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

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

Towards a cleaner neurofeedback signal

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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 gradients[1]; suboptimal whole-brain BOLD contrast due to average T_2*-weighting[2]; and confounders like subject motion and physiology[3]. During fMRI neurofeedback a metric calculated from real-time brain activity is presented visually to the subject in the scanner[4]. **To prevent sham feedback, new methods should focus on improving BOLD signal quality in real-time.**

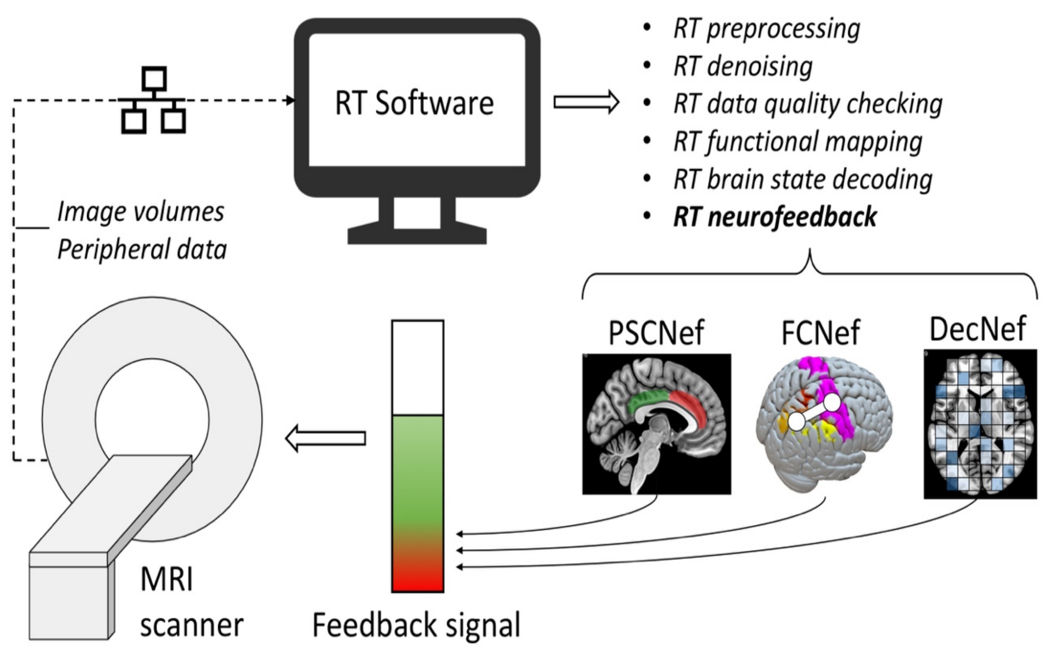

Fig. 1 – Real-time fMRI neurofeedback (image adapted[4])

2. Multi-echo combination

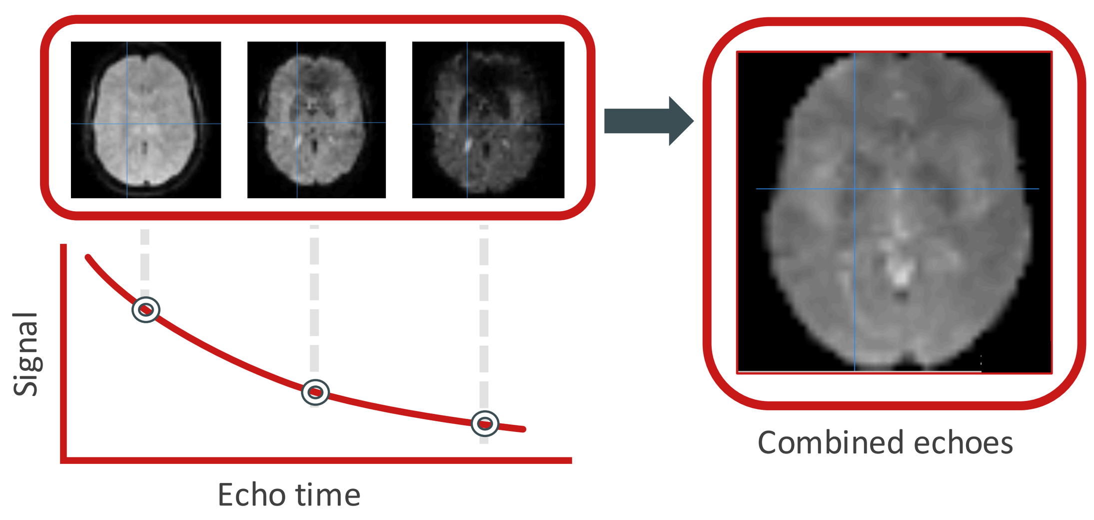

Fig. 2 – Multi-echo combination

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 equation[6]. **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 schemes[7] on resulting time series temporal signal-to-noise ratio (tSNR).

