Gradient non-linearity correction relocates normalised group activation hotspot

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Introduction

Gradient coils in MR scanners are assumed to produce linear magnetic field gradients, however high-speed gradients show nonlinear characteristics as a trade-off[1]. This fact creates structural deformations in MR images during reconstruction, as the gradients are assumed to be linear. A correction for these structural deformations has been shown to be imperative in multi-site structural studies, this issue has to our knowledge not been taken into account when dealing with fMRI data. Accurate localisation of activation is important for instance in presurgical planning where the location of activation may determine where and where not to perform surgery. Here we show that using the known information of the how the gradient field are distorted, it is possible to reveal significant differences in activation localisation even in situations that are supposed to be unaffected by these distortions, in particular in group data results where EPI-times series are realigned, normalised and smoothed before group inference is made.

Methods

18 data sets from a previous study of motor mapping of voluntary and passive ankle movements were used [2]. Subjects were scanned in a Siemens Trio 3T magnetom with sonata gradients. TR=2.4s, TE=30ms, 3x3x3 mm voxels in 64x64 matrix and 42 slices in 350 volumes, using a PACE sequence to correct for movement during scanning. Data were preprocessed using SPM5[3]: data were converted from DICOM to nifti-format, realigned to the mean image, normalised using a standard EPI template in MNI space and the mean image of the time series and finally smoothed with 8 mm gaussian kernel. Additionally another data set was created where the images were unwarped prior to normalisation in order to correct for the gradient non-linearities (see theory below). In both cases a GLM was created for each dataset where the two types of movements were modelled as separate regressors. A one-way ANOVA was used for 2nd level random effects analysis, using the beta estimates from the single subject analysis. Sensorymotor region hot spot was used as location of activation and measure of deviation.

Theory

Images were processed using the methods described in [1], however the accompanying software was rewritten in order to correct non-structural scanning sequences, and to accommodate for the positional updates induced by the PACE movement correction. The correction relies upon precalculated displacements fields centered at the iso center of the bore. These displacement fields are calculated from a polynomial expansion of the magnetic field gradients produced by the gradient coil, which were provided by Siemens. The actual position of the head within the bore is written in the DICOM header of the images, however these do not include positional updates done by the PACE movement correction. The displacement of each voxel along each of the x,y,z-coordinates is therefore calculated using the displacement fields, together with the PACE movement parameters which were calculated retrospectively as the cumulative sum of the movement parameters from the realignment step of the preprocessing. The extra processing time for the entire series was a few minutes.

Results

Both sensorymotor hotspot regions near the central sulcus found in the voluntary and passive movement condition were shifted in more than 12 subjects (of 18) for the individual data (without (*) and with (o) correction on Fig1&2). For the group data analysis sensory motor hotspot was also shifted both for the voluntary and passive condition (without (●) and with (**o**) correction on Fig 1&2). There were significant differences in the activation maps when comparing the data with and without gradient unwarp correction (Fig 3 for voluntary movement and Fig 4 for passive movements).

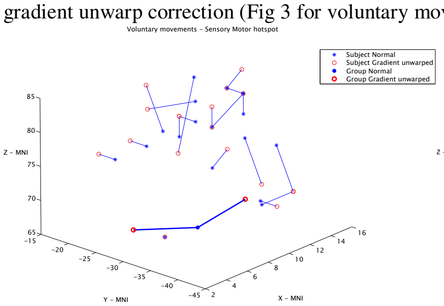

Fig 1: Location of sensory motor hotspot individual data (without (*) and with (o) correction and group data (without (●) and with (**o**) correction) for voluntary movements.

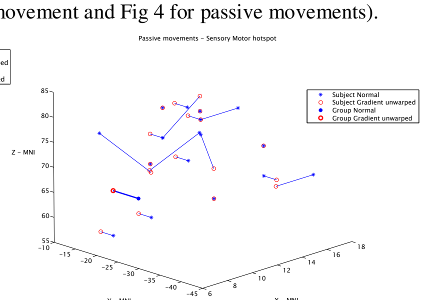

Fig 2: Location of sensory motor hotspot individual data (without (*) and with (o) correction and group data (without (●) and with (**o**) correction) for passive movements

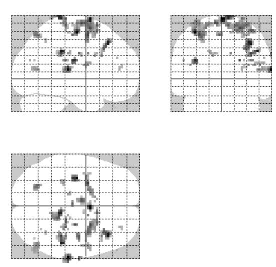

Fig 3: Regions were activation maps were different for vol. move. when comparing with and without grad. unwarp (FDR, p<0.05).

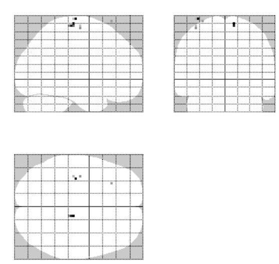

Fig 4: Regions were activation maps were different for passive movements when comparing with and without grad. unwarp (FDR, p<0.05).

Discussion

We have used standard preprocessing procedures which normally would be applied in fMRI studies that considers group activation studies. In our study the localisation of activation is shifted significantly when corrected for gradient non-linearities, and this shift is dependent on the task as there is tendency towards larger displacement for the voluntary movements where subject head movements also were larger.

Conclusion

These results suggest that correction for gradient non-linearities even in 'best' case scenarios, where data is spatially normalised and smoothed, shifts localisation of functional activation. Thus results reported in MNI coordinates depends on the hardware used for the study. More importantly, these results suggest that gradient non-linearity correction is important for all sequences acquired in multi-site/modality studies, and not only structural sequences.

References

[1] Jovicich et al. (2006) NeuroImage 30(2): 436
[2] Christensen et al. (2007) Cerebral Cortex 17:1906
[3] http://www.fil.ion.ucl.ac.uk/spm/