# Effects of background suppression on the sensitivity of dual-echo arterial spin labeling MRI for BOLD and CBF signal changes

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**Introduction** Dual-echo arterial spin labeling (DE-ASL) techniques enable simultaneous acquisition of BOLD and ASL fMRI data, since the images acquired at the first echo time are perfusion (CBF) weighted, while the images from the second echo are primarily $T_2^*$ weighted, thus sensitive to the BOLD signal[1]. This also makes these techniques interesting for $CMRO_2$ measurements by means of calibrated BOLD fMRI and measurements of cerebrovascular reactivity (CVR) by, for example, a hypercapnic challenge. Unfortunately, ASL techniques in general suffer from low SNR, and therefore have low statistical power for functional studies. One of the main sources of noise are physiological artifacts, and a frequently-applied method to increase the ASL SNR is to employ background suppression (BGS) by incorporation of additional inversion pulses in-between the labeling and imaging modules[2]. However, the application of these BGS-pulses in DE-ASL sequences is generally believed to be undesirable, because by attenuating the background signal these pulses would also decrease BOLD SNR and therefore the sensitivity for the detection of (functional) activation. Nevertheless, because BOLD SNR is much higher than ASL SNR, the level of background suppression could be adjusted so that the ASL and BOLD SNRs are comparable. In this study, the influence of the amount of background suppression on the relative ASL SNR and BOLD SNR was studied in an fMRI visual stimulation study, used as a model for a typical CVR measurement.

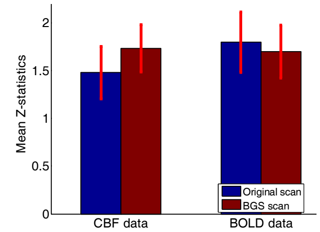


Figure 1: Mean statistics values for activated voxels for CBF and BOLD data for original and BGS

**Methods** Eight volunteers were scanned using pseudo-continuous multi-slice DE-ASL with and without two BGS-pulses (scan parameters: TR=4.0s, multi-slice single shot EPI, TE1/TE2=10/26.7ms, label duration/post label delay=1650/1525ms, BGS-pulses timing=1680/2760ms after a saturation pulse preceding the labeling, 17 slices, voxel size: 2.75x2.75x6mm, 75 pairs of label and control images, ascending slice order). Due to the fact that a multi-slice sequence was used, the amount of BGS, defined as the reduction in signal after the application of BGS-pules compared to the non-background suppressed scan, decreased with increasing slice number, being highest in the lower parts of the brain. Because our ultimate goal is to optimize the DE-ASL sequence for hypercapnic reactivity measurements the paradigm was designed to resemble the general layout of such experiments, and consisted of three 2 min blocks of resting periods (r) interlaced with two 2 min blocks of visual stimulation (A) (rArAr=10min). Post-processing consisted of realignment of the data (based on the second echo control images) with FSL MCFLIRT. BOLD and perfusion weighted pseudo Z-statistic maps were calculated with FSL FABBER using Bayesian inference methods which, by extracting probabilistic estimates of the percentage change in $R_2^*$, CBF and static magnetization, yields better estimates than analyzing the data separately with general linear models[1]. To select activated regions, thresholds ($Z \geq 1$) were applied to these maps. The perfusion activation maps and BOLD activation maps were intersected to create a "visual cortex" mask. Using this mask, the mean Z-statistics values for BOLD and perfusion were calculated for all the slices for each subject. Only slices with more than 20 voxels in the visual cortex-maps were included for further analysis. For each slice the BOLD and perfusion activation ratios were calculated by dividing the (whole slice) mean statistics of the BGS scan by the mean statistics of the non-suppressed scan for each subject. To illustrate the effect of background suppression on the relative sensitivity for functional activation, these ratios were plotted for BOLD and ASL data as a function of background suppression.

