The effects of slice-timing and the use of registration parameters as covariates in the analysis of fMRI experiments exhibiting either task-correlated motion or residual motion from image-based motion tracking.

S. Gobets[1], J-H. Seppenwoolde[1], S. Koudijs[1], J. Pluim[1], and M. J. van Osch[2]

[1]Image Science Institute, University Medical Center Utrecht, Utrecht, Netherlands, [2]Department of Radiology, Leiden University Medical Center, Leiden, Netherlands

Introduction – Subject motion is one of the principal confounding factors in fMRI. In particular, motion correlated to the activation pattern is a major source of corruption of activation maps. Such motion is common in patients with specific neurological impairments, such as hemiparesis, stroke, or brain tumors. These motion problems can be dealt with prospectively (during the acquisition) and retrospectively (during post-processing). Several prospective motion correction procedures have been proposed, using either navigator echoes[1], image-based tracking[2], or optical motion tracking[3]. The application of these prospective methods is still far from common practice, but image-based tracking is most easily implemented, since it does not require the special hardware of optical tracking, nor does it disturb the spin system with navigator echoes. Even if prospective motion correction is applied, post-processing remains an essential part of the analysis. The standard post-processing step is the (rigid) registration of images to a reference image. Slice timing, the correction for differences in acquisition time between slices within one volume is another common post-processing step. Slice timing can be performed before, or after registration, or can be left out. When data is substantially affected by motion the registration parameters may be included in the General Linear Model as covariates of no interest[4]. Here we present a comparative study of the effects of slice-timing and the use of registration parameters as covariates upon the quality of the inferred activation maps for data sets with one of two task-correlated motion patterns, which differ in amplitude, and a motion pattern reflecting the residual motion remaining after image-based tracking.

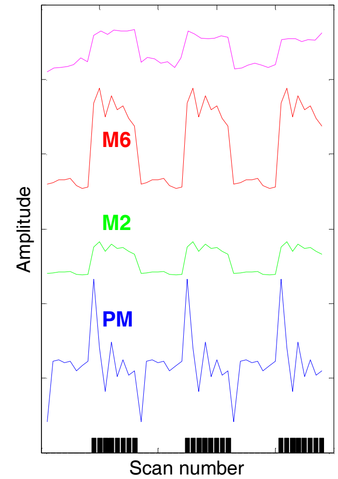

Fig 1. Investigated motion patterns: Task correlated motion with amplitude 6mm (red) and 2mm (green), motion pattern remaining after prospective motion correction (blue). Registration parameters of patient data (purple) are included for comparison. Active blocks in black.

Methods -.Eight right-handed healthy volunteers, (29-36 years old) were subjected to multiple scan series, while performing a block-design task protocol consisting of making a fist of the right hand and releasing it, repeating this every 2s during the task blocks. The subjects were well restrained and task-correlated motion artifacts were induced by planning a slightly different volume for each scan according to precisely defined motion parameters (see ref. 5 for details). For each scan series (condition) one of four motion patterns was applied: M6 (task-correlated motion with an amplitude of 6 mm/degrees), M2 (the same as M6 but 2 mm/degrees amplitude), NM (no motion), or PM (simulated prospective motion correction residual motion pattern, derivative of M6) (see figure 1). Translation was in FH-, and rotation in AP-direction. For each condition 160 FEEPI scans were performed. Task- and rest blocks consisted of 8 scans each. Subjects were scanned using a 3T Philips Achieva MRI scanner scanning 16 interleaved slices per volume and using a TR/TE/voxel size of 2.5s/35ms/3.125x3.125x3.5 mm^3. The data were registered and analyzed using SPM2. Registration/slice-timing was performed in three different ways: registration first (RF), slice-timing first (SF), and registration only (RO) (no slice-timing). Analysis was performed both with (-R) and without using the registration parameters as covariates[4], thus resulting in six post-processing schemes: RF, SF, RO, RF-R, SF-R, and RO-R, Activation maps were thresholded at p=0.05 (family wise error). The resulting activation maps were evaluated in terms of their maximum t-value (tmax) and, using the activation map for NM as a reference: the cross-correlation (CC) with the reference map, the fraction of true positives (tpos) found (relative to reference), and the fraction of false positives (fpos) found (relative to the total number of active voxels).

