Modelling large head motion events in fMRI studies of patients with epilepsy

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Introduction

The problem of head motion-related nuisance effects in fMRI has long been recognised (Hajnal et al., 1994). In general, head motion is detrimental to fMRI in two ways: on one hand, it can give rise to false positives when correlated with the stimuli or events of interest, and on the other it can lead to reduced sensitivity when not accounted for properly through an increase in unexplained variance (error) (Lund et al., 2005). Residual motion-induced signal can be modelled as linear and non-linear functions of the scan realignment parameters derived from the procedure (Friston et al., 1996). This modelling approach can result in increased sensitivity, particularly in the absence of stimulus-correlated motion, and reduced likelihood of motion-related (false) activation, and has been shown to be statistically efficient (Lund et al., 2005).

In the context of EEG-fMRI's potential clinical use, an additional consideration is the propensity of patients to move more than normal subjects. In this work, we evaluate the use of individual regressors consisting of a Heaviside step function for each scan coinciding with motion events of a magnitude above a pre-set threshold, resulting in so-called 'scan nulling' regressors. The purpose of this work was to formally evaluate the efficacy of the 'scan nulling' regressors based on the amount and anatomical extent (# of voxels) of the signal variance explained.

Methods

34 patients were scanned on a 1.5 Tesla Horizon EchoSpeed MRI scanner (General Electric, Milwaukee, USA) using T_2*-weighted single-shot gradient-echo echo-planar images. 700 scans were acquired continuously over a 35-minute period. Standard manufacturer-supplied cushions, ear plugs and plastic ear defenders were used. 5 patients underwent two experiments. All fMRI data were analysed using SPM2 (Statistical Parametric Mapping, www.fil.ion.ucl.ac.uk/spm). Scan realignment proceeded with an iterative estimation of the six rigid body motion parameters.

Motion and fMRI models

The scan-to-scan displacement was calculated by estimating the absolute magnitude of the first derivative of Pythagorean sum of linear shift along the 3 axes (d), $|d'|$. Individual head jerks were defined by $|d'| > 0.2$ mm/scan (Salek-Haddadi et al., 2006). Effects of motion were modelled in two ways within each design matrix (DM): by the inclusion of a Volterra expansion of the realignment parameters (Friston et al., 1996) and by additional 'scan nulling' regressors whereby 4 regressors, each in the form of a Heaviside function corresponding to a scan, are included for each head jerks (>0.2mm) spanning a 12 second interval beginning with the jerk-scan.

The significance of the effects of interest was assessed using an F-test and thresholding ($p<0.05$, corrected). The proportion of the brain at which significant motion effects were significant was estimated for the Volterra and scan nulling regressors. The number of brain voxels was determined automatically as part of the pre-processing (masking) in SPM2.

Results

The session-wise mean inter-scan displacement averaged over the group was 0.06mm (±0.05; range: 0.02-0.19; median: 0.05); the mean of the session-wise maximum inter-scan displacement was 3.38mm (±7.44; range: 0.17-37.2; median: 1.12); the mean number of head jerks was 30.7 (±46.5; range: 0-235; median: 14). In 4 experiments, there were no head jerks and in four others there were head jerks equivalent to a displacement of 1cm or more.

The F-test across all motion-related regressors revealed a significant effect over the majority of the brain in 37/39 of cases. There was significant effect for the scan-nulling regressors over the majority of the brain in 14/39 of cases. As a general rule, motion effects tended to be stronger in cortical than in subcortical brain regions. Taking this into account, scan-nulling effects were significant in the majority of the neocortex in approximately 50% of cases. A representative example is shown in the figure.

There was a tendency for increased motion effects as a function of motion however, the relationship is not monotonous. Two cases stand out because despite having large numbers of head jerks, the anatomical extent of the scan nulling effect is relatively small.

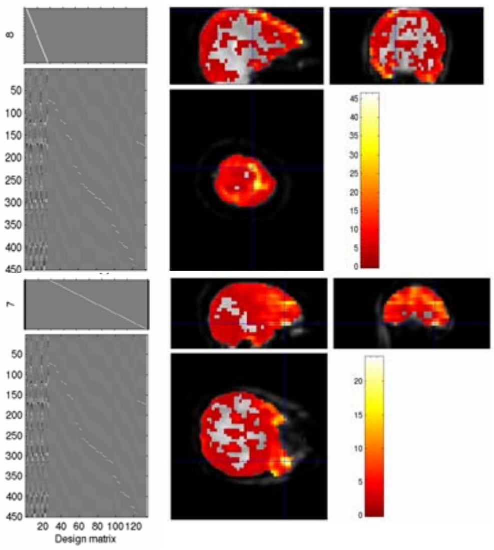

Figure. *Extent of motion effects in representative case. The degree of motion in this case was close to the median across the group:* $|d'|_{avg} = 0.05$*mm;* $|d'|_{max} = 0.86$*mm; 20 head jerks. SPM{F}'s: Top: Volterra regressors; bottom: scan nulling regressors. The design matrix and contrast are represented on the left, with the supra-threshold voxels overlaid on cross-sections of the mean image on the right. The proportion of the brain with a significant overall motion effect was 96.4%, with 96.4% for scan nulling component and 73.1% for the Volterra component.*

Discussion

We have evaluated the effectiveness of including two types of model for motion-related effects in the analysis of fMRI data acquired in patients with focal epilepsy: the first is Friston's Volterra expansion of the six realignment parameters to account for spin excitation history effects across successive scans (Friston et al., 1996); the second is an *ad hoc* method that attempts to account for effects due to very large motion events (head jerks) by effectively extracting signal variations uniquely correlated to each such event (Salek-Haddadi et al., 2006). Our results demonstrate the general effectiveness of the approach in terms of the proportion of brain voxels for which a significant amount of additional variance is explained by motion-related regressors. Specifically, we have confirmed the Volterra component to be effective, irrespective of the degree of motion, while the addition of scan nulling of the model is efficient for datasets with relatively high, but commonly observed degrees of motion.

Acknowledgements

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Reference List

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