# Motion or Activity: their role in intra- and inter-subject variation in fMRI

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## Introduction
It is well known that fMRI possesses large intersession variability [1]. This is problematic both with regard to the field of brain mapping, but not least to the application of fMRI for presurgical planning. The purpose of this study was to investigate whether the inclusion of regressors, describing movement related effects, in the design matrix of a General Linear Model (GLM) reduces intersession and inters-subject variability in the observed fMRI activation.

## Materials & Methods
Ten healthy volunteers (A,B,C,D,E,H,I,J,K,L) were examined with two different word generation tasks: Categorical (generation of words from a specific category) and Alphabetical (generation of words starting with a specific letter). Two of the subjects (A&B) were examined 10 times. Both paradigms were presented in a boxcar design with active and baseline condition lasting 44s each. Using a 1.5T Siemens Vision scanner and a gradient echo EPI, a set of 104 volumes (20 slices, matrix:128$\times$128, resolution: (xyz) 1.56mm$\times$1.56mm$\times$5mm ) was acquired in each of the two paradigms. Data was realigned and spatially normalized and spatially smoothed using a gausian kernel (FWHM 5mm) using SPM99. Residual movement effects were modelled by including a Volterra expansion of the 6 motion parameters as nuisance covariates in the design matrix of a GLM as implemented in SPM2 http://www.fil.ion.ucl.ac.uk/spm/spm2.html). The Volterra expanded motion parameters model linear and quadratic effects of the 6 movement parameters belonging to each volume, but also model spin-history effects [2] as linear and quadratic effects of motion parameters in the previous volume, giving a total of 24 regressors in addition to those describing the paradigm and baseline. Six different sets of images (A-Categorical, A-Alphabetical, B-Categorical, B-Alphabetical, 10Subjects-Categorical and 10Subjects-Alphabetical) were analyzed with two models each. Both models were a fixed-effect analysis of the word generation paradigms, and both modelled serial correlations as an AR(1)-process and low frequency drifts as a discrete cosine set (128s cut-off). In the first model, only the paradigm regressor and session specific baseline (mean value) were included in the design matrix (size1040x20). In the second model, the Volterra expanded motion parameters (24 regressors per session) were also included in the design matrix (size 1040x260). For each of the 12 analyses a t-contrast was used to test for the effect of the paradigm, and an F-contrast was used to test for the intersession or inter-subject variation. The F-test was constructed so that each of the 10 rows (SPM notation) in the F-contrast tested for the deviation of a specific session (or subject) from the mean of the other 9 sessions/subjects. For example, the third row in the F-contrast of a model without motion parameters reads [ -1/9 –1/9 1 –1/9 –1/9 –1/9 –1/9 –1/9 –1/9 –1/9]. All statistic maps were thresholded at $p=0.05$ (corrected using Gaussian Random Field Theory).

## Results
In 3 of 4 intra-subject analyses inclusion of motion parameters reduced or removed the intersession variation (see Figure 1) and cleaned up the activation map. In the 4th case (B-Categorical) the intra-subject variation was dominant in areas visible in the activation maps (model with motion parameters), indicating a true variation in brain activity. In both of the inter-subject analyses, inclusion of the motion parameters also reduced the intra-session variance significantly (see Figure 2), leaving only a few voxels located in areas found active in the activation map.

## Discussion
In the present study we were able to assign a large amount of the intersession variation found in fMRI to differences in movement during scanning. This effect seemed equally large within and between subjects. These results emphasize the need for a true mixed effect analysis in multi-subject studies, and the importance of proper data processing in single subject analysis e.g. in the case of presurgical mapping. Finally it should also be noted that different movement patterns are not the only source of inter-session variation. Differences in physiological noise (cardiac and respiratory) and true differences in the BOLD signal also exist.

## References
[1] McGonigle, DJ. et al. Neuroimage 11: 708-734, 2000
[2] Friston, K. et al. Magnetic Resonance in Medicine 35: 346-355, 1996
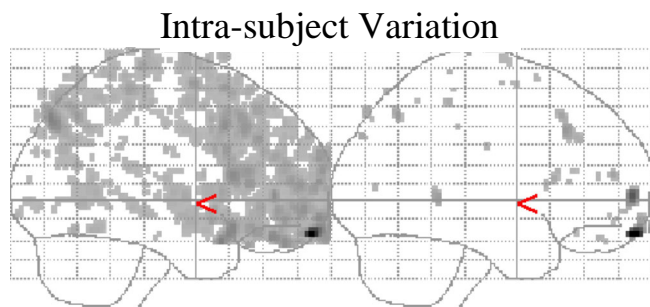
## Intra-subject Variation



**Figure 1:** Categorical word generation. Intra-subject variation in activation with (right) and without (left) motion parameters included in the design matrix.
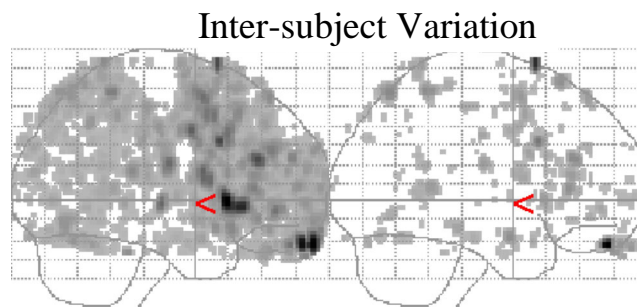
## Inter-subject Variation



**Figure 2:** Alphabetical word generation. Inter-subject variation in activation with (right) and without (left) motion parameters included in the design matrix.