Dynamic Phase Echo-Planar Imaging - Detection and Correction of Dynamic Off-Resonance

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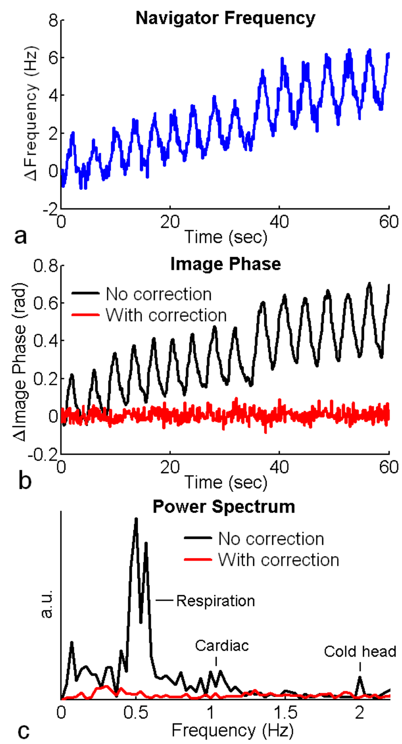
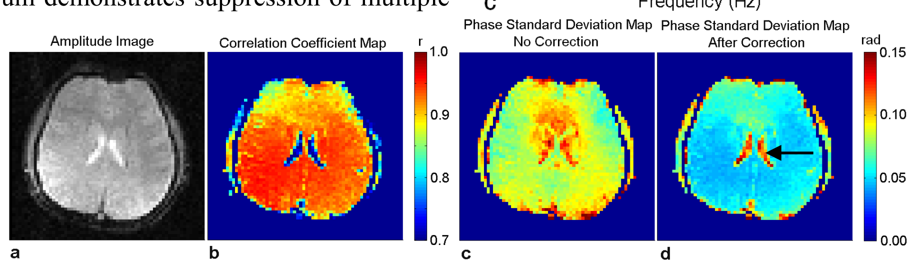
Introduction: Dynamic B0 off-resonance, caused by respiration or scanner drift, leads to dynamic image artifacts in fast imaging sequences, such as pixel shifts in phase-encode (PE) direction for blipped EPI or blurring for spiral EPI. Common means to detect and correct these B0-induced artifacts are navigator signals [1] and methods such as DORK [2], which so far have been demonstrated and applied widely to *magnitude* image time series used for fMRI, diffusion or perfusion. In contrast, studies using dynamic *phase* EPI were used rather sparsely, though they can provide additional detection power and sensitivity for fMRI [3]. Moreover, the image phase information can be used for distortion correction in a static or even dynamic mode using field maps (multi TE) or similar techniques such as PLACE [4]. When utilizing phase images from several volumes, physiological off-resonance changes from respiration directly affects the stability of the phase EPI series – in a first approximation a global frequency change translates into a zero-order offset in space of the phase images - however more complicated models suggest also a spatial distribution for the dynamic phase EPI.

The goal of the current study is firstly to investigate the effects of global frequency drifts (caused by subject physiology) on dynamic phase EPI – secondly to employ navigator methods to robustly correct for these effects and evaluate remaining dynamic phase EPI stability.

Methods: Two healthy subjects were imaged in several sessions using a 3T MAGNETOM Verio (Siemens Healthcare, Erlangen, Germany). Dynamic magnitude and phase images were obtained using a single-shot, gradient echo EPI sequence based on the vendor's sequence. Three different orientations were acquired (axial, sagittal, coronal – PE in A-P direction), resolution = 3x3x3 mm^3, TE = 21 ms, TR = 100 ms (1 slice, N=600) and 2 s (9 slices, N = 30), respectively. Subjects were asked to breathe freely. The image recon was extended to perform *inline* dynamic off-resonance detection and correction. Global frequency changes Δf were traced with DORK [2] from a navigator with 3 central k-space lines directly after excitation - Δf was calculated from the phase difference between the two odd lines. The correction was done in k-space according to [2]. The phase image series were processed with and without correction - phase images were calculated as difference maps relative to a reference volume, to evaluate the relative changes in the phase maps over time.



Results: The navigator-detected frequency shift (**Fig. 1a)** is very similar to the average image phase value over time (**Fig. 1b**). The corresponding power spectra from the phase time series before and after correction (**Fig. 1c,** detrended**)** show respiratory, cardiac and scanner noise. The detected frequency shift and average image phase changes were highly correlated, with r > 0.9 in all experimental EPI series. The DORK correction effectively alleviates global off-resonance induced image phase fluctuations. The power spectrum demonstrates suppression of multiple peaks associated with human physiology and scanner hardware after correction (**Fig. 1bc,** red lines). **Fig. 2** shows a correlation coefficient map of voxel-based image phase variation versus Δf, and maps of temporal phase standard deviation (SD) before and after correction. The navigator-detected frequency shift *for each voxel* is highly correlated to phase variation across the brain **(Fig. 2b)**. Global reduction of temporal image phase variation is clearly seen in regions with high correlation **(Fig. 2d)**. The remaining high SD after correction in some locations is related to cerebrospinal fluid pulsation (arrow), which is not captured by the global navigator signal. **Table 1** reports the average phase temporal SD before and after correction from both subjects with different imaging orientations and number of slices. The phase temporal SD could be significantly reduced across all sessions and different orientations.



phase temporal SD	Subject 1			Subject 2		
	Axial	Cor	Sag	Axial	Cor	Sag
Single-slice(rad)	0.068	0.070	0.052	0.039	0.089	0.048
With correction (rad)	0.025	0.029	0.034	0.019	0.023	0.018
Multi-slice (rad)	0.050	0.028	0.041	0.056	0.114	0.068
With correction (rad)	0.028	0.016	0.025	0.013	0.019	0.010

Conclusions: Our study demonstrates the effects of global physiologically-induced and scanner-hardware-related frequency changes on dynamic *phase* EPI. DORK [2] can be applied to effectively correct these global dynamic off-resonance variations in the *phase* EPI series. This correction approach facilitates reliable acquisition of serial phase EPI information which enhances detection power and sensitivity of fMRI and subsequently can be used for robust EPI distortion correction.

References: 1. HuX MRM(1994) 2. PfeufferJ MRM(2002) 3. HagbergGE MRI(2008)1026, RoweDB NI(2009)742 4. JezzardP, XiangQS MRM(2007)731