Head motion as a potential source of artifacts in fMRI of motor cortex: a comparative study of healthy volunteers and patients with space-occupying lesions of the brain.

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Pre-neurosurgical planning is among the most widely used clinical applications of functional MRI (fMRI), since fMRI allows to assess relative position of the eloquent cortex and mass lesion of the brain [1]. Therefore using fMRI in surgery planning leads to greater preservation of speech and motor functions and reduced postoperative disability in patients with space-occupying lesion of the brain. This is why reliability of fMRI data is so important. The most frequent cause of false negative results in fMRI is a head movement artifact that leads to a low signal-to-noise ratio (Fig. 1 on page 3). This problem exists for various functional tests, but according to the literature, motion artifacts arising from the motor tests are among the worst [2].

The purpose of this study was to compare efficiency of fMRI procedures localizing cortical representation of lower and upper extremities in both healthy volunteers and patients with mass lesion of the brain, and to investigate the relationship between the head motion parameters and the volume of activation in sensoriomotor cortex for two procedures.
**Fig. 1:** Head movement artifact. This figure shows the typical motion artifact from movements in the sagittal plane (up and down) that decreases signal-to-noise ratio and may cause false results (negative or positive).

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Methods and Materials

Study design and procedure

The study included two conditions: localizing cortical representations of upper and lower extremities. The first condition involved a finger-tapping task (participants opposed their thumb to all the other fingers) and the second involved a foot-tapping task. Participants performed tapping at their own comfortable pace within the range of one movement per 1-2 seconds. In either task, movements of the right and left limb alternated. Participants switched from movements of one limb to movements of another limb following the oral commands of the experimenter.

Six parameters of head motion and volume of activation within sensorimotor cortex (SMC) were measured as dependent variables and compared across patients and healthy controls. All patients (group 1) performed both a finger-tapping task and a foot-tapping task. Healthy volunteers performed either finger-tapping (group 2) or foot-tapping (group 3).

Imaging protocols for both procedures were identical. Block design was used. Each functional run lasted for approximately 7 minutes and consisted of 20 blocks lasting 21 sec each. Blocks of movement of the right and left limb alternated. 120 functional volumes were acquired during each run. One functional run was acquired in each healthy volunteer and one run of each task was acquired in each patient.

Participants

Research was carried out at the Radiology Center based on Federal Center of Medicine and Rehabilitation in Moscow. One group of 11 patients with space-occupying lesions of the brain (group 1) and two separate groups of 16 healthy right-handed volunteers (group 2 - hand-tapping and group 3 - foot-tapping) took part in the study. Group 2 (hand-tapping) included 8 women and 8 men, mean age 25 ± 5 years. Group 3 (foot-tapping) included 9 men, 7 women, mean age 26,5 ± 6,9 years. Patient group consisted of 6 men and 5 women, mean age 34,5±17 years.

Equipment and imaging parameters

Images were acquired using Siemens Magnetom Avanto 1.5T scanner. After a low-resolution survey scan, T1-weighted images were obtained for anatomical reference with MPRAGE sequence (TR/TE/FA 1900/2.9 /15, 176 sagittal slices, slice thickness 1
T2* weighted functional images were obtained with EPI sequence (TR 3560 ms, including 500 ms delay, TE 50 ms and FA 90°). Each functional image covered the whole brain and consisted of 36 slices, 3 mm thick with a gap of 0.75 mm, and in-plane resolution of 3.6 x 3.6 mm. Slices were oriented parallel to the line connecting anterior and posterior commissure (AC/PC plane). Homogeneity of the magnetic field (a fieldmap) was measured with a gradient echo sequence (GRE) and have the same slice prescription as the T2* images.

**Data analysis**

Data were analyzed using SPM.8. The analysis sequence included: reorientation of functional, structural and fieldmap images (in a way that the origin of coordinates was shifted to coincide with the anterior commissure); correction of motion artifacts and magnetic field inhomogeneities ("Realign&Unwarp"); spatial coregistration of functional and structural images; segmentation of structural images into white and grey matter volumes; spatial normalization of both functional and structural images; spatial smoothing of functional images; general linear model (head movement parameters were not included into design matrix since the effects of head motion and motion-by-susceptibility artifacts were already taken into account during "Realign&Unwarp" procedure); second-level group analysis using ANOVA with random-effects model.

Individual volume of SMC and cerebellum activation was measured at the threshold of p<0.05 (FWE corrected). Motor areas were considered as successfully localized if a cluster of 5 or more voxels was revealed within the appropriate candidate anatomical structure.

Six parameters of the head motion were estimated during "Realign&Unwarp" stage and further analyzed (Fig. 2 on page 7):

- translation along axis "x" (left-right),
- translation along axis "y" (forward-back),
- translation along axis "z" (up-down),
- rotation around the axis "x" (pitch),
- rotation around the axis "y" (roll),
- rotation around the axis "z" (yaw).

In the group analysis, each participant was represented by the mean value and standard deviation of each parameter (since 120 data points were collected for each parameter and each subject). Because of the consistent deviation from the normal distribution, between-group comparisons of motion parameters were based on nonparametric statistics (Mann-Whitney test). Chi-square statistics (\#²) was used to compare binary data on successful/
unsuccessful localization of motor areas. Correlation between head motion parameters and volume of activation in primary sensorimotor cortex (measured as number of clustered voxels above the statistical threshold) was analyzed with nonparametric Pearson's correlation coefficient. Between-group comparisons of volume of activation were performed with t-test.
**Fig. 2:** Head motion parameters measured from functional images.