(i) pre-calculated tSNR-weighted combination;
(ii) pre-estimated T_2*-weighted combination;
(iii) real-time estimated T_2*-weighted combination.

Data - We used publicly available data from OpenNeuro[8]. 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 purposes[9]

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 plots[10]) 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.

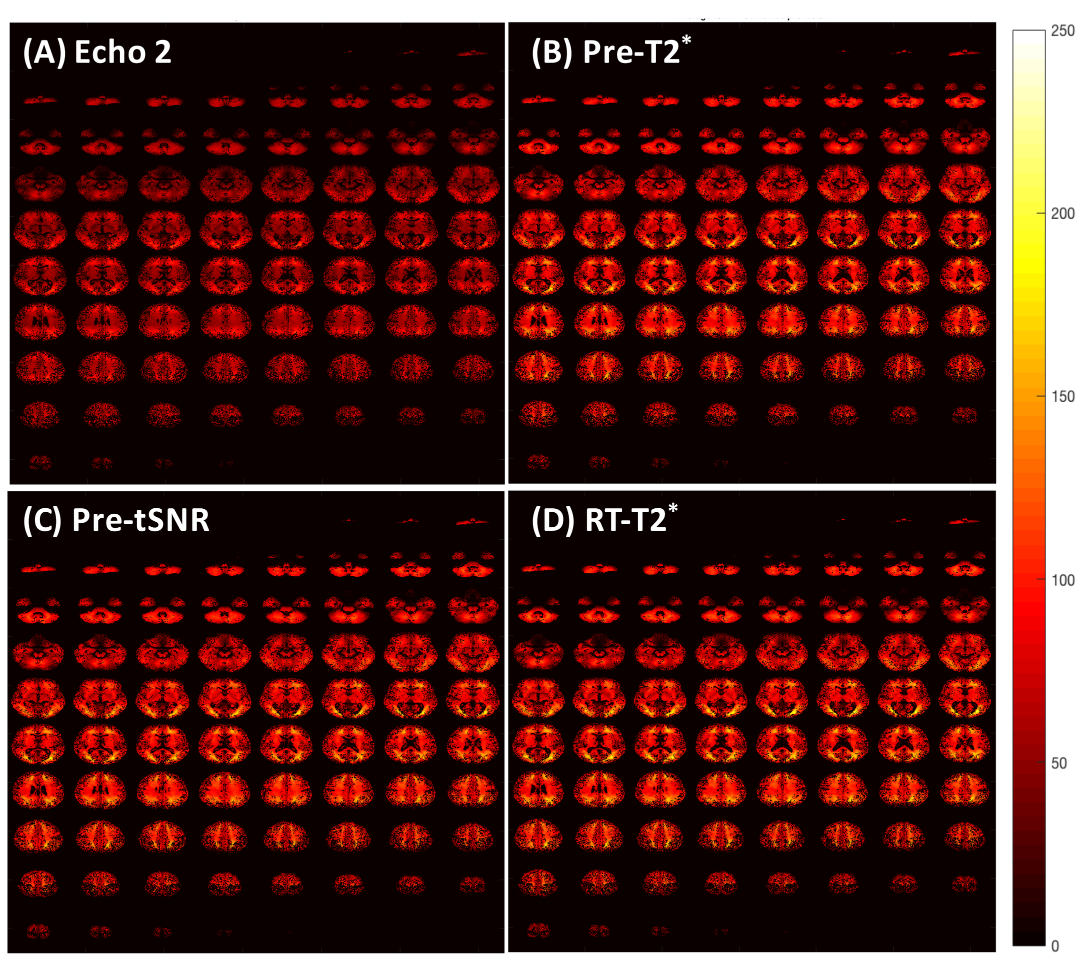

Fig. 3 – Montage of group averaged tSNR maps for echo 2 and the three combination methods

