# Investigating the impact of temporal signal fluctuations and local effective echo times on indices of BOLD sensitivity in healthy subjects and tumor patients at 7T.

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Synopsis

**Temporal signal fluctuations (tSNR) and local effective echo time ($TE_{local}$) are explored and their influence on BOLD sensitivity is investigated at 7T for healthy subjects and tumor patients, where prominent spatial variations in those two measures are expected. We show that tSNR may indicate sufficient sensitivity to detect activation but that BOLD sensitivity may be dramatically reduced by changes in $TE_{local}$ close to pathologies and vital brain functions (motor, speech, auditory). Neglecting local TE variations can thus lead to false negative results in clinical fMRI. We thus suggest a new BOLD sensitivity metric based on $TE_{local}$·tSNR.**

Purpose

To explore spatial variations in temporal signal-to-noise ratio (tSNR) and echo time ($TE_{local}$) and develop the most reliable metric for BOLD sensitivity estimation.

Introduction

Estimating BS is useful for fMRI studies in selecting the sequence (simultaneous-multi-slice, 3D or slice-by-slice EPI) and optimizing parameters[1–3], but also in the assessment of the reliability of the functional results (considering false negatives and positives)[4]. BS is commonly estimated using two different metrics: 1) the product of the local effective echo time and the image signal ($TE_{local}$·S)[2,5] or 2) tSNR[3,6]. We explore the pitfalls of each metric, suggest $TE_{local}$·tSNR as a more reliable measure of BS and investigate all three approaches at 7T in healthy volunteers and tumor patients, where prominent regional variations are expected.

Theory

Gradients in $B_0$, induced by tissue-air susceptibility differences, introduce intravoxel dephasing and signal loss, but also local modifications of the effective echo time through shifts in the k-space signal[7]. If $TE_{local}$ is reduced by the gradients, image signal (S) increases, but BS decreases, as BOLD contrast has less time to develop. In such regions BS metric 2 (tSNR) overestimates BS. If, on the other hand, the $TE_{local}$ is increased, signal is reduced, but BOLD contrast increases. Here tSNR underestimates BS unless $TE_{local}$ is so long that the signal is not acquired. At this point, signal, tSNR and BS suddenly fall to zero (type 2 signal loss). Metric 1 ($TE_{local}$·S) considers both signal and $TE_{local}$ changes, but does not identify dynamic physiological and technical noise sources, which are included by substituting S by tSNR. We, thus, suggest using a third metric: $TE_{local}$·tSNR as a more reliable BS measure.

Methods and analysis

Measurements were carried out with a 7T Siemens scanner and a 32-channel head coil. Field maps (multi-echo GE, TEs=[5,10,16]ms, TR=400ms, 1.7x1.7x3.0mm$^3$, bandwidth=540Hz/pix) and a 5 min long resting state scan (EPI, TE=22ms, TR=2000ms, 1.7x1.7x3.0mm$^3$, bandwidth=1447Hz/pix) were acquired for 3 volunteers and 11 tumor patients. Field maps were calculated using the Hermitian inner product[8]. $TE_{local}$ maps were derived from field gradient according to Ref.[9] and normalized to TE=22ms. Voxels with type 2 signal loss (TE>47ms) were marked white in $TE_{local}$ maps. EPI runs were coregistered to GE scans, distortion corrected, and mean signal S and tSNR were calculated.

Results

Fig. 1 shows normalized $TE_{local}$ and two BS maps calculated according to metric 1 and 2 for a representative healthy subject. BS metric 1 shows high values in CSF and gray matter and low values in white matter (Fig.1c), whereas metric 2 shows rather the opposite: higher values in homogeneous white matter (Fig.1d). This does not, however, include variations due to changes in $TE_{local}$ (Fig.1b). Since metric 1 does not consider temporal variations in signal, as tSNR does, it was

omitted from further consideration.

Variations in $TE_{local}$ and the differences in BS metric 2 and 3 representative for healthy volunteers are presented in Fig. 2. In a ventral slice (number 3) tSNR values are highest (about 70) close to sinuses and ear canals (Fig.2e, see arrows), where $TE_{local}$ is strongly reduced (Fig.2d, by about 50%). The reduction in BS due to short TE is apparent in $TE_{local}$·tSNR maps (reducing BS values from 70 to 35 in Fig.2f at the arrow positions). $TE_{local}$ is also reduced by up to 40% in the basal ganglia (Fig.2d, slice 12, see arrows). Ventrally, close to the ear canals and dorsally in frontal lobes the $TE_{local}$ increases strongly leading to type 2 signal loss (Fig.2d and f, white regions).

Results in the four tumor patients with the strongest gradients in $B_0$ are presented in Fig. 3. In all cases large regions with strongly reduced $TE_{local}$ (by about 50%) but relatively high tSNR were found in the proximity of pathologies (see arrows). For patient 1 and 2 this occurred close to primary motor cortex, for patient 3 near Broca's area and patient 4 near auditory cortex. In BS metric 3 the tSNR values are readjusted accordingly (Fig.2f).

Discussion and conclusion

We have shown that tSNR maps may indicate sufficient BS to detect activation but that BS may be dramatically reduced by changes to $TE_{local}$. This effect was prominent at 7T in patients with large oedema, postoperative cavities close to vital brain functions (motor, speech, auditory). Neglecting changes to $TE_{local}$ can lead to false negative results in clinical fMRI being hard to detect, because underlying EPI and tSNR indicate that there is adequate signal. We therefore advise that both, $TE_{local}$ and tSNR, be considered in the assessment of bold sensitivity.

Acknowledgements

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References

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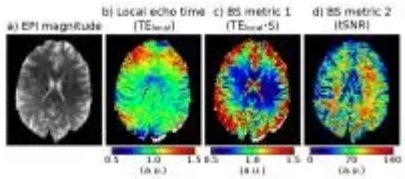
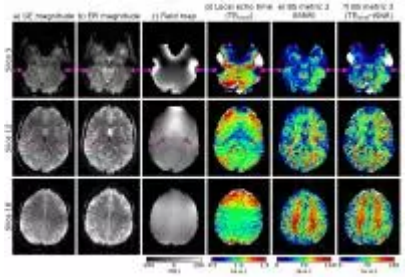
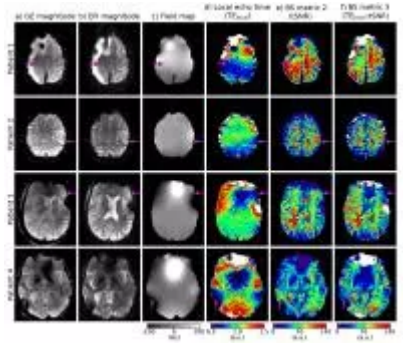
Figures




Spatial differences between $TE_{local}$ (b), BS metric 1 (c) and metric 2 (d) in representative healthy subject. $TE_{local}$·S metric neglects physiological noise showing high values in ventricles and gray matter, in contrast to tSNR. Additionally, values in white matter are low in $TE_{local}$·S in comparison with tSNR.



The spatial distribution of $TE_{local}$ (d), BS metric 2 (e) and metric 3 (f) in a representative healthy subject. Strong $TE_{local}$ reduction (-50%) is observed in regions with high tSNR (marked with arrows). BS metric 3 includes this effect, reducing BS from around 70 (as in tSNR map) to 35.



Spatial differences between $TE_{local}$ (d), BS metric 2 (e) and metric 3 (f) in four patients with strongest $B_0$ gradients. Strong $TE_{local}$ reduction (-50%) is observed close to pathologies, where tSNR was high (see arrows). BS metric 3 considers this effect, reducing BS values in these regions.