Conventional 2D-EPI or Segmented 3D-EPI? A Temporal SNR Study at 3 and 7 Tesla

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Target Audience: This work is primarily targeted at neuroscientists and MR physicists focusing on high resolution functional MRI applications.

Purpose: Recently, segmented 3D-EPI has been proposed for application of BOLD functional MRI at ultra-high fields such as 7 Tesla[1]. Unfortunately, the statistical power, especially of 3D-EPI time series data, is limited by physiological noise (signal fluctuations due to breathing, etc.): with increasing base SNR the temporal SNR (tSNR=AVG/STD with respect to time) tends towards a constant value, which is smaller the more shots per EPI-volume are required[2]. This work compares the tSNR and signal sensitivity (tSNR/√acquisition time) characteristics of 2D-EPI vs. 3D-EPI under "real-life" conditions, i.e. for different low- and high resolution protocols for fast fMRI data acquisition at 7 and 3 Tesla.

Methods: All experiments were performed on Siemens (Erlangen) MRI scanners, 3T Skyra and Magnetom 7T, both utilizing a 32 channel head array for signal reception. At 7T RF transmission was performed using a birdcage coil surrounding the receive array. For each field strength (3T/7T) four "low-" (3mm/2mm isotropic) and four "high-resolution" (1.5mm/1mm isotropic) whole brain protocols were prepared according to Table 1 based on a conventional slice-selective 2D-EPI sequence (a) and a custom 3D-EPI sequence with three different configurations: no slice acceleration (b), acceleration by means of parallel imaging (PI) and/or partial Fourier acquisition (c) and optimized for high sensitivity (d). The latter utilized a simple water excitation method based on a single rectangular pulse proposed recently[3] in order to reduce "dead time" largely caused by fat saturation as in (a-c). With the slice orientation changed to sagittal the primary phase encoding direction was still along anterior-posterior. However, compared to (b,c) the protocol requires more steps in the secondary phase encoding dimension to cover the field-of-view in left-right direction. Temporal SNR computation was performed from 96 images following co-registration and detrending using FSL[4]. The 3mm 2D-EPI protocol (a) at 3T and the corresponding optimized protocol (d) are utilized for bilateral finger tapping fMRI (blocked paradigm: 20s rest/tapping, alternating for 4:20 minutes). GLM statistical analysis was performed using FSL. At no stage smoothing was applied.

	3T (TE=30ms)		7T (TE=26ms)	
Protocol	**3.0mm**	**1.5mm**	**2.0mm**	**1.0mm**
(a)	**2D-EPI (axial)**			
PI factor	-	3	2	3
PF factor	-	-	-	6/8
TR [ms]	2720	6060	3200	8800
(b)	**3D-EPI, no slice acc. (axial)**			
PI factor	-	3x1	2x1	3x1
PF factor	-	-	-	6/8
TR [ms]	2650	5920	3200	8800
(c)	**3D-EPI, slice acc. (axial)**			
PI factor	1x2	3x2	2x2	3x2
PF factor	-	-	1x7/8	6/8x7/8
TR [ms]	1330	2920	1400	3800
(d)	**3D-EPI, optimized (sagittal)**			
PI factor	2x2	2x2	2x2	3x2
PF factor	1x7/8	7/8x6/8	1x6/8	6/8x6/8
TR [ms]	939	2510	1280	3800

Tab. 1 *Summary of imaging protocols.*

Results: Fig. 1 shows representative axial slices on the example of protocols (a) and (d) for the finger tapping fMRI results (left), the tSNR maps at all field strengths and resolutions (center) and example magnitude images for 1mm isotropic resolution at 7T (right). The histograms in Fig. 2 summarize tSNR for all protocol types on the example of 3T.

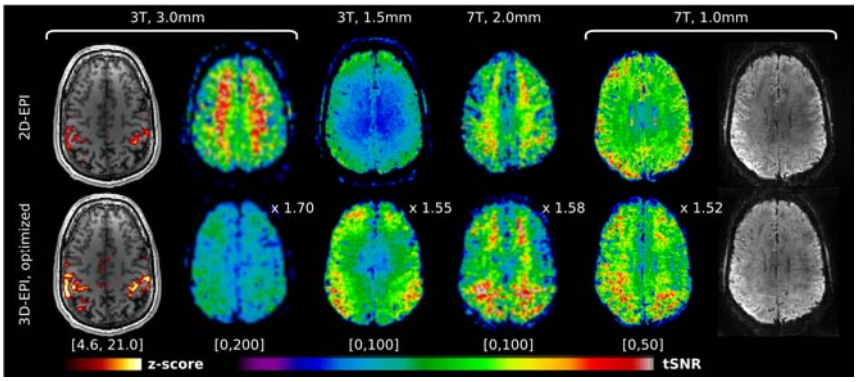

Fig. 1 *Left: Detected activation for finger tapping fMRI with conventional 2D-EPI (top) and optimized 3D-EPI (bottom). Center: tSNR maps (numbers in brackets denote the respective ranges). The bottom map values have to be scaled by the indicated factors to account for the increased temporal resolution. Right: example magnitude images at 7T and 1mm isotropic resolution.*

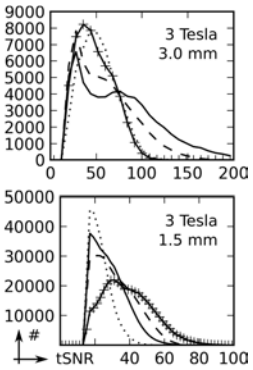

Fig. 2 *Histograms of tSNR ignoring different temporal resolutions (solid=a, dashed=b, dotted=c, +=d).*

Discussion: Fig. 1 demonstrates an increase in tSNR at higher spatial resolution for 3D- compared to 2D-EPI, both at 3T and 7T. Furthermore, even though tSNR at 3T and 3mm resolution is reduced, using the optimized 3D-EPI sequence results in a 70% increase of sensitivity due to PI and, therefore, a more robust detection of activation (higher z-scores) and a larger activated volume. The fact that the optimized, PI-accelerated sagittal protocol results in increased tSNR compared to the corresponding PI-accelerated axial protocol (cf. Fig. 2) is largely due to employing water excitation instead of conventional fat-saturation[3] since the latter suffers from signal suppression due to unwanted magnetization transfer effects [5].

Conclusion: As expected, segmented 3D-EPI has higher tSNR than 2D-EPI at high imaging resolution, which was confirmed at 7T and 3T. However, 3D-EPI is also useful at typical coarse resolutions, as it was shown in the 3T fMRI example. Here, 3D-EPI outperforms conventional slice-selective 2D-EPI, since parallel imaging acceleration in two phase encode directions was applied. This results in a significant sensitivity advantage, which translates to more robust fMRI results. Unexpectedly, the observed tSNR advantage at 7T with 1mm vs. 2mm isotropic resolution was not as clear as at 3T with 1.5mm vs. 3mm, which might be related to different versions of the vendor-provided image reconstruction algorithms at 3T and 7T. The increased sensitivity, however, remains a clear bonus for 3D-EPI at 7T and 3T.

References: [1] Poser et al., NeuroImage 52, 2010; [2] Van der Zwaag et al., Magn. Reson. Med. 67, 2012; [3] Stirnberg et al., Proc. Intl. Soc. ISMRM 21, 2013; [4] Jenkinson et al., NeuroImage 62, 2012, [5] Shin et al., Magn. Reson. Med. 62, 2009