Complex interactions of physiological noise and acceleration on tSNR in 3D EPI

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Introduction: Multi-slice 2D EPI for functional MRI has the considerable advantages of speed and robustness, but is relatively SNR inefficient, particularly at high resolution. Multi-shot 3D EPI provides a theoretical thermal SNR gain [1] compared to 2D EPI and can utilize parallel imaging acceleration along two (independent) dimensions, leading to the potential for high-resolution data with reasonable temporal resolution. However, these multi-shot acquisitions span several seconds, making them susceptible to physiological fluctuations [2]. Here, we explore the temporal SNR (tSNR) of 3D EPI at a range of spatial and temporal resolutions, with the latter controlled by kz acceleration (Rz factor). In particular, we consider potential interactions between acceleration (with higher Rz reducing SNR due to thermal noise and g-factor losses) and physiological noise (which increases with the number of shots and likely with the volume scan time), such that the tSNR will reflect the balance of these processes.

Methods: Five healthy subjects were imaged using a gradient and RF spoiled 3D EPI pulse sequence, which allows acceleration using GRAPPA along both phase encoding directions. Time series of 50 volumes were acquired at 7T using a 32 channel coil. We acquired three different isotropic resolutions (1, 1.5, 2mm) and four different slice acceleration factors (Rz=1, 2, 3, 4). All acquisitions had FOV of 225 mm, 96 k_z planes, in-plane acceleration factor of 3. The protocols for 1/1.5/2mm resolution used TR=88/51/41 ms, TE=43/25/20 ms, FA=12°/14°/16° and BW=1302/1388/1396 Hz/pixel.

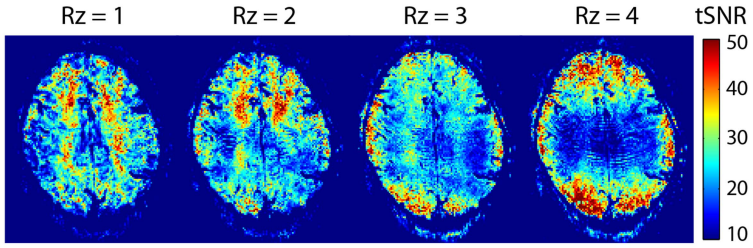

Fig. 1. **tSNR:** Maps of tSNR for the four different z parallel imaging factors (R_z) for an example subject at 1.5 mm isotropic resolution.

Each data set was motion corrected and brain extracted, and tSNR was obtained voxel-wise as the mean signal divided by temporal standard deviation. The tSNR maps were then linearly registered to the structural space for each subject. Atlas-based cortical grey matter masks were used to calculate average cortical tSNR. Physiological noise correction (using the FSL PNM) was performed using 34 and 12 regressors [3]. We ran a three-factor, fixed-effects ANOVA to examine the interactions between resolution, Rz, and physiological correction on the mean tSNR across subjects.

The protocol was also repeated on a doped agar gel phantom to examine data without any physiological noise. Here, tSNR was calculated as above, using a mask that encompassed most of the phantom.

Results: Our data generally exhibited complex behavior of tSNR across acceleration factors, as shown in Fig 1. The expected *decreases* in SNR due to R- and g-factor are observed in the center of the brain, while tSNR *increases* at the periphery, particularly in gray matter. This pattern led us to hypothesize that the tSNR may have a maximum at which physiological noise contamination balances thermal noise losses due to acceleration. Such a pattern is reflected in our 1 and 1.5mm data, where tSNR increases with moderate Rz factor, opposite to the pattern predicted by pure thermal effects, as shown in our phantom data (Fig 2). However, our 2mm data is not consistent with this picture, displaying a more complicated variation with Rz that is difficult to interpret. Moreover, physiological noise regression did not alter the form of the dependence on Rz factor, but instead uniformly increased the tSNR across all Rz factors (Fig 3). The results of the ANOVA indicate significant main effects of each factor (resolution, Rz and physiological correction), as well as significant interactions between resolution×Rz and resolution×physio correction (all effects $p<0.05$).

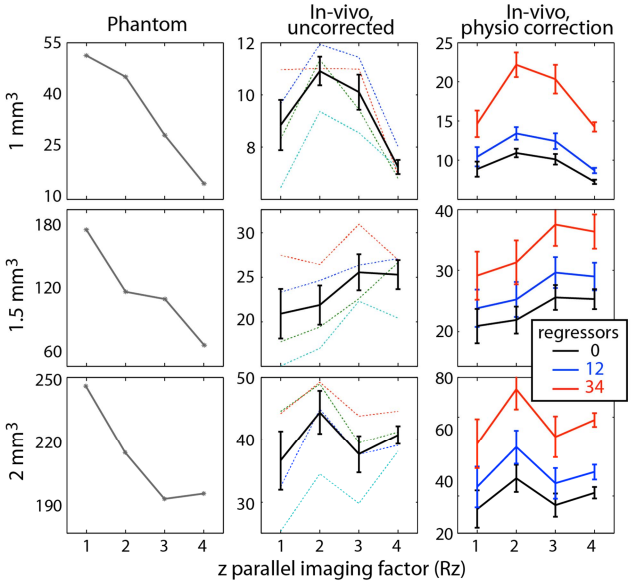

Fig. 2. **tSNR for different Rz factors:** tSNR curves observed in phantom (left) and in-vivo (middle and right) data. Error bars indicate standard error across subjects (individual subjects are dashed lines).

Discussion: To our knowledge, the effect of Rz acceleration on temporal stability in 3D EPI has not been explored, although alteration of physiological noise sensitivity with segmentation has been reported [2]. At a given resolution, lower Rz factors tend to be dominated by physiological noise, due to the long volume acquisition time (here up to 8 s). With increasing Rz (and corresponding decreases in volume acquisition time), the impact of physiological noise is reduced, and thermal noise becomes dominant. The balance of these competing effects would also be predicted to have a dependence on resolution, with the peak of maximum tSNR at lower Rx factors for smaller voxels due to the high thermal noise levels. While our data are not entirely consistent with this picture, the significant resolution×Rz interaction suggests that a structured underlying mechanism is driving the complex tSNR behaviour. Furthermore, because no change in the shape of the curves was observed with physiological noise correction, the precise effect of volume-based physiological noise regression on 3D data warrants further investigation, possibly including k-space based corrections [4]. Given the potential that 3D EPI has for enabling high-resolution FMRI, characterization and optimization of these effects could enable these methods to be adopted more broadly.

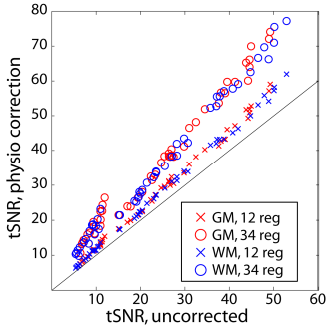

Fig. 3. tSNR improvement with physiological noise correction

[1] Poser *NeuroImage* 2010. [2] van der Zwaag *MRM* 2012. [3] Glover *MRM* 2000. [4] Tijssen *NeuroImage* 2013