Simultaneous Multislice Acquisition to Avoid Motion Artifacts in Challenging Patient Populations

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Target Audience: Those interested in functional neuroimaging acquisition methods that are robust to patient motion

Purpose: Multiband/simultaneous multislice (MB/SMS) imaging is widely used throughout the field of functional neuroimaging [1-4]. Primary uses of MB/SMS imaging include increasing spatial resolution and volume coverage for a given repetition time. Leading this is work of the Human Connectome Project (HCP) that has achieved full brain isotropic 2mm coverage in resting state acquisitions with 0.720 s repetition time [5]. This work is focused upon translating MB/SMS technology for more challenging patient populations where subject motion becomes extreme, including the resting state functional imaging of children. Resting state data, which is generally smoothed with a full width half maximum point spread function of 5 to 10 mm. In this work multi and data is acquired with lower resolution than in the HCP project to reduce volume acquisition time. With sufficient acceleration of volumetric acquisitions, subject motion can be effectively frozen and corrected with registration software, thereby enabling correlation analysis on data that includes severe patient motion.

Methods: An 8-fold MB/SMS accelerated echo planar imaging (EPI) acquisition utilizing blipped-CAIPI [4] was implemented on a General Electric Discovery MR750 (General Electric, Waukesha, WI) running software release DV24.x. Images were reconstructed offline using the MATLAB Orchestra software development kit (General Electric, Waukesha, WI) with custom developed modules for unaliasing inserted into the standard product EPI reconstruction pipeline. Slice specific, phase encoding free reference scans and relative coil sensitivity maps were acquired through integrated, Hadamard encoded repetitions [6] in the first 32 shots of the time series acquisition. These data were used for column-wise inverse reconstruction [7] of the remaining repetitions. Single band data with 2 s repetition time were acquired and reconstructed with the standard GE pipeline for comparison. 36 sagittal images were acquired with a 96x96 matrix, 25.6 cm field of view, 4 mm slice thickness, 20 ms echo time, and 390 ms volume coverage time over 8 shots.

A subject was instructed under an IRB approved protocol to periodically flex and extend his ankles, yielding motion of several mm [8]. Data were inspected for intra-volume motion artifact and volume registration software [9] was applied to the time series. After volumetric registration, a seed was placed in the posterior cingulate cortex for identification of the default mode network [10].

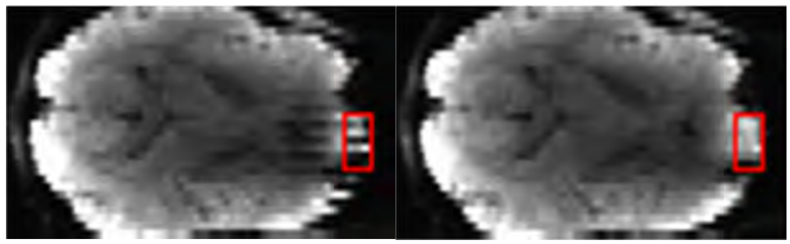

Figure 1: Axial depiction of artifacts arising from intra-volume acquisition motion in a sagittal acquisition. The physical displacement of interleaved slices resulting from intra-acquisition motion is highlighted in the red box of the left image. On the right, an image of the same slice, acquired at a time point when the subject was stationary, shows a smooth edge to the brain with no displacement of imaged tissue between interleaves of the volume acquisition.

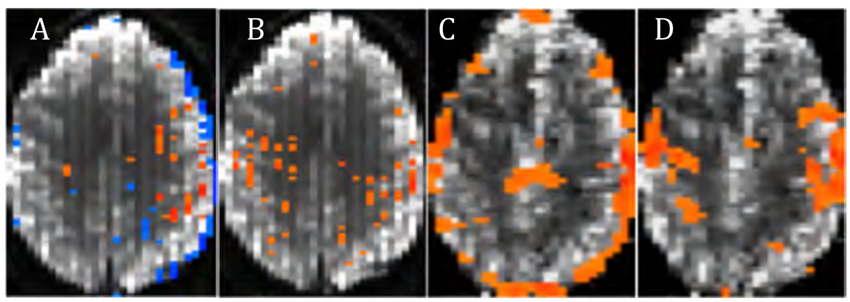

Figure 2: Seed-based resting state connectivity maps from the left hand region of the motor cortex in the presence of motion, overlaid on functional acquisition time point images. With a 2 second repetition time, motion during the acquisitions of time point volumes yields preferential correlations between the interleaved slices, without (A) and with (B) processing with motion correction software. With a 390 ms acquisition time without motion correction (C) strong correlations are present around boundaries due to the motion between repetitions. Use of a 390 ms acquisition time and subsequent volume registration removes artifactual correlations arising from intra-volume acquisition motion and repetition-to-repetition motion, yielding an appropriate map of the motor regions (D).

Results: Figure 1 shows typical intra-volume motion artifact in single-band data as interleaved slices were acquired with the head in varying positions throughout the volume acquisition. No data from the multiband acquisition show such artifacts. Results from the volume registration show the improvement offered through multiband acquisition. After volume registration software is run, uncorrected motion is obvious in the single band data in Figure 2b while motion related contrast in the multiband acquisition in Figure 2c is removed though registration in Figure 2d. While registration software erroneously reports a maximal translation of 25.5 mm in the single band data, it appropriately calculates motion of 4.2 mm in multiband data.

Discussion: It has been widely postulated that accelerated resting state imaging acquisitions yield improved cortical network identification. The improvement has been attributed to an increase in statistical samples with reduced repetition time, better sampling of physiologic contrast of non-neural origin, and reduced intra-acquisition motion sensitivity. This work seeks to capitalize on this third benefit by further reducing volume acquisition time by acquiring data with lower spatial resolution while achieving less than 400 ms volume coverage time in the presence of significant subject motion. Further acceleration can be achieved if volume coverage were to be further compromised, yielding full brain isotropic 8 mm resolution coverage with a volume coverage time of 150 ms while preserving a BOLD sensitive 20 ms echo time (data not shown). However, as illustrated in this data, such further reduction in volume coverage time is not necessary in the presence of motion of several mm. However, such speed may be needed with even more extreme motion. The inclusion of integrated reference image acquisitions brings with it some benefits of auto-calibrated parallel imaging methods, enabling the use of coil sensitivity maps that most closely match the magnitude and phase distributions present in each motion corrupted image.

Conclusions: Highly accelerated multiband acquisition methods can effectively freeze significant subject motion in functional neuroimaging acquisitions, yielding data of sufficient quality to make network identifications in situations where the data would have previously been undiagnostic.

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