Dependence of acquisition trajectory on BOLD sensitivity changes due to magnetic susceptibility differences in the brain

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Introduction

Magnetic susceptibility differences between air and tissues lead to magnetic field inhomogeneity in the brain. This field inhomogeneity can result in many artifacts for both gradient and spin echo acquisitions, but is particularly detrimental to functional MRI studies using the gradient echo BOLD technique. The artifacts that result from field inhomogeneity can include: geometric distortions, signal loss, and also shifts in effective echo times that can change sensitivity to the BOLD signal [1]. The exact effect of the field inhomogeneity gradients on the sensitivity of the BOLD signal depend on the timing of the acquisition, the acquisition trajectory, and the magnetic field map. In this work, BOLD sensitivity changes caused by susceptibility induced echo time shifts are compared for four common acquisition trajectories, using EPI and spiral readouts, with the same echo time. This is done by comparing a hypercapnic challenge, otherwise known as a breath hold (BH) task [2] for all 4 trajectories, as well as a comparison to the expected BOLD sensitivity based on echo time shift.

Method

In vivo BOLD sensitivity experiment

Three functional BH experiments were conducted on a Siemens 3 T Trio scanner using different k-space trajectories for each experiment. The trajectories used were: EPI with phase encoding in the A/P direction (EPI up), EPI with phase encoding in the P/A direction (EPI down), and a Spiral In/Out sequence. Additionally, a fieldmap was collected for determining the theoretical BOLD sensitivity map. T2 and MRPAGE images were acquired for registration purposes. All functional tasks had 20 slices, 4 mm slice thickness, TE 35 ms, TR 2 s, field of view 24 cm, and 64x64 matrix side. The BH task consisted of 36 s rest intervals, interleaved with five 18 s expiration events. Data was analyzed in FSL (fmrib.oxford.ac.uk) to create activation maps. These activation maps are compared to the expected BOLD sensitivity maps based on the field inhomogeneity map for the subject.

Model Based Estimation of BOLD sensitivity

The gradient of the field map was used to determine the spatially varying susceptibility gradients in the x and y directions ($G_{x,susc}$ and $G_{y,susc}$). These were used to calculate the effective K-space trajectory for each voxel ($K_{x,eff}$ and $K_{y,eff}$). The time point when the K-space trajectory was closest to zero was used to determine the effective echo time (TE_{eff}) as shown in [3]. Some areas miss the center of K-space entirely. A ratio between BOLD percent signal change nominal to BOLD percent signal change effective was calculated using gray matter T2* values at 3 T [4]. The expected percent signal change (PSC_{eff}) is given in the expression below (1-2), along with a sensitivity factor that reflects the susceptibility induced change in BOLD sensitivity (PSC_{ratio}) (3).

(1)
$$PSC_{eff} = \frac{\exp\left(-\frac{TE_{eff}(r)}{T2^*_{act}}\right) - \exp\left(-\frac{TE_{eff}(r)}{T2^*_{rest}}\right)}{\exp\left(-\frac{TE_{eff}(r)}{T2^*_{rest}}\right)}$$

(2)
$$PSC_{nom} = \frac{\exp\left(-\frac{TE}{T2^*_{act}}\right) - \exp\left(-\frac{TE}{T2^*_{rest}}\right)}{\exp\left(-\frac{TE}{T2^*_{rest}}\right)}$$

(3)
$$PSC_{ratio} = \frac{PSC_{eff}}{PSC_{nom}}$$

Results and Discussions

The PSC_{ratio} maps show large regions with no BOLD sensitivity, on the ventral side of the brain, especially in the frontal and temporal lobes. These regions correspond well with the actual BH task PSC results (Figure 1). Specifically areas with no BOLD sensitivity may have PSC values less then 0. Areas of lowered percent signal change due to echo time shift around -30% and 30% are also shown in the PSC_{ratio} maps, through these are harder to interpret. While the BH task is expected to provide near global activation, these activations are not expected to be uniform throughout the brain, but spatially dependent on local vasculature responses. Spatial smoothing during FSL analysis (2 mm) and registration to MNI space may have affected the spatial extent of the actual measured PSC maps, as well.

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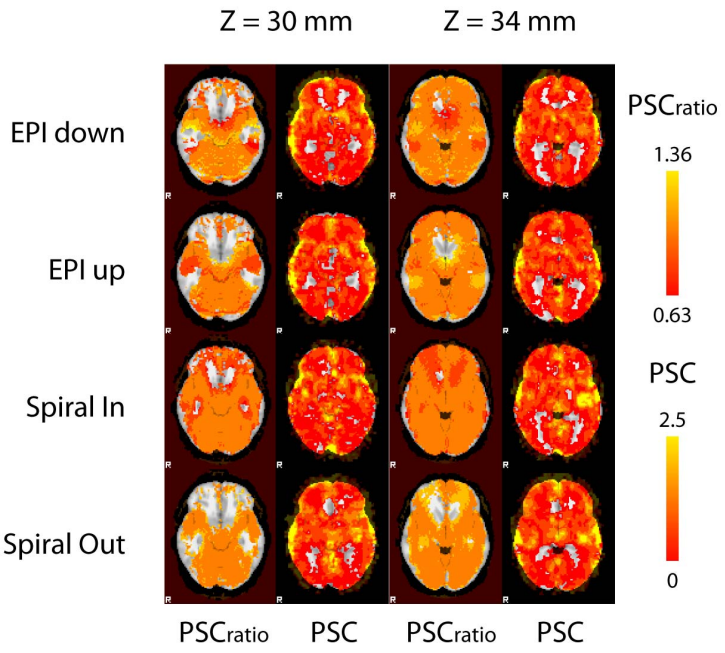

Figure 1 ⇒. PSC_{ratio} and measured PSC maps for two different slice positions (z=30 mm, z= 43 mm) and for 4 trajectories, EPI down, EPI up, Spiral In and Spiral Out. In the PSC_{ratio} maps, grey regions represent voxels which failed to capture the center of k-space and have no BOLD contrast. They are expected to correspond to grey regions in the Z stat which are insignificant. In the measured PSC maps, grey regions represent percent signal change values less then zero.

References

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