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Dynamic off-resonance correction improves functional data quality in fMRI of awake behaving NHPs

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Authors:

Mo Shahdloo[1], Nima Khalighinejad[1], Caroline Harbison[1], Karla Miller[2], Matthew Rushworth[1], Mark Chiew[2]

Institutions:

[1]Wellcome Centre for Integrative Neuroimaging, FMRIB, Department of Experimental Psychology, University of Oxford, Oxford, UK, [2]Wellcome Centre for Integrative Neuroimaging, FMRIB, Nuffield Department of Clinical Neurosciences, University of Oxford, Oxford, UK

First Author:

Mo Shahdloo
Wellcome Centre for Integrative Neuroimaging, FMRIB, Department of Experimental Psychology
University of Oxford, Oxford, UK

Co-Author(s):

Nima Khalighinejad
Wellcome Centre for Integrative Neuroimaging, FMRIB, Department of Experimental Psychology
University of Oxford, Oxford, UK
Caroline Harbison
Wellcome Centre for Integrative Neuroimaging, FMRIB, Department of Experimental Psychology
University of Oxford, Oxford, UK
Karla Miller
Wellcome Centre for Integrative Neuroimaging, FMRIB, Nuffield Department of Clinical Neurosciences
University of Oxford, Oxford, UK
Matthew Rushworth
Wellcome Centre for Integrative Neuroimaging, FMRIB, Department of Experimental Psychology
University of Oxford, Oxford, UK
Mark Chiew
Wellcome Centre for Integrative Neuroimaging, FMRIB, Nuffield Department of Clinical Neurosciences
University of Oxford, Oxford, UK

Introduction:

The considerable scale differences between human and non-human-primate (NHP) brains necessitate high-resolution functional MRI to achieve comparable levels of spatial specificity to human neuroimaging protocols. In-plane and multiband accelerated fMRI1 have been increasingly used to facilitate higher-resolution protocols in anesthetized NHP scans2. Accelerated fMRI in awake behaving NHPs however poses a significant challenge due to presence of strong, fluctuating B0 field inhomogeneities resulting from motion in the behaving animal's body, hands, jaw, and facial musculature. Despite the fact that the animal's head is fixed, these dynamic field inhomogeneities cause considerable ghosting and residual aliasing artifacts that are not addressable in post processing and can degrade image quality.

Recently, we proposed a method to correct for these dynamic B0 changes by using the reference navigator data which are already available in most typical EPI sequences3. This method uses the navigator data acquired at every time-point to estimate a first-order dynamic field perturbation, which is then used to transform the acquired data to maintain consistency with the calibration data for a ghost- and alias-free image reconstruction. While we have shown improvements in image fidelity3, the functional significance of this off-resonance correction method has yet to be quantified.

Here, we aim to investigate this using task-fMRI data from awake behaving NHPs. Our results show significant reductions in image bias and variance, and improvements in z-statistics in a GLM analysis.

Methods:

In vivo 2D fMRI data from two awake behaving Macaque monkeys were collected. After training, animals performed a behavioural task in which they were presented with opportunities to act for potential reward. They could decide whether to act or refrain from action and wait for future opportunities. All procedures were conducted under ethics licenses from the UK Home Office. The animal was head-fixed in sphinx position in an MRI-compatible chair in a 3T clinical scanner. Data were acquired using the CMRR multi-band GRE-EPI sequence4 with parameters: TE/TR=25.4/1282ms, FA=63, FOV=120mm, 1.25mm isotropic resolution, 42 slices, MB=2, in-plane acceleration factor R=2, 15-channel receive coil, 1364 volumes. Raw data were separately reconstructed using the online reconstruction provided as part of the CMRR multi-band EPI sequence package, and using our proposed GRAPPA-operator based dynamic off-resonance corrected reconstruction method.

Preprocessing was performed using in-house scripts based on tools from FSL5, ANTs6, and MrCat7. In each run, each volume was non-linearly aligned to a high-quality EPI volume. Aligned volumes were then registered to each animal's high-resolution structural image. Finally, data were temporally high-pass filtered (3-dB cutoff of 100s) and spatially smoothed (Gaussian FWHM of 3mm). Data fidelity was evaluated using the mean image difference to the single-band reference (bias), and the temporal coefficient of variation (variance). To assess the functional data quality, a first-level GLM analysis was performed to identify voxels with significant response to the motor action.

