# Improved Retrospective Motion Correction in fMRI using A Biophysical Model

Tim M Tierney[1], Louise J Croft[2], Maria Centeno[1], Elhum A Shamshiri[1], Suejen Perani[1,3], Torsten Baldeweg[2], Christopher A Clark[1], and David W Carmichael[1]
*[1]Developmental Imaging and Biophysics, UCL Institute of Child Health, London, United Kingdom, [2]Cognitive Neuroscience and Neuropsychiatry, UCL Institute of Child Health, London, United Kingdom, [3]Department of Basic and Clinical Neuroscienc, KCL Institute of Psychiatry, Psychology & Neuroscience, London, United Kingdom*

**Target audience:** This presentation will be of interest to those involved in patient or paediatric research using fMRI where motion control is particularly problematic.
**Purpose:** Subject head motion negatively affects task based fMRI and connectivity based studies[1,2] .We propose to develop a theoretical biophysical model for the identification and correction of subject head motion.
**Theory:** To identify spurious variation a threshold needs to be set in terms of percentage signal intensity change. To estimate the percentage signal intensity change relative to baseline we assume that the Blood Oxygen Level Dependent (BOLD) signal can be modelled according to the following equation*: S = Smax*e -TE/T2**, where *S* = BOLD Signal Intensity, *Smax* =100, *TE*= echo time and *T2* = 1/R2 +1/R2'*, *R2* = spin-spin relaxation rate and *R2'* = relaxation due to magnetic field inhomogeneities. Empirical and theoretical models allow for the estimation of *R2* and *R2'* [3,4]. We can then solve the following equation to estimate $BOLD_{max}$ (The threshold beyond which signals are likely to be artefactual):

$$Bold_{max} = S_{max}\, e^{-TER2^{*}_{Activation}} - S_{max}\, e^{-TER2^{*}_{Baseline}}$$

This model will break down in areas where the noise is exceptionally high such as at the edge of the brain and in the veins and arteries. However, these areas can be segmented automatically using the Expectation Maximisation algorithm on the median/ (median absolute deviation) image (which robustly estimates TSNR). This is possible as the median of *S* is a decreasing function of *R2'* and the median absolute deviation of *S* is an increasing function of *R2'*. The ratio of these images is then sensitive to blood volume (Figure 1) as *R2'* is scaled according to blood volume[3]. Once these noisy areas are segmented a principle component analysis across voxels can be performed to obtain a parsimonious model of the temporal noise, here the first six principal components are extracted. These regressors can be included as effects of no interest in one's regression analysis in order to improve the motion model. We call this method Functional Image Artefact Correction Heuristic (FIACH).

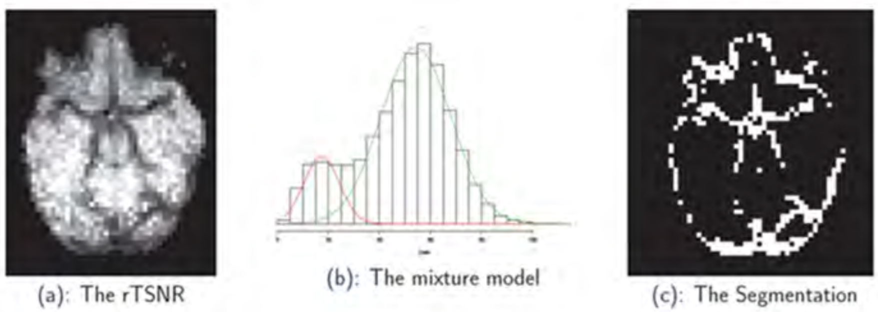


Figure 3: An Example Segmentation of high noise areas. The rTSNR (median/median absolute deviation) of a lower axial slice (a) is fitted with two gaussians (b) and the high noise areas are segmented(c).

**Methods:** We validated FIACH using a sample of 42 healthy children while performing a language task with known activations[5, 6]. These expected regions consisted of the following: left inferior frontal gyrus, bilateral superior temporal gyrus, bilateral middle temporal gyrus, bilateral primary motor, bilateral somatosensory, bilateral cerebellum, bilateral temporal pole, left hippocampus and supplementary motor area. There were 16 Regions of Interest (ROIs) in total. The scan parameters were as follows: 2D gradient echo EPI, 1.5T, 30 slices (in ascending order), TR = 2.16s, TE=30ms, resolution = 3.3 x 3.3 x 4mm³. A number of other retrospective motion correction methods were also examined for the purpose of comparison. The other methods included were: Robust Weighted Least Squares[7], Motion Fingerprint[8], Realignment Parameter Expansion[1, 9] and simply including the realignment parameters as effects of no interest in the GLM.

**Results:** FIACH had the highest t-value in 12 out of the 16 ROIs across all five methods. Using a binomial test this was found to be a statistically significant effect ($p<.05$). The probability of the proposed method having the highest t-value in the regions of interest = 0.75 (95% CI [0.476, 0.927]). FIACH had the maximum number of voxels in 12 out of the 16 ROIs across all five methods. Using a binomial test this was found to be a statistically significant effect ($p<.05$). The probability of the proposed method having the greatest extent in the regions of interest = 0.75 (95% CI [0.476, 0.927]). Figure 1 displays the t-maps for the standard GLM (a) and for FIACH (b). Large differences can be seen in inferior frontal and inferior temporal areas

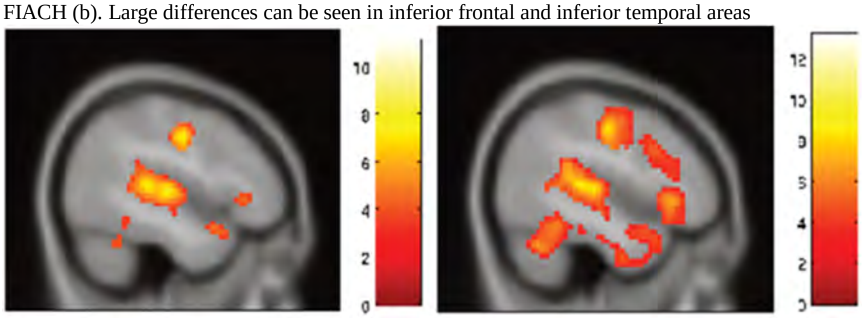

Figure 1: Comparison of FIACH with standard GLM. a) Group t-map overlaid on normalised T1-weighted image for standard GLM approach. b) Group t-map overlaid on normalised T1-weighted using FIACH

**Conclusion**: We have developed a biophysically based framework for motion correction named FIACH. We have demonstrated its efficacy in a paediatric population during overt speech where subject motion is a severely limiting factor. We have shown that FIACH reveals additional brain areas involved in language at the group level (Figure 2). It also substantially increases the statistical power in language related areas relative to other methods. Furthermore, this methodology is capable of correcting data near inferior temporal areas. These areas have proven problematic for fMRI and FIACH provides the opportunity to improve knowledge of these areas function.

**References:**
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