# Motion Insensitive ACS Acquisition Method for in-plane and Simultaneous Multi-Slice Accelerated EPI

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**TARGET AUDIENCE:** Clinicians/researchers interested in in-plane and/or simultaneous multi-slice accelerated EPI.

**PURPOSE:** Echo planar imaging (EPI) is one of the most commonly used neuroimaging techniques. There are two acceleration schemes applicable to EPI: (i) in-plane acceleration with a parallel imaging method like GRAPPA, which is essential for reduced spatial distortion and/or increased spatial resolution, and (ii) Simultaneous Multi Slice (SMS) acquisition [1-5] which greatly increases the temporal efficiency of EPI. Both of these acceleration techniques rely on auto calibration signals (ACS) which are acquired at the beginning of the scan. In-plane GRAPPA ACS are fully-sampled whereas SMS ACS are under-sampled in-plane similar to the accelerated EPI data. To ensure equivalent distortion the ACS data and under-sampled EPI data should be acquired with the same echo spacing. As a result the ACS data are conventionally acquired in segments over multiple TRs with slice interleaving (here called the conventional approach). This implies that adjacent segments in k-space are separated in time by an amount equal to TR, making the conventional approach susceptible to physiological or bulk subject motion during ACS acquisition. In addition, GRAPPA and SMS ACS scans are usually acquired separately, thereby further increasing the total ACS acquisition time and increasing its vulnerability to motion. A novel application of Fast Low angle Excitation Echo Train imaging (FLEET) has recently been demonstrated for GRAPPA ACS acquisition [6]. FLEET acquires the ACS k-space segments *sequentially* in time thereby minimizing the time between segments and reducing sensitivity to motion. In this work we extend the FLEET method for acquiring GRAPPA and SMS ACS data. In addition to the sequential segment property of FLEET there are two additional optimizations performed to minimize sensitivity to motion during ACS: (i) slices which are simultaneously excited in the accelerated EPI scan (slice groups) are acquired closely in time, and (ii) GRAPPA and SMS ACS scans are acquired in a combined fashion thereby reducing the total ACS acquisition time.

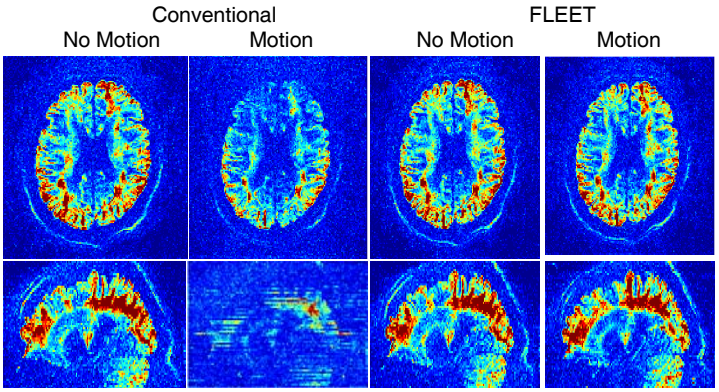


*Fig 1: tSNR maps in a healthy subject for diffusion EPI with R=3, MB=2.*

**METHODS:** Three healthy subjects were scanned on a 3T scanner (MAGNETOM Skyra, Siemens Healthcare). To evaluate the different ACS acquisition schemes two spin echo diffusion EPI protocols were acquired: (i) GRAPPA acceleration factor 2 and SMS with MultiBand factor 3 ($R$=2, MB=3) with resolution/TR/TE/BW/matrix = 2×2×2mm$^3$/3700ms/104ms/1685Hz/pix/110×110, and (ii) GRAPPA acceleration factor 3 and MB factor 2 ($R$=3, MB=2) with resolution/TR/TE/BW/matrix=1.5×1.5×1.5mm$^3$/5600ms/108ms/1205Hz/pix/148×148. For each sequence 60 repetitions with a b-value of 2500 s/mm$^2$ were acquired for time series SNR (tSNR) measurements. tSNR was calculated as the time-series mean divided by the standard deviation after motion correction. Both sequences were acquired with and without head nodding motion during the ACS acquisition with two different ACS acquisition schemes: conventional and FLEET. The FLEET scan acquires each slice (for GRAPPA) and slice group (for SMS) closely in time. In addition, for demonstration purposes a BOLD-weighted gradient echo EPI (GRE-EPI) sequence was also acquired in 1 healthy subject on a 7T scanner with the following parameters: $R$=3, MB=3:resolution/TR/TE/BW/matrix/fa = 1.5×1.5×1.5mm$^3$/1500ms/25ms/1776Hz/pix/128×128/62°. In all cases the FLEET ACS acquisition consisted of 5 dummy pulses followed by the segmented ACS acquisition. A flip angle of 20° was used for the FLEET ACS acquisition.