**Results** Measurements confirmed that the level of background suppression decreases with increasing slice number with little inter-subject variation. This indicates that different slices can indeed be used to study the effects of the level of BGS on BOLD and perfusion sensitivity. Figure 1 shows the effect of background suppression on the overall mean Z-statistics averaged across all subjects. For BGS scans the mean perfusion statistics value was significantly higher ($p=0.033$), and the BOLD statistics value non-significantly lower ($p=0.242$), than for the non-BGS scans. Figures 2 and 3 show the relationships between the activation levels on the original non-background suppressed scans and the scans with BGS for perfusion and BOLD-weighted data, respectively. Background suppressed scans show increased levels of significance for perfusion activation(fig. 2), while the relationship is reversed for BOLD fMRI data, showing decreased mean Z-scores for BGS scans (fig. 2). The ratios of the mean Z-values for perfusion-weighted data also show the increased sensitivity for activation detection for the background suppressed images, while those for BOLD-weighted data show a reduction of less than 40% in Z-statistics values, even with high levels of BGS, i.e. little residual background signal.

**Conclusion and discussion** DE-ASL makes the simultaneous acquisition of BOLD and perfusion-weighted data possible. The addition of two background suppression pulses at 1680/2760ms after the saturation pulse increases the sensitivity to CBF changes by decreasing the level of physiological noise, without significantly decreasing the functional sensitivity of BOLD data. This makes DE-ASL with BGS an excellent candidate for calibrated BOLD fMRI and cerebrovascular reactivity measurements. The small decrease in BOLD functional sensitivity suggests BGS levels could be further increased without reducing the BOLD sensitivity significantly. In future work the BGS levels will be optimized further and their effects on DE-ASL sensitivity studied in combination with other read-out schemes.

**References** [1] M. W. Woolrich, et al, *MRM* (56:4), 2006. [2] F. Q. Ye, et al, *MRM* (44:1), 2000.

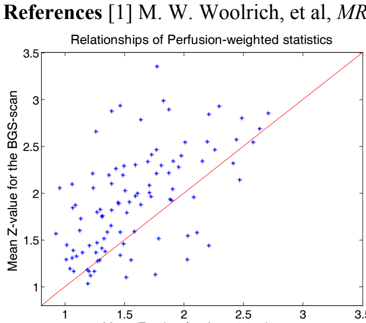


Figure 2: Mean perfusion-weighted Z-statistics values for the BGS scan vs. the original non-BGS ASL scan. The red diagonal line indicates the x=y line.

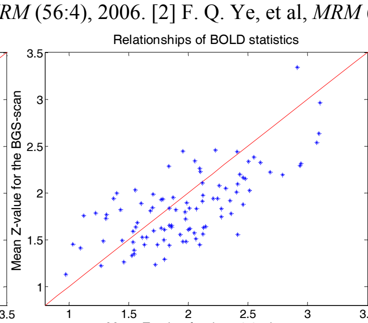


Figure 3: Mean BOLD Z-statistics value for the BGS scan vs. the original non-BGS ASL scan. The red diagonal line indicates the x=y line.

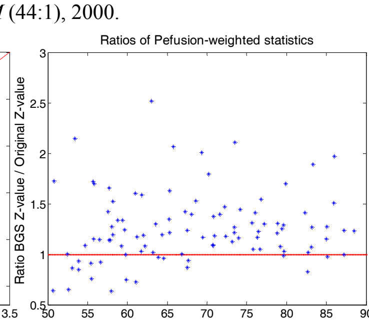


Figure 4: Ratio of the mean statistics values for perfusion-weighted data. The data suggests an improvement with the use of background suppression pulses.

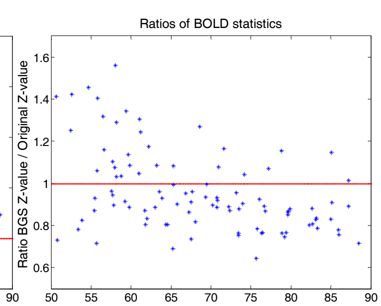


Figure 5: Ratio of the mean statistics values for BOLD data indicating that the functional sensitivity of these data is acceptable even at low levels of