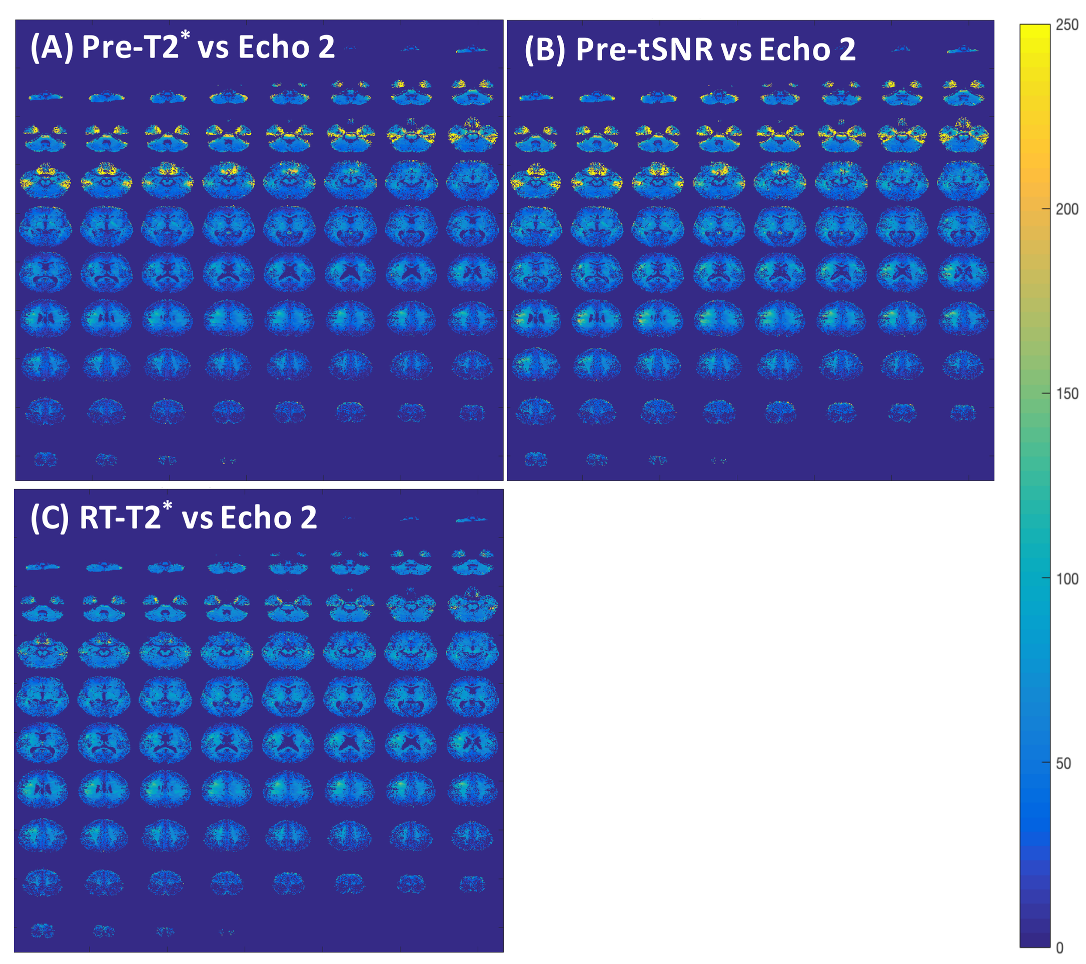

Fig. 4 – Montage of group averaged percentage difference maps of the three combination methods vs echo 2.