Results:

As shown in Fig. 1, off-resonance correction yields lower bias and temporal variation. Notably, dynamic off-resonance had originally led to reconstruction artifacts that were not addressed using the performed conventional preprocessing. The reconstruction quality improvement leads to enhanced statistical power as shown in Fig. 2. Both the number of significantly activated voxels in the motor cortex and the z-statistic magnitudes in the activated voxels are increased in the corrected reconstruction.

Conclusions:

Our results show that our recently proposed reconstruction with dynamic off-resonance correction can enhance data quality in existing NHP protocols with no sequence or protocol changes. The proposed method can enable more robust and reliable accelerated awake, behaving NHP imaging.

Modeling and Analysis Methods:

Motion Correction and Preprocessing [1]

Novel Imaging Acquisition Methods:

BOLD fMRI [2]

Keywords:

FUNCTIONAL MRI
Other - dynamic off-resonance

[1][2]Indicates the priority used for review

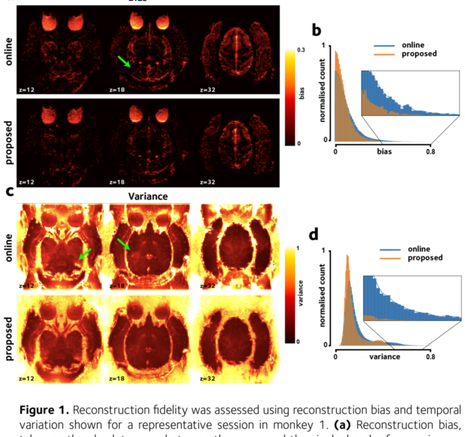

Figure 1. Reconstruction fidelity was assessed using reconstruction bias and temporal variation shown for a representative session in monkey 1. **(a)** Reconstruction bias, taken as the absolute error between the mean and the single-band reference image. Off-resonance correction reduces the reconstruction bias across the brain. This is specifically noticeable in slices where residual aliasing had previously caused high bias **(green arrows)**. **(b)** Histogram showing decreased bias as a result of off-resonance correction (taken over brain voxels, pooled across sessions). **(c)** Temporal coefficient of variation, defined as standard deviation divided by the mean. Reconstruction variance in the brain is noticeably reduced using off-resonance correction. **(d)** Histogram showing decreased temporal variation with the proposed reconstruction (taken over brain voxels, pooled across sessions). Results were consistently replicated in monkey 2 (data not shown here).

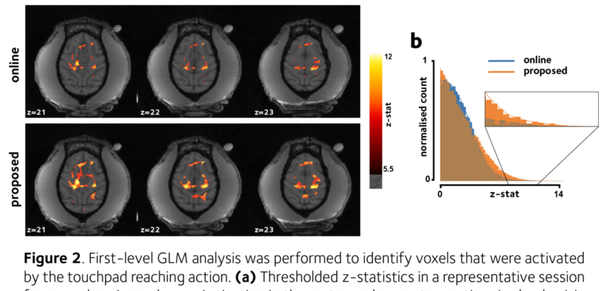

Figure 2. First-level GLM analysis was performed to identify voxels that were activated by the touchpad reaching action. **(a)** Thresholded z-statistics in a representative session from monkey 1 are shown. Activation in the motor and premotor cortices is clearly visible. Functional signal quality is improved using the dynamic off-resonance corrected reconstruction, as manifested by the higher z-statistics and larger extent of activation. **(b)** Improved z-statistics are also demonstrated in the histogram of the z-statistics (taken over brain voxels, pooled across sessions), where the corrected reconstruction yields more voxels with large z-statistics. Results were consistently replicated in monkey 2 (data not shown here).

My abstract is being submitted as a Software Demonstration.

No

Please indicate below if your study was a "resting state" or "task-activation" study.

Task-activation

Healthy subjects only or patients (note that patient studies may also involve healthy subjects):

Healthy subjects

Was any human subjects research approved by the relevant Institutional Review Board or ethics panel? NOTE: Any human subjects studies without IRB approval will be automatically rejected.

Not applicable

Was any animal research approved by the relevant IACUC or other animal research panel? NOTE: Any animal studies without IACUC approval will be automatically rejected.

Yes

Please indicate which methods were used in your research:

Functional MRI
Structural MRI

Which processing packages did you use for your study?

AFNI
FSL
Other, Please list - MrCat

Provide references using author date format

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