Evaluating the effect of task-correlated subject motion in fMRI experiments upon the inferred BOLD activation maps

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Introduction - Functional MRI experiments are frequently used to study brain function in patients with specific neurological impairments such as hemiparesis, stroke or brain tumors. During an fMRI scan such patients often show significantly more motion as compared to healthy individuals. Moreover, this motion may be strongly correlated to the task blocks of the experiment, especially if the experiment involves a motor task. Such motion may have a strong effect upon the inferred BOLD activation maps. Here we present a novel approach to investigate the effects of such motion upon the accuracy of fMRI studies. Motion in fMRI is frequently simulated by constructing mathematical phantom datasets by adding motion, activation, and noise to a single image *in silico*[1)]. Instead, in our approach, a real fMRI experiment is conducted during which the entire planned stack of slices (SOS) is moved slightly between scans according to precisely defined motion parameters. This experiment is performed on a healthy, well restrained volunteer who is subjected to the same clinical task protocol as the patient. By comparing the activation map obtained with the moving SOS to that of a standard fMRI experiment, performed in the same session, the effect of (task correlated) motion can be studied. Advantages of our *in vivo* approach over the *in silico* approach are: 1) Scan-to-scan spin-history effects are included 2) Real BOLD response 3) No interpolation artifacts in the data 4) Real natural variation (noise) 5) Realistic golden standard is provided by the standard fMRI scan of the healthy subject. We propose that for any fMRI study in which patient disorder related motion is an issue, the effect of this motion upon the inferred BOLD activation maps could retrospectively be studied using our approach. The registration parameters of the patient data could, for instance, provide the motion parameters for the SOS. In our institute strong task-correlated motion has been observed in an fMRI study performed to locate motor activity in hemiparetic children. Here we apply the proposed moving SOS approach to investigate the effect of such motion upon the accuracy of this fMRI study.

Methods - Three right-handed healthy volunteers, 29-36 years old, performed a block design task protocol identical to that of the hemiparesis patients, which consisted of making a fist of the right hand and releasing it, repeating this every 2s during the task blocks. The subjects were scanned under 3 different conditions 1) subject performing the protocol during a standard fMRI experiment, 2) subject performing the protocol while the SOS was slightly translated/rotated between scans according to specific motion parameters (fig. 1, blue line), 3) subject at rest, while the SOS moved as for the second condition. During each condition 160 FEEPI scans were performed. Task- and rest blocks consisted of 8 scans each. Subjects were scanned using a 1.5 T (n=1) or a 3 T (n=2) Philips Achieva MRI scanner with 16 slices and TR/TE/voxel size of 3s/46ms/3.6x3.6x4mm^3 and 2.5s/35ms/3.125x3.125x3.5 mm^3, respectively. The data were registered and analyzed using SPM2, both with and without using the registration parameters as additional regressors[2)].

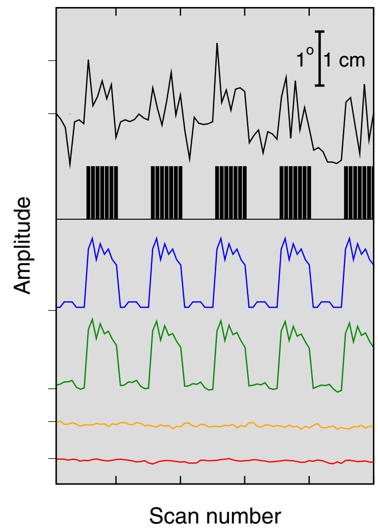

Fig 1. *Registration parameters of patient data (black), block design (blocks), scanner motion parameter (blue), registration parameters for the healthy subject in moving SOS data (green), difference blue and green (orange), registration parameters of a healthy subject in a standard fMRI experiment.*