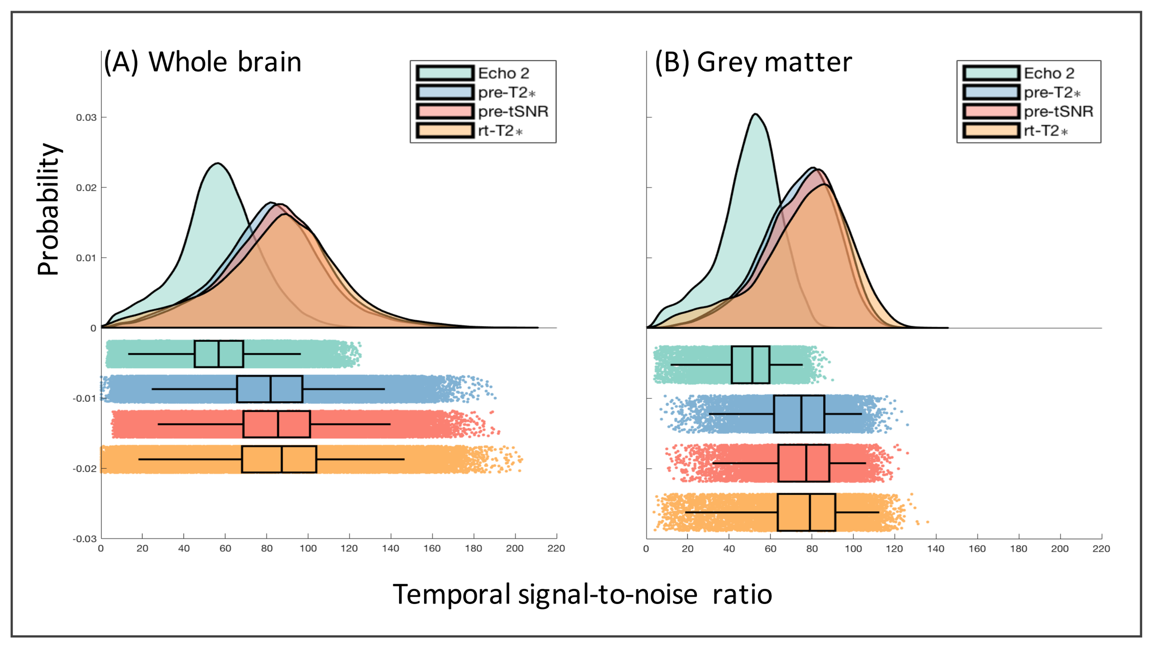

Fig. 5 – Raincloud plots fit to the group averaged tSNR maps (from Fig 3) for echo 2 and all combination methods.

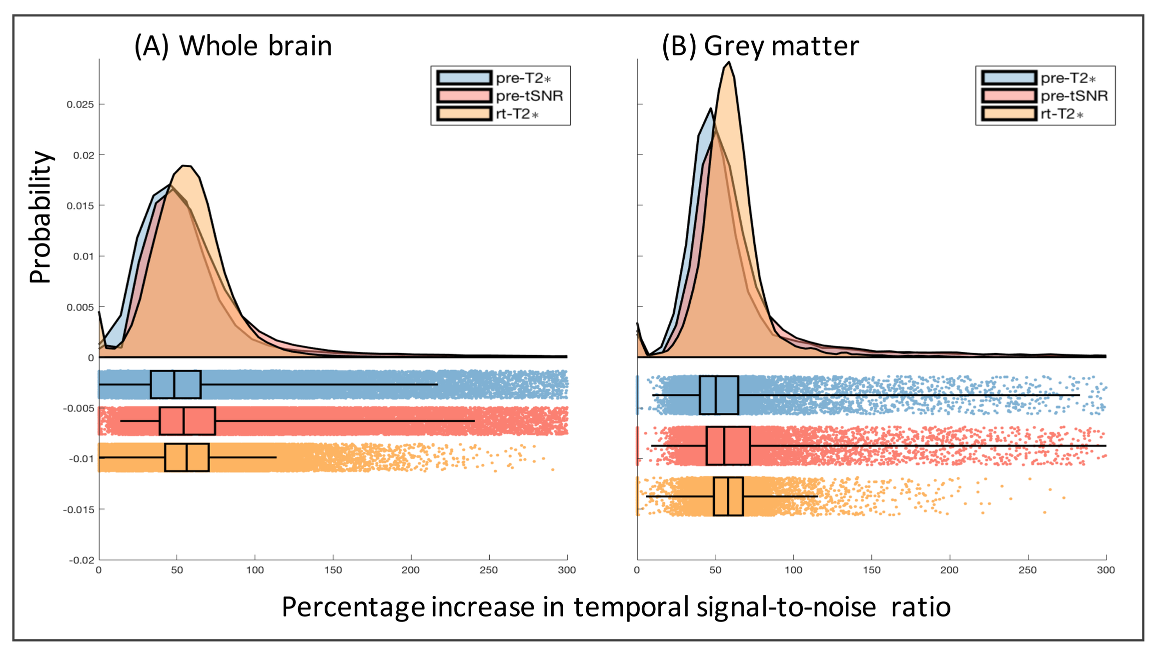

Fig. 6 – – Raincloud plots fit to the group averaged percentage difference maps (from Fig 4) all combination methods vs echo 2

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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