A multi-echo approach to removing task-correlated motion artefacts in fMRI

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Introduction

In fMRI, subject motion can severely affect data quality, decreasing the sensitivity to detect activation. This is a particular problem when movement is locked to the experimental paradigm as this potentially causes artefactual activation. Several approaches have been investigated to mitigate this effect (1-4). Here, results from a multi-echo approach aimed at reducing the spurious activation caused by task-correlated motion are presented. This method uses the signal time course from a very early echo in which BOLD contrast is still negligible, but I_0 fluctuations are present as a voxel-wise regressor of no interest for a later echo that is sensitive to BOLD. By doing this, it is possible to dissociate task-locked motion artefacts from true activation. In addition, the combination with the commonly employed method of including motion estimates as covariates of no interest in a general linear model (GLM) analysis is investigated.

Methods

8 subjects were scanned at 1.5 T (Siemens Sonata, TR 3050 ms, 31 slices, voxel size $3.5mm^3$). Visual activation was elicited using a reversing checkerboard pattern (14 repeats of 21s) separated by 30s of baseline (B). Subjects were instructed to slightly nod their heads on every other visual stimulation block as indicated by an arrow pointing up or down (conditions V – just visual stimulus and VM – visual stimulus + motion). 2 echoes were recorded at TE=14 (E1) and 60ms (E2). Data was motion-corrected using MCFLIRT and baseline drifts were removed. To assess the value of the early echo (E1) time course as a covariate of no interest in reducing motion-induced artefacts, the second echo (E2) time course was corrected on a voxel-by-voxel basis using the General Linear Model (GLM): $E2corr = E2 - X\beta$, where E2 is the observed second echo signal, E2corr is the corrected second echo signal (the residuals), X is the matrix containing the regressors and β is the corresponding weight vector. Three correction types are considered, in which X contains, besides a constant term and the drift regressors, 1) the E1 time course (E1); 2) the estimated motion parameters (MP); and 3) both (E1+MP). Additionally, corrected datasets were obtained using spatially in-plane smoothed E1 data (E1_5mm and E1_10mm) to check the hypothesis that this might reduce the local effect of using E1 and increase its similarity to the global effect of MP. To further investigate the different information in E1 and the motion parameters, the data was corrected using only the through-plane motion parameters, both separately and in combination with E1 (MPtp and E1+MPtp respectively). Statistical analysis was performed on the uncorrected E2 (the reference data set) and the different corrected data sets (two-tailed t test, $p<5\cdot10^{-6}$). The correction efficiency was assessed by comparing the number of activated voxels and max/mean t values in activation (ACT) and motion (MOT) ROIs (defined as the significant voxels resulting from t tests of V vs. B and VM vs. B minus V vs. B respectively) across correction types.

Results

Table 1 shows results of the correction averaged over all subjects. When using E1 as regressor, the number of spuriously activated voxels decreases by about 50%. The true activation shows an increase with respect to the uncorrected data, however the inter-subject variability is quite high. Figure 1 shows an (extreme) case where using E1 significantly reduces motion artefacts in the time course both in an activated region as outside, whereas using MP has little effect. The inclusion of motion parameters leads to a strong decrease in the spurious activation of about 80%, but also has a negative effect on the true activation. Although not statistically significant, the combination of E1 and MP gives a intermediate result for the true activation and has the lowest number of false positives. Spatially smoothing E1 does not substantially alter the correction although it adds to the inter-subject variability. Finally, the combination of E1 with only the through-plane motion parameters results in a considerable reduction of spurious activation compared to being applied separately.

Discussion

This method shows promise in removing motion-induced artefactual activation, even when motion is correlated to the task. Combining E1 with the motion parameters as covariate of no interest seems beneficial for the sensitivity to detect true activation. Although the correction effects are similar there is different information in E1 and MP, which is substantiated by the lack of change in correction effect when E1 is smoothed. This and the additive effect of E1 and the through-plane motion parameters on the spurious activation suggest partially different mechanisms behind the correction. Limitations of the method include possible failure in regions of strong through-plane dephasing and an increase of temporal noise. The method can also easily be combined with a multi-echo acquisition strategy (5) to increase sensitivity.

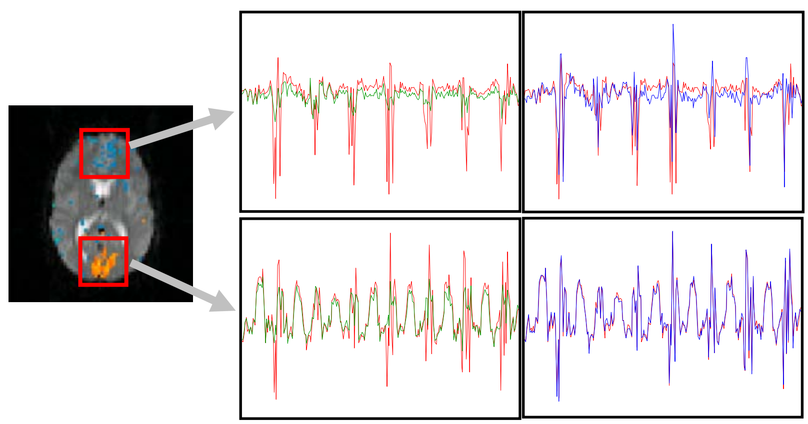

Fig. 2. Average time courses in ACT (lower) and MOT (upper) ROIs before and after correction. Red = uncorrected, green = E1, blue = MP.

References

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		E1	MP	MPtp	E1+MPtp	E1+MP	E1_5mm	E1_10mm
ACT	# significant voxels	1.19 ± 0.70	0.79 ± 0.24	0.85 ± 0.17	0.93 ± 0.48	0.83 ± 0.42	1.21 ± 0.92	1.17 ± 0.94
	mean t score	1.04 ± 0.39	0.90 ± 0.16	0.92 ± 0.15	0.93 ± 0.36	0.88 ± 0.31	1.02 ± 0.51	0.99 ± 0.55
MOT	# significant voxels	0.47 ± 0.13	0.18 ± 0.23	0.29 ± 0.26	0.13 ± 0.11	0.09 ± 0.10	0.40 ± 0.15	0.40 ± 0.17
	mean t score	0.64 ± 0.15	0.56 ± 0.19	0.62 ± 0.25	0.41 ± 0.20	0.38 ± 0.17	0.53 ± 0.19	0.48 ± 0.20

Table 1. Average correction result in ACT and MOT ROIs for the different correction types. All values normalized with respect to E1