A new, highly effective slicewise motion correction for BOLD MRI: SLOMOCO

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Target Audience/Purpose: fMRI/connectivity researchers. To solve head motion corruption.

Introduction:

Head motion is a big unsolved problem for BOLD fMRI and rs-fMRI. Today, motion correction and characterization methods are incomplete due to the volumetric assumption[1-5], as well as other issues. In-scanner head motion is faster than most volume acquisitions[5] so this assumption is unrealistic. This is a major reason why current methods don't robustly identify and correct motion corruption. Secondorder motion correction (MOCO2) can be effective[1,2], but has variable performance because the regressors are also volumetric. It has been shown that the majority of motion artifact could be removed using model-based regression if the motion parameters were known for every slice[4].

We have developed a completely retrospective algorithm for obtaining slicewise motion estimators, SLice-Oriented MOtion COrrection (SLOMOCO, Fig 1) that picks up all 6DOF slice motions. With motion-injection BOLD data in cadavers, we show SLOMOCO accurately represents truth (injected) motion for performing a highly effective slicewise correction. We show the image temporal stddev (tSTD) is reduced equivalently to the reduction when using the truth motion parameters, and over 40% greater reduction compared to current most popular MOCO2 methods. And finally, we show SLOMOCO on rs-fMRI data. We also show that typical MOCO2s using volumetric models[1] are only half as effective as those using a voxel-specific model[2], but this is rarely used in practice.

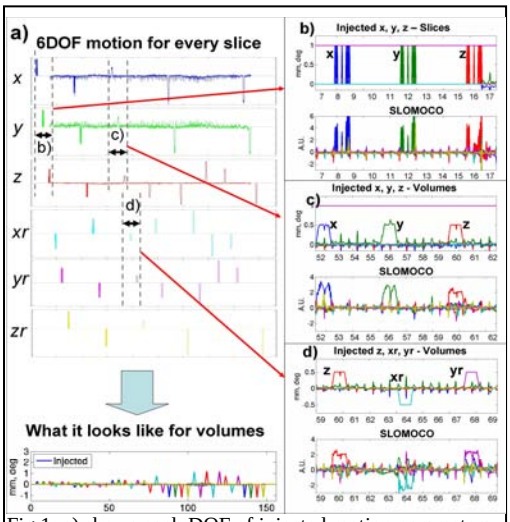

Fig 1: a) shows each DOF of injected motion parameters, and at bottom, what these DOF look like with a volumetric correction. b-d) show zooms on the slicewise injected motion above and SLOMOCO below. b) shows in particular 1mm motions (8 slices of vols 8, 12 and 16 were injected with 1mm x-trans, y-trans and z-trans respectively), c/d) show volumetric injections on later volumes. **SLOMOCO retrospectively detects 6DOF slicewise motion, which no other tool can do.**

Methods:

SimPACE[4] BOLD data was collected in 7 cadavers and 3 live subjects. Induced motion was abrupt instantaneous slice-wise (realistic) or volumetric motion (unrealistic) from 0.5, 1 and 1.5mm/degree in each of the 6 DOF, separated by 4 volumes (Fig 1a, note below is the collapsed result of volumetric registration, colors=same DOF as separated above). SimPACE generates accurate motion corrupted data with known motion corruption.

SLOMOCO consists of in-plane slicewise motion correction (in this case, for x-trans, y-trans, z-rotation). Then, on the in-plane corrected data, we perform volumetric registration but with all slices replaced with non-moving mean image data, except for the slice of interest, repeated for all other slices. This doesn't work in the traditional sense, in that the parameters are incorrect and the resultant reslicing is incorrect (partly due to scaling by the portion of the volume represented and slice location). However, the timecourse is highly accurate in shape to the true motion parameters. The timecourses are then used in a MOCO2 on the in-plane corrected data. The MOCO2 model is modified to incorporate adjacent slice timeseries information (SLC)[4]. For comparison, the raw data was also corrected with various literature motion corrections, including volume registration (VOL)[3], MOCO2 with volumetric model (FRS)[1], MOCO2 with voxel-specific model (BUL)[2], and MOCO2 with the injected motion parameters and the slicewise regression model(GLD-SLC)[4]. The histogram peak tSTD was computed for each corrected dataset.

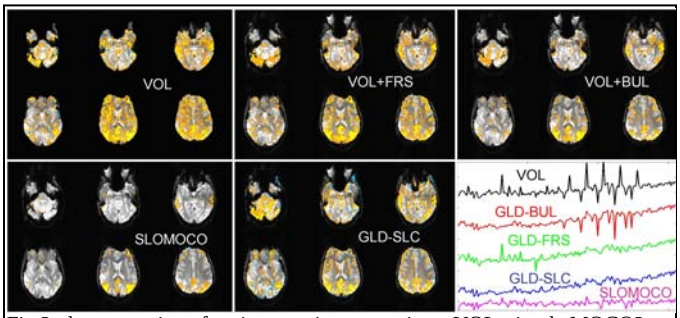

Fig 2: demonstration of various motion corrections: VOL, simple MOCO2 (VOL+FRS), more complex MOCO2 (VOL+BUL) and SLOMOCO

DOF	Linear Correlation
x-translation	0.7019 ± 0.1541
y-translation	0.7043 ± 0.147
z-translation	0.8641 ± 0.0172
x-rotation	0.7969 ± 0.0306
y-rotation	0.7795 ± 0.0466
z-rotation	0.7977 ± 0.0786

Table 1: Linear correlation between SLOMOCO and GLD, for each DOF.

Peak tSTD	Cadaver Data	Live Subjects
Raw	20.98 ± 5.98	19.62 ± 3.56
VOL	17.25 ± 3.95	15.96 ± 1.99
FRS_GLD	14.68 ± 3.22	14.17 ± 3.07
BUL_GLD	11.57 ± 2.13	12.77 ± 2.14
SLC_GLD	10.89 ± 2.28	12.18 ± 1.85
BUL_SLOMOCO	11.23 ± 2.06	11.06 ± 0.54
SLC_SLOMOCO	11.68 ± 1.96	10.9 ± 0.57

Table 2: tSTD histogram peak vs correction. Cadavers best tSTD seen using known motion in model, in live subjects best with SLOMOCO due to additional motion

Results: SLOMOCO parameters proved highly accurate to the temporal shape of the true motion (Table 1). The tSTD showed that SLOMOCO out-performs all existing methods (Table 2), and even outperformed using the known motion in the model in live subjects, presumably due to real head motion in addition to the injected. The images in Fig 2 show the improvement over the best (rarely used) BUL model, and greater improvement over the less efficacious (but easy) FRS volumetric model, and surprisingly better performance than GLD-SLC, which was not seen in cadavers and thus is likely due to additional real subject motion in live subjects. We recommend that users use the BUL model or SLOMOCO to correct their data.

Conclusions:

We have demonstrated, for the first time, a novel slicewise motion correction and validated with motion-injection data. Future work will focus on validating with a more realistic range of injected motion and improving the algorithm's robustness, in particular the use of adjacent slices and iterative fitting to data to improve the estimates.

References:

1) Friston, KJ et al, MRM 1996; 35:346-355., 2) Bullmore, ET et al, HBM 1999; 7:38-48., 3) Cox, RW et al, MRM 1999; 42:1014–1018., 4) Beall, EB and Lowe, MJ, "BOLD motion injection shows total correction possible with accurate parameters and parameterization", OHBM.