Effects of a slice-dependent template-based gradient compensation method on the BOLD sensitivity

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INTRODUCTION Gradient-echo echo planar imaging (EPI) is the most common imaging method for functional magnetic resonance imaging (fMRI). However, this technique is limited in the presence of anatomy-related susceptibility-induced field gradients in the human head, especially in the prefrontal cortex. These field gradients can cause severe signal dropouts as well as local geometric distortions. Previous studies demonstrated the compensation of local signal losses using additional gradient moments for each imaging direction. Recently it has been shown that the use of a slice-dependent template-based gradient compensation method results in improved BOLD sensitivity (BS) in areas affected by strong susceptibility gradients (e.g. the orbitofrontal cortex) [1]. The aim of this work is to evaluate in detail the BS changes for a compensated measurement in relation to an uncompensated measurement.

METHODS All measurements were performed on a 3T Magnetom Trio Tim scanner (Siemens, Erlangen, Germany) equipped with the AutoAlign module. Eight subjects (5 female, 3 male) participated in the study. A modified EPI sequence, which allows free choice of additional compensation gradients in each imaging direction, with distortion correction and Prospective Acquisition Correction (PACE) (40 slices, slice thickness 3 mm, matrix size 64x64, FoV 192 mm, TE 30 ms, TR 2.5 s) was used with and without compensation gradients for signal dropout reduction. The template-based compensation gradients were derived from field maps by averaging the susceptibility-induced gradients of four subjects and were optimized for the orbitofrontal cortex and the amygdala regions. For the functional evaluation the subjects performed six repetitions of alternating periods of breath-holding and self-paced breathing (40 s blocks, in total 240 s). The BS for all compensated slices was calculated using $\mathrm{BS} = \mathrm{I} * \mathrm{TE} * \exp[-(\mathrm{TE} - \mathrm{TE}_0)/\mathrm{T}_2^*]$ [2], where the measured echo planar images were used for the signal intensity I, the local echo time was calculated using $\mathrm{TE} = (\mathrm{TE}_0 + \Delta\mathrm{TE}_0)/\mathrm{Q}$ with the measured susceptibility-induced gradients and the given compensation gradients, where TE_0 is the nominal echo time in the absence of susceptibility (usually equal to the echo time entered on the scanner interface). T_2* was set to 60 ms. Functional MRI data for both acquisitions were processed using SPM8 (Wellcome Trust Centre for Neuroimaging, London).

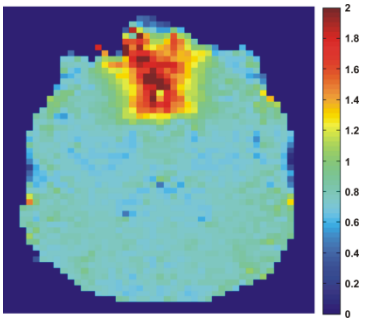

Figure 1: Ratio map of the BS change between the compensated and uncompensated measurement for one slice of a typical subject.

RESULTS and DISCUSSION For a typical subject, an analysis of the BS changes using the template-based compensation was done. Figure 1 shows a ratio map between a compensated and uncompensated measurement for one slice. The BS is significantly increased in the target area, the orbitofrontal cortex, and in the rest of the slice it is slightly decreased. This shows a locally effective compensation. Figure 2 shows the distribution and Figure 3 the cumulative sum of the BS changes for all 15 compensated slices. In addition, the percentiles with P_{25}=0.87, P_{50}=0.99 and P_{75}=1.17 are given (where a percentile of 1 represents no change in BS). The ratio of signal loss to signal gain is well balanced and shows no global improvement, but allows the sensitivity in target areas to be optimized. A ROI-based analysis results in an improved BOLD sensitivity of 43/30% in the orbitofrontal cortex/amygdala areas, respectively. The functional BS experiment shows also improved fMRI sensitivity in the target area, here given for the orbitofrontal cortex, Figure 4a. As expected, regions outside the target areas, but inside compensated slices, show decreased BS, Figure 4b. All areas outside the compensated slices show no difference in the fMRI statistical maps, which is a property of the slice-selective compensation method.

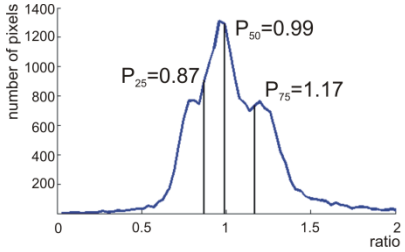

Figure 2: Distribution of BS changes for the ratio between compensated and uncompensated measurements for all compensated slices.

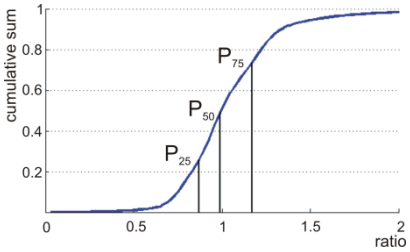

Figure 3: Cumulative sum of the BS changes according to Figure 2. The percentile P_{25}, P_{50} and P_{75} are shown in addition.

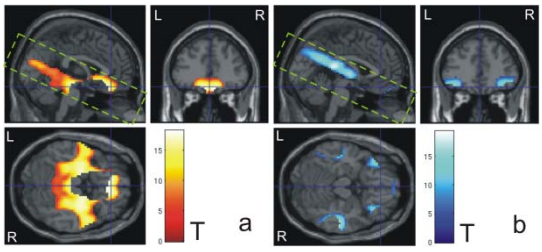

Figure 4: Statistical maps of the hypercapnia experiment due to the compensation gradients, (a) show t-score maps with increased and (b) with decreased activation; crosshairs show the orbitofrontal cortex. The location of the compensated slices is shown by the green volume box.

CONCLUSION The use of the slice-dependent gradient compensation method improves BOLD sensitivity in areas where the compensation is optimized (e.g. the orbitofrontal cortex) and which are otherwise affected by signal losses. It is shown that the given method is locally effective and simultaneously the ratio of signal gain to signal loss for all compensated slices is well balanced. These results are affirmed in a functional experiment. The combination of slice-dependent compensation and template-based correction allows the use for event-related functional experiments, where a high temporal resolution is needed.

REFERENCES

[1] Rick et al., Magn Reson Mater Phy 23:165-176 (2010), [2] Deichmann et al., Neuroimage 19:430-441 (2003).

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