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\(^2\), suboptimal whole-brain BOLD contrast due to average $T_2^*$-weighting\(^3\), and confounders like subject motion and physiology\(^4\). During fMRI neurofeedback a metric calculated from real-time brain activity is presented visually to the subject in the scanner\(^5\). To prevent sham feedback, new methods should focus on improving BOLD signal quality in real-time.

2. Multi-echo combination

Efforts to reduce noise have extended to multi-echo EPI (ME-EPI)\(^6\), which allows the estimation of brain-wide magnetic relaxation parameters ($T_1$, $T_2$, $S_0$) according to the standard decay equation\(^7\). Multiple echoes can be combined using various weighting schemes to increase BOLD sensitivity and decrease dropout\(^8\) (Fig. 2). This work investigates its use in real-time fMRI.

**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\(^9\)) displayed in Figures 5 and 6.**

3. Methods, Data and Code

We introduce a novel real-time multi-echo fMRI processing pipeline. To quantify scanner improvements, we investigate the influence of 3 real-time multi-echo combination schemes\(^10\) 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\(^6\). 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 $T_1$, $T_2$ 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\(^6\).

6. References


*A available online: https://github.com/heunis/fmri

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