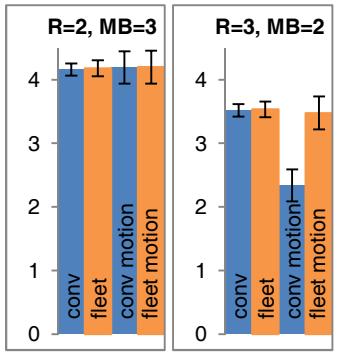


*Fig 2: tSNR comparison across 3 subjects for diffusion EPI.*

**RESULTS:** Sample tSNR maps for the $R$=3, MB=2 s are shown in Fig. 1. The conventional and FLEET methods result in equivalent tSNR performance for the case without motion. For the case with motion the FLEET method performs qualitatively better than the conventional method. Average tSNR values for both diffusion EPI protocols are shown in Fig. 2. For the $R$=2, MB=3 scan the FLEET and conventional methods result in equivalent tSNR values with and without motion. For the $R$=3, MB=2 scan the FLEET method outperforms the conventional method by a factor of 1.45 in terms of tSNR. For the case without motion, conventional and FLEET methods perform equivalently. Fig. 3 shows sample a BOLD-weighted GRE-EPI image with $R$=3, MB=3 acquired with head nodding during the ACS. The conventional method results in artifacts (red arrows) which are eliminated with the FLEET method.

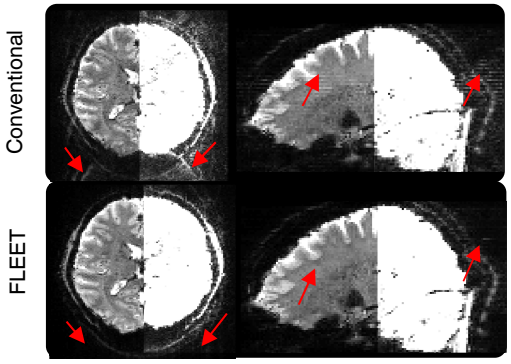


*Fig 3: Example R=3, MB=3 GRE-EPI images acquired during ACS motion in a subject.*

**DISCUSSION:** For the $R$=2, MB=3 case the FLEET and conventional methods result in similar performance with and without motion. This can be attributed to the fact that for $R$=2 the conventional ACS scan was acquired as a single-shot fully-sampled GRAPPA ACS scan followed by a single-shot under-sampled SMS ACS scan. This is not optimal since the echo spacing does not match between the GRAPPA ACS and under-sampled EPI data. Practically, this mismatch is acceptable for the $R$=2 case, but not for $R$=3 and higher. The improvement with FLEET for $R$=3 is due to the fact that the ACS acquisition time for each slice (for GRAPPA) and slice group (for SMS) is minimized. One concern for the FLEET method is the ACS scan will have lower SNR than a conventional reference scan due to lower flip angle excitation. Thus its performance should be carefully evaluated for higher spatial resolution acquisitions.

**CONCLUSION:** We demonstrated a novel motion-insensitive ACS acquisition technique for in-plane and Simultaneous Multi-Slice accelerated EPI.

**REFERENCES:** [1] Larkman DJ. et al., *JMRI* **13**:313-17. [2] Breuer F. et al., *MRM* **53**:684-91. [3] Moeller S. et al., *MRM* **63**:1144-53. [4] Feinberg DA. et al., *PLoS One* **5**:e15710. [5] Setsompop K. et al. *MRM* **67**(5):1210-24; [6] Polimeni JR. et al. *ISMRM* 2013, #2646.