Results and discussion - The black line in fig. 1 displays one of the registration parameters of an fMRI dataset for a child with hemiparesis. The motion is clearly correlated with the block design depicted underneath. Not only do the registration parameters clearly follow the block design (type I motion), but also the variance in motion parameters is clearly larger during the task block due to the repetitive nature of the task (type II motion). The blue line in fig. 1 depicts the parameters according to which the SOS was translated and rotated in our experiments. This pattern was designed to contain both type I and type II motion. The amplitude of the motion was about 1.2 mm, or degrees. A typical example of the registration parameters for the subject performing the task with a moving SOS is depicted by the green line in fig 1. These registration parameters follow the SOS motion remarkably well, as is corroborated by the orange line reflecting the difference between the two. This difference is very comparable to the registration parameters of the standard fMRI data, without SOS motion (red line). In each subject, motor activation was clearly visible, and appeared similar, both with, and without SOS motion. However, in the moving SOS data, both the size of the largest cluster of activated voxels, and the maximum t value in the activation map were generally reduced as compared to the data without SOS motion. Moreover, the relative number of active voxels located in small clusters, N_{small}, was much larger in the moving SOS data. These voxels are concentrated in the outer region, most likely due to the more prominent effect of the rotational motion at larger distances of the center of rotation. N_{small} was much larger at 3 T as compared to 1.5 T. This could be explained by the longer TR value used in the 1.5 T experiment and the lower T1 value of CSF at 1.5 T. The effect of using registration parameters as additional regressors varied: in one subject N_{small} decreased dramatically, both with and without a moving SOS. In the second subject, however, N_{small} increased for both conditions. In the third subject (scanned at 1.5 T) no effect was found for the static SOS data, while a decrease of N_{small} was observed for the moving SOS data. N_{small} in the data of a moving SOS without the subject performing the task did not correspond to N_{small} found in the data of a moving SOS with task. The use of registration parameters as additional regressors for these datasets resulted in a decrease of both the total number of active voxels and N_{small}. However, it also resulted in the appearance of larger clusters of active voxels.

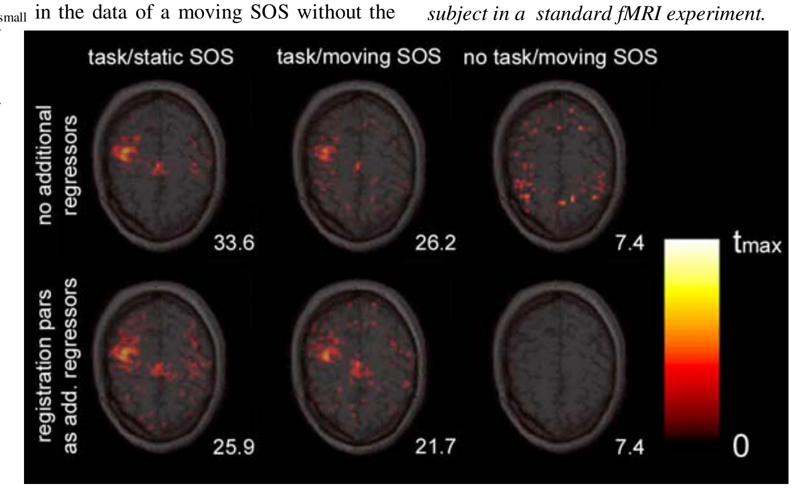

Fig 2. *Representative slice of a single subject performing (left to right) a block-design motor task with static SOS, performing this task with a moving SOS and performing no task with moving SOS. Top row: no additional regressors, Bottom row: registration parameters as additional regressors. Numbers indicate the maximum t-value found in each entire scan volume, to which the color-coding was scaled.*

Conclusions – We have proposed a novel approach to investigate the influence of motion on the outcome of fMRI experiments, and we have demonstrated this approach by investigating the effects of motion such as observed in a study of hemiparesis patients. It was found that, although the registration parameters suggest a near perfect registration, the activation maps are clearly affected by motion, mainly due to the increase of N_{small}. The motor activation, however, was clearly distinguishable in all cases. The effects of motion were significantly smaller in the 1.5 T experiment as compared to the 3T experiment. The use of registration parameters as additional regressors yielded somewhat unpredictable results for our data. Finally, our moving SOS approach may also prove to be a useful tool for the evaluation of different motion correction algorithms.

References

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