Results and discussion – The results are displayed in Table 1, and are discussed by condition. *-NM-* This condition serves as a reference, but was repeated twice to assess the reproducibility of the reference. For NM tmax is highest (~30) without the use of the registration parameters as covariates. Neither CC (~78%), nor tpos (~57%) or fpos (~32%) depends strongly on the type of analysis. Note that these numbers differ significantly from the optimal values (100%, 100% and 0% respectively). The numbers for NM provide an upper (for tmax, CC and tpos) and lower limit (for fpos) for what may maximally be attained *with* motion. *–M6* - Tmax does not depend too strongly on the analysis type, although RF, RO-R, and RR-F perform best with a value of 16. CC is best for RF (27%), which coincides with the lowest fpos (74%). tpos is best for RO-R (26%), but this comes with a higher value of fpos (84%). For condition M6 post-processing schemes RF seems to be the best choice. *-M2-* Similar to condition TN, tmax is higher without the use of additional regressors. Also tmax is higher as compared to condition M6 (23 for RO and RF). CC is by far the best for SF-R (39%), and corresponds to the lowest fpos. This does not correspond to the best value of tpos, which occurs for RF-R, but comes with a much higher value of fpos. For condition M2 SF-R seems to be the best choice. The difference between the optimal post-processing schemes for M2 and M6 may be due to the fact that for M2 motion is restricted to partially into and out of the adjacent slice. Since M6 motion extents further than that, slice-timing may not be as effective as for M2, and result in distortions that may not be repaired by using the registration parameters as covariates. *-PM-* Surprisingly the results are pretty similar to those for M6, the motion pattern that PM is supposed to be improving on. However, this may be understood as follows: for M6 the motion discontinuity occurring at the beginning and end of each task-block, is only severely affecting one scan by spin history effects[6] (the one immediately after the discontinuity). For motion pattern TP, however, both the 1st and 2nd scan after the beginning of the block are affected due to the back-and-forth movement pattern.

Conclusions – For large task-correlated subject motion (in the order of the slice-thickness, M6, PM) the best results were obtained by performing registration before slice-timing, without using the registration parameters as covariates. For smaller task-correlated motion(< slice-thickness, M2) slice-timing correction performed before registration, combined with the use of registration parameters as covariates yielded the best results. Remarkable is the observation that the image-based tracking motion pattern did not perform better than the data without tracking, which, for the specific task-correlated motion patterns applied, can be attributed to increased spin-history effects as compared to none-tracking data. Finally, one of the major problems with task-correlated motion remains the large fraction of false positives.

References

1) C.C. Lee et al. *MRM* 39 (1998) 234-243.
2) S. Thesen et al. *MRM* 44 (2000) 457-465.
3) O. Speck et al. *Magn.Reson.Mater.Phy.*19 (2006) 55-61.
4) T. Johnstone et al. *HBM* 27 (2006) 779-788.
5) S. Gobets et al. *Proc. ISMRM* 14 (2006)
6) K.J.Friston et al. *MRM* 35 (1996) 346-355.

	Maximum (tmax)						Cross-Correlation (CC in %)						True Positive Fraction (tpos in %)						False Positive Fraction (fpos in %)					
	RO	RF	SF	RO-R	RF-R	SF-R	RO	RF	SF	RO-R	RF-R	SF-R	RO	RF	SF	RO-R	RF-R	SF-R	RO	RF	SF	RO-R	RF-R	SF-R
NM	**30**	**31**	**30**	23	24	24	**79**	**79**	**79**	77	77	77	57	57	57	58	57	55	33	32	32	33	31	29
M6	15	**16**	14	**16**	**16**	13	**25**	**27**	18	25	25	25	15	14	12	**26**	**25**	20	77	**75**	84	84	82	76
M2	**23**	**23**	**20**	20	19	16	23	**25**	26	26	26	**39**	**48**	**50**	37	**51**	**50**	36	94	94	90	93	93	**74**
PM	15	15	13	**18**	16	**17**	26	**29**	21	27	27	21	28	28	14	**42**	**35**	28	87	85	84	90	86	84

Table 1: The average values (over subjects) of the maximum, cross-correlation, true- and false-positive fractions for each motion condition (vertical) as a function of post processing scheme (horizontal). Post-processing schemes were also scored on a scale from 0 to 1 by their average ranking as method for each subject (for tmax, cc, and tpos higher values are considered better, for fpos lower values). Methods that scored higher than 0.6 were considered better than average, and **are indicated in bold**. The conditions with underlined numbers scored highest. Note that the methods with the highest score are not always better than average, and also do not necessarily correspond to the highest average value. Green cells correspond to the preferred method for that motion pattern (see text)