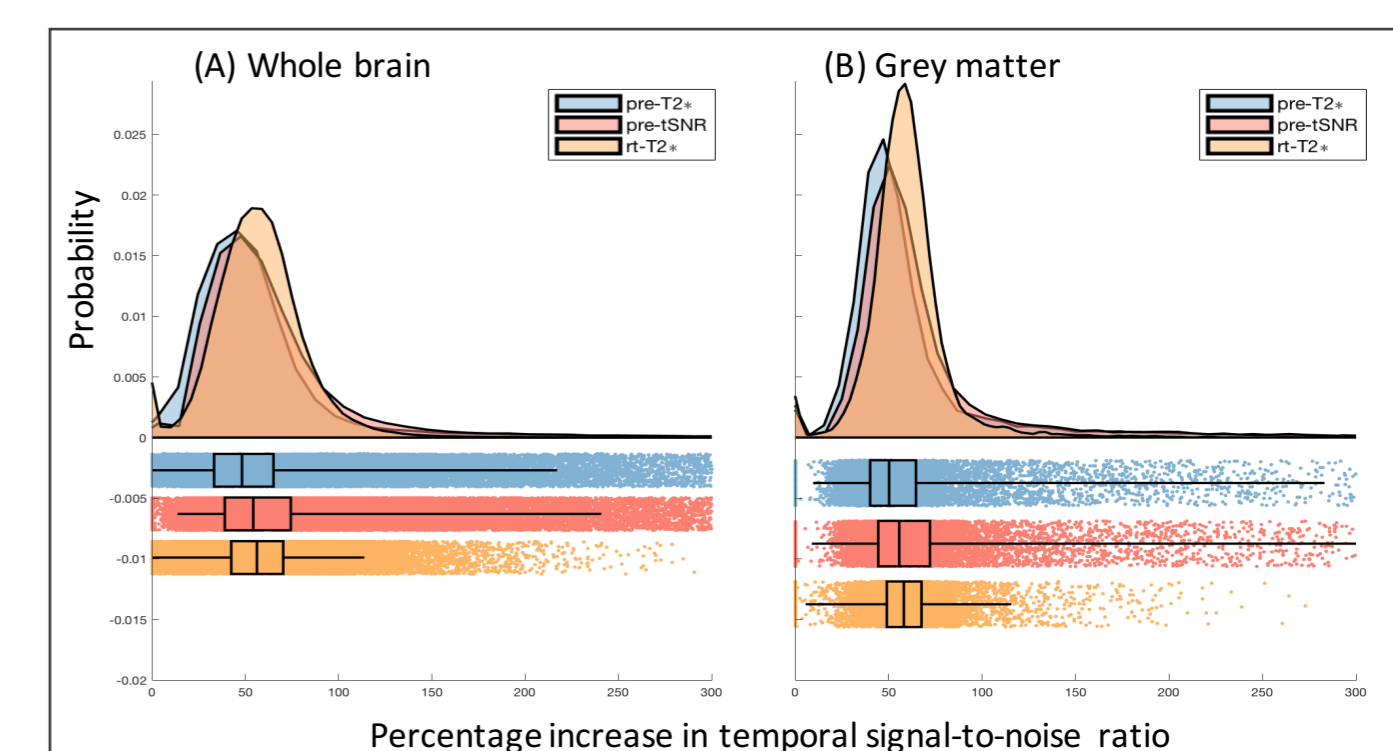


Fig. 6 - Raincloud plots fit to the group averaged percentage difference maps (from Fig 4) all combination methods vs echo 2

5. Discussion

- Real-time multi-echo fMRI combination substantially increases whole brain and grey matter $tSNR$, irrespective of the real-time combination method.
- 3 factors influence the selection of a real-time combination method: (i) availability of prior data, (ii) region of interest and (iii) required processing time.
- Availability of prior data allows pre-real-time estimation of T_2^* and $tSNR$. These methods generate weighted multi-echo combination yielding overall $tSNR$ improvement and decreased signal dropout in medial temporal regions. This could be especially useful for studies focusing on amygdala neurofeedback.

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