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Results

Activation from finger and foot tapping tasks was revealed in the primary sensorimotor cortex (SMC) of the contralateral cerebral hemisphere and in the ipsilateral hemisphere of cerebellum (Fig. 3 on page 10). Activation in the SMC and cerebellum from finger tapping task was successfully revealed in all healthy volunteers (100%). The percentage of successful localization of main motor areas in the foot-tapping task was lower than that for the finger-tapping task: 81.25% for both SMC and cerebellum for the right foot, 87.5% for SMC and 68.75% for cerebellum for the left foot. This difference was statistically significant only for the activation in the cerebellum and only for the left limbs ($\chi^2=5.59$, p<0.02).

In patients with mass lesion of the brain the percentage of successful localization of motor cortex for finger tapping task was 90.9% for the right hand and 100% for the left hand. Activation in the cerebellum was found in 81.8% for the right hand and in 90.9% for the left hand.

For foot tapping, no primary sensorimotor cortex and cerebellum activation was found in four patients (36.4%). Thus, the percentage of successful localization of main motor areas for lower limbs was 63.6%. However, the difference from the finger tapping was statistically significant only for SMC activation and left limbs ($\chi^2=4.5$, p<0.05).

Analysis of six head motion parameters in healthy volunteers revealed significantly greater head motion (Mann-Whitney U= 60, n1=n2=16, p = 0.01) in subjects performing foot tapping (as compared with the subjects performing hand movements) along axis "z" (up-down), but not for other directions. However, no statistically significant differences were revealed by comparison of the six head motion parameters in patients performing the two motor tasks.

Comparative analysis of head motion parameters in healthy volunteers and patients has demonstrated statistically significant differences only for the finger-tapping task. Patients manifested significantly greater head translation than healthy volunteers along axis "x" (Mann-Whitney U= 14, n1=16, n2=11, p < 0.01), along axis "z" (Mann-Whitney U= 46, n1=16, n2=11, p = 0.038), and also greater pitch rotation (Mann-Whitney U= 38, n1=16, n2=11, p = 0.014) and yaw rotation (Mann-Whitney U= 28, n1=16, n2=11, p = 0.03).

At the same time we have found that volume of SMC activation was smaller in patients than that in healthy volunteers for foot-tapping (p=0.042) for right limbs (Fig. 4 on page 10), but not finger-tapping task (Fig. 5 on page 11).
Correlation between activation within SMC and head motion was found for the healthy volunteers both in group 2 and group 3. SMC activation volume significantly correlated with:

- translation along axis "y" for the left hand tapping (group 2; r= 0.525, p= 0.307);
- rotation around the axis "y" (roll) for the right foot tapping (group 3; r= -0.521, p=0.039).

A different pattern of correlation was obtained for patients (group 1). For foot tapping, no significant correlation was found between the volume of SMC activation and parameters of the head motion, while for the hand tapping there was a correlation of SMC activation volume with:

- translation along axis "z" for the right hand (group 1; r= -0.728, p=0.011);
- standard deviation of translation along axis "x" for both hands (group 1; r=-0.611, p=0.046 for the right hand; r= -0.663, p=0.026 for the left hand);
- standard deviation of yaw rotation for the left hand (group 1; r= -0.660, p=0.27).

Discussion.

Therefore, correlations of SMC activation volume and head motion parameters were not consistent: three out of four data subsets (group 1 finger tapping, group 2, group 3) demonstrated their own specific list of motion parameters correlated with the volume of SMC activation. None of these subsets also replicated the list of motion parameters differentiating patients and healthy subjects. More than that, no motion parameters correlated with the volume of SMC activation were found for the data from patients performing foot tapping. Also patients didn't differ significantly from healthy controls in terms of head motion parameters in foot-tapping task. This result may be considered as evidence against the assumption that relatively poor localization of the cortical representations of lower limbs in patients originate from excessive head motion. Increasing of the patient sample group may further clarify this issue.
Fig. 3: Activation in primary sensorimotor cortex (SMC) in patients: A - Patient H., female, 31 y.o., glioblastoma in the left frontotemporal area, activation from finger-tapping task, B - Patient K., male, 33 y.o., glioblastoma in the right frontal lobe, activation from foot-tapping task, R - right hemisphere; L - left hemisphere, SMC - primary sensorimotor cortex, T - mass lesion of the brain.

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**Fig. 4:** Activation in primary sensorimotor cortex (SMC) in healthy volunteers (4A) and patients (4B) performing foot-tapping task. R - right hemisphere; L - left hemisphere, SMC - primary sensorimotor cortex.

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**Fig. 5:** Typical activation in primary sensorimotor cortex (SMC) obtained from hand movements in healthy volunteers (5A) and patients (5B). R - right hemisphere; L - left hemisphere, SMC - primary sensorimotor cortex, T - mass lesion of the brain.

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Conclusion

When compared to healthy volunteers, patients with space-occupying lesions of the brain show greater head motion in finger-tapping fMRI test and lower volume of brain activation within sensorimotor cortex in foot-tapping task.

Correlations of the volume of sensorimotor cortex activation and head motion parameters were not consistent across groups of participants and tasks.

Taken all the results into account, the decreased volume of SMC activation in patients cannot be accounted for primarily by excessive head motion.
References

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