K-space Density Weighted Echo Planar Imaging

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Introduction: In echo planar imaging (EPI) the short acquisition time limits the achievable signal to noise-ratio (SNR). Applying an SNR matched filter retrospectively to the k-space improves the SNR, yet amplifies sidelobes of the point spread function (PSF) leading to Gibbs ringing artifacts. On the other hand, the application of filters which apodize the k-space periphery (e.g. Hanning or Gaussian filters) reduces the side lobes yet does not provide optimal SNR. K-space density weighting [1-4] combines the advantages of both approaches: A Gaussian filter is achieved by acquiring the k-space in phase encoding direction with a non-Cartesian trajectory, while filtering with an SNR matched filter proportional to the T_2* decay provides optimal SNR. In this work, possible SNR advantages of density weighted EPI were examined.

Materials and methods: Measurements were performed on a 3 T scanner equipped with a 12-channel head coil. In-vivo Cartesian and k-space density weighted images of the human brain were acquired with a single-shot EPI sequence (96x96 matrix, FOV 220x220 mm², slice thickness 3 mm, echo spacing ES=0.76 ms). The density weighted k-space sampling was calculated according to [4]: The Fourier transform of the PSF yields the modulation transfer function (MTF):

$$\text{MTF}(k) = \text{Signal}(k) \cdot \text{Filter}(k) \cdot \rho(k).$$

The MTF is defined by the multiplication of the signal, an optional retrospective filter and the k-space density ρ(k). In EPI, the signal decays exponentially with the relaxation time T_2*:

$$\text{Signal}(k) = \exp(-\text{ES}\cdot n(k)/T_2^*).$$

Here n=0…95 are the respective echoes of the echo train. In conventional Cartesian imaging (i.e. ρ(k)=const.) the signal is often retrospectively multiplied with a Gaussian filter. The shape of this filter deviates considerably from the shape of an SNR matched filter [3,4], which suggests Filter(k)=Signal(k), and thus does not provide optimal SNR. In contrast, k-space density weighting allows the application of an SNR matched filter, as the k-space density is variable. Thus, by sampling the k-space according to [4]:

$$\rho(k) = \text{MTF}(k) \cdot \text{Signal}(k)^{-2},$$

a desired MTF and optimal SNR can be realized at the same time.

In the case presented, density weighting was incorporated using a k-space trajectory that resulted in an MTF that is obtained when applying a Gaussian filter with full width half maximum FWHM=1.6 voxel to an object with relaxation time T_2*=50 ms (i.e. approximately the relaxation time of brain matter at 3 T). The minimum k-space density was limited to a factor of 0.5.

The density weighted sampling yielded an effective echo time $TE_{eff,DW}$=33 ms, while conventional Cartesian acquisition yielded $TE_{eff,Cart}$=42 ms. Thus, Cartesian data was additionally acquired using a partial Fourier method, providing both the identical echo time $TE_{eff,PF}=TE_{eff,DW}$ and the identical slice acquisition time as density weighted imaging. Image reconstruction was performed using a non-Cartesian GRAPPA/PARS algorithm [2]. Cartesian datasets were filtered with the Gaussian filter described above in phase encoding direction. Off-resonance correction was performed utilizing a multi-frequency reconstruction method [5]. A pseudo multiple replica technique was employed for SNR assessment [6].

Results: Figure 1 shows the images obtained after reconstruction and off-resonance correction for Cartesian, density weighted and Cartesian partial Fourier acquisition (top) with the corresponding SNR maps (bottom). While providing slightly different contrasts, the geometric shape of the brain could be corrected for all acquisition methods. The averaged ratio of density weighted SNR to Cartesian SNR was 1.22±0.13, while the averaged ratio of density weighted SNR to Cartesian partial Fourier SNR was 1.25±0.12.

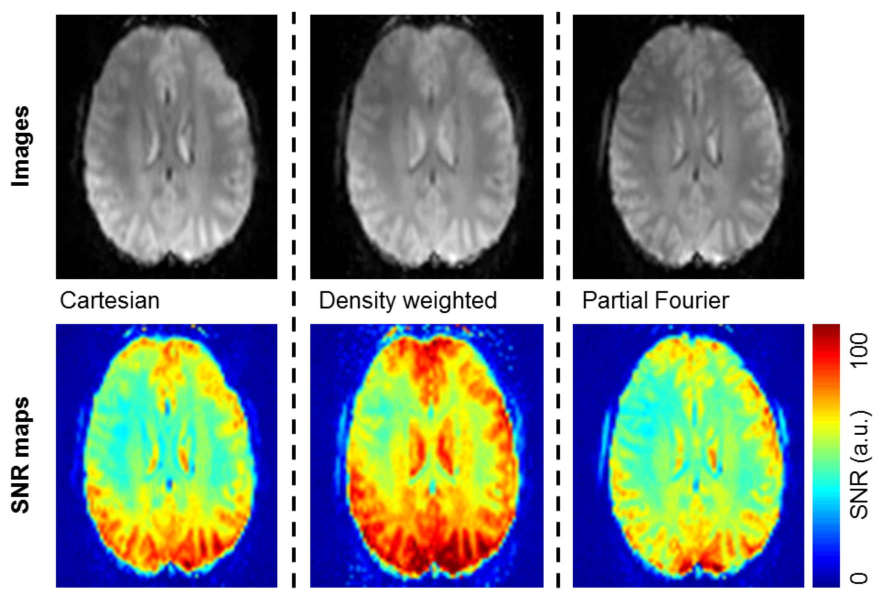

Figure 1: Reconstructions (top) and SNR maps (bottom) of Cartesian, density weighted and Cartesian partial Fourier in-vivo reconstructions.

Discussion and Conclusion: K-space density weighted EPI acquisition provides significant SNR gains compared to both, standard Cartesian and Cartesian partial Fourier imaging. The SNR gain does not solely result from the shortened echo time, as can be concluded from comparing k-space density weighted and Cartesian partial Fourier reconstructions. Instead, the SNR gain is achieved by the application of an SNR matched filter. The application of such a filter in Cartesian imaging would result in amplified Gibbs ringing artifacts. In contrast, the shape of a prospectively defined PSF can be preserved in k-space density weighted imaging due to the non-Cartesian k-space sampling trajectory. The results suggest applying k-space density weighting in scenarios such as functional magnetic resonance imaging, where retrospective filtering is typically applied, while at the same time the SNR is desired to be as high as possible.

References: [1] Greiser MRM 2003;50:1266-75 [2] Geier MAGMA 2007; 20:19-25 [3] Gutberlet MRI 2010:28;341-350 [4] Zeller JMRI 2012;in press [5] Man MRM 1997;37:785-92 [6] Robson MRM 2008;60:895-907