Contribution of residual BOLD susceptibility-induced local field gradients in diffusion fMRI

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Introduction A transient decrease of water diffusion has been reported during activation of human visual cortex using a MRI sequence sensitized to diffusion by a monopolar pair of gradient (MPG) pulses (1). However, MPG diffusion MRI remains sensitive to variations of BOLD susceptibility-induced background field gradients (2). Our aim was to investigate the contribution of those gradients by comparing diffusion fMRI acquisitions obtained from a MPG sequence and a twice refocused spin-echo sequence sensitized to diffusion by an interleaved pair of bipolar gradient pulses, which is immune to background susceptibility effects (3).

Principles In a conventional MPG sequence a pair of gradients with identical polarity is used. In this condition the local background field gradients caused by blood deoxy-hemoglobin produces a spatial modulation of the net MPG signal (Fig.1a) which can be described as a decrease of effective b-value:

$$b_{eff} = b_{org}\left\{1 - 0.5\gamma^2\Delta\sigma^2 D(TE - \Delta/2)^2\right\}, \qquad [1]$$

where b_{org} is the original b-value from the MPG, γ is the gyromagnetic ratio, Δ is the intergradient interval, σ is the standard deviation of the background gradient distribution and D is the diffusion coefficient (2). In contrast a bipolar, twice-refocused sequence is not sensitive to background gradients (3) (Fig.1b).

Material & Methods The study was performed on 3 volunteers using a 3T whole-body scanner equipped with a 8-channel phased-array coil (Siemens, Erlangen). Spin-echo EPI sequences with monopolar or twice-refocused bipolar gradients were implemented with b-values of 1200 and 2400 s/mm^2. Acquisition parameters were: voxel size=3.8^3 mm^3 (8 slices), partial Fourier transform (6/8 k-space), TE=86ms/TR=1s, bandwidth=1446Hz. Visual stimulation was obtained from a flickering dartboard during 3 epochs of 20 seconds (or TRs) separated by a 20 second (or TR) interval. The acquisition was repeated three times at each b-values for the 2 diffusion-sensitized sequences. BOLD fMRI images were also acquired to define areas with potentially largest deoxyHb induced background field gradients using a GE EPI sequence with the same parameters (except TE=30ms). Activation maps were then calculated individually for each subject from the b=2400 s/mm² bipolar data set using SPM5b software and a volume of interest (VOI) centered on calcarine fissures was defined from the voxels classified as activated (0.001 threshold) and subsequently used for all data sets. For each combination, mean signals at rest and activation were calculated respectively by averaging voxel values in the VOI through rest and activation frames. The fractional signal change was calculated by dividing the difference of activated and the rest signals by the mean rest signal, for each b value and each diffusion sequence.

Results & Discussion Activation of visual cortex was well defined in all 3 subjects (Fig.2). A diffusion-weighted signal increase was found for each b-value for the bipolar sequence, and the signal change dS/S was larger with the highest b value, as expected from of a slow water diffusion pool swelling model (4) (Table 1). The signal increase at b=1200 s/mm^2 was not significantly different between the monopolar and bipolar sequences suggesting susceptibility effects in the monopolar sequence were not significant at this b value. By contrast, the signal change at b=2400 s/mm² was significantly lower for the monopolar sequence, suggesting that BOLD induced background field gradients were significantly reducing the b value and the diffusion activation effect.

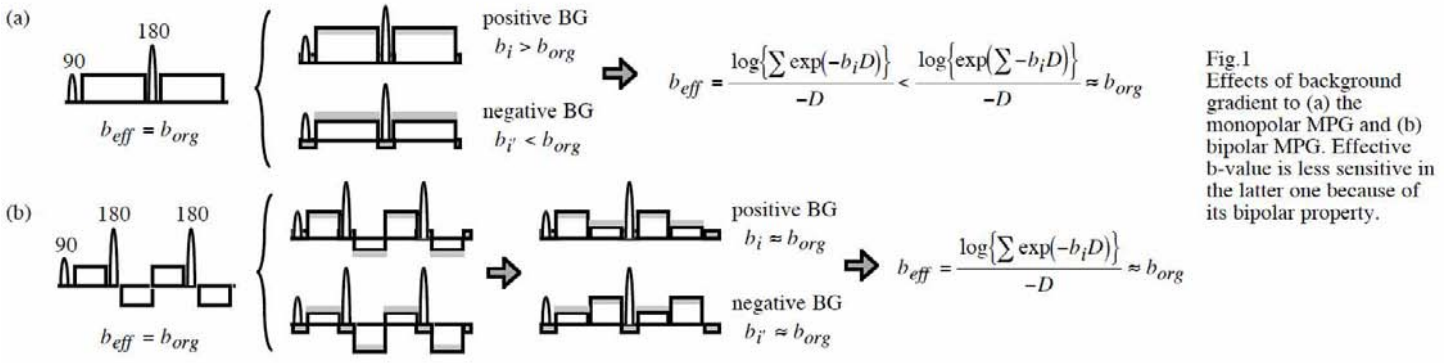

Fig.1 Effects of background gradient to (a) the monopolar MPG and (b) bipolar MPG. Effective b-value is less sensitive in the latter one because of its bipolar property.

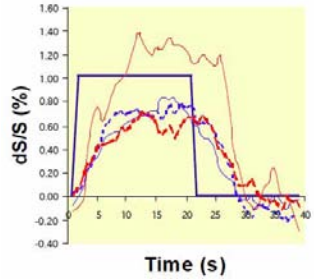

Fig.2 Averaged %signal change obtained using monopolar MPG with b value of 1200 (dotted blue) or 2400 (solid blue) or bipolar MPG with that of 1200 (dotted red) or 2400 (solid red) during a single epoch.

Table.1 %signal changes

Sub.1	monopolar	bipolar
b2400	0.91±0.21	1.54±0.20
b1200	1.07±0.16	0.95±0.15
Sub.2	monopolar	bipolar
b2400	0.68±0.18	1.20±0.21
b1200	0.79±0.08	0.61±0.14
Sub.3	monopolar	bipolar
b2400	0.73±0.19	0.97±0.16
b1200	0.67±0.10	0.69±0.15

Conclusion Although voxel misregistration resulting from eddy-current induced geometric distortion present with the monopolar sequence cannot be fully ruled out at this stage, these preliminary results which must be confirmed suggest that a bipolar gradient sequence should be used for diffusion fMRI to prevent signal contamination by BOLD related susceptibility induced background gradients and to increase sensitivity, especially at high b values and high Bo. Comparison of monopolar and bipolar activation results could also potentially give as estimate of the standard deviation of the background gradient distribution from Eq.[1]. Furthermore, such as bipolar sequence would also be less prone to eddy-current induced geometric distortion (3).

Reference 1.Darquie et al. (2001) PNAS 98, 9391-9395; 2.Kennan et al (1995) in Diffusion and Perfusion MRI, Raven Press, p.110-121; 3.Reese et al. (2003) MRM 49, 177-182; 4. Le Bihan et al. (2006) ISMRM.