# Adaptive averaging improves the Signal to Noise Ration in ASL experiments especially at high inflow times

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Introduction: Previously, optimal design strategies have been proposed [1, 2], which aim at optimally sample the inflow of labeled blood in Arterial Spin Labeling (ASL) experiments. However, only the sampling scheme was optimized, but the inherent Signal to Noise Ratio (SNR) of each time point was not taken into account. But low SNR and physiological noise are a challenge, especially at inflow times (TI) above 2500ms. In conventional ASL sequences a constant number of averages is acquired for each inflow time. By imaging time series from inflow times of 500ms to over 3000ms a high number of averages are necessary to guaranty sufficient SNR. This automatically leads to very long scan times, which are not convenient for every day routine. In this work, a 3D-GRASE sequence is presented, which is capable of adaptive averaging, allowing the acquisition of higher TIs more often than lower ones. Due to this scan time can be halved with still sufficient SNR at inflow times above 2500ms.

Material and Methods: All ASL experiments were performed on a 3T scanner (Siemens Magnetom Trio) with a 32 channel head coil, at two healthy volunteers (male, 33 and 30 years). A 3D-GRASE ASL sequence [3] was used with a spatial resolution of 3.3mm x 3.3mm x 3.3mm.
For the distribution of the adaptive averages three modes are possible: quadratic, linear or equal (which corresponds to the normal mode). The distribution works as follow: the total number of images measured by the scanner is calculated by multiplying the number of averages with the number of TIs. An internal algorithm distributes the total number of images linearly or quadratically to the different inflow times. For each mode two time series (start 300ms, increment 500ms, with seven TI and six/three averages) were imaged. The distribution with six averages is as follows: quadratic mode (1,2,3,5,7,10,14), linear mode (2,4,5,6,7,9,9) and equal mode (6,6,6,6,6,6,6). The total scan time was 10 minutes, remaining the same for each mode. To measure SNR a large region-of-interest (ROI) was placed in a air region of the ASL difference images and the standard deviation of the noise was calculated for every TI and every imaging mode. A second ROI was put in a region with high signal intensity (compare figure1; right side). The SNR is calculated out of the ratio signal intensity and standard deviation of the noise. For further evaluations it is important to keep in mind that SNR is proportional to the square root of the number of averages ( $SNR \sim \sqrt{n}$ ).

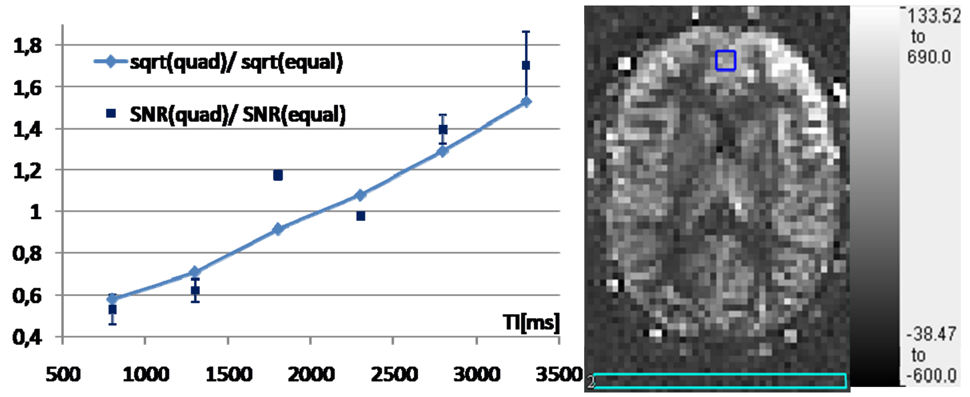


**Figure 1: Left side: theoretical value $\sqrt{n_{quad}} / \sqrt{n_{equal}}$ compared with the ratio SNR(quadratic)/ SNR(equal); Right side: ASL difference image at 2300ms. In the turquoise ROI the standard deviation of the noise is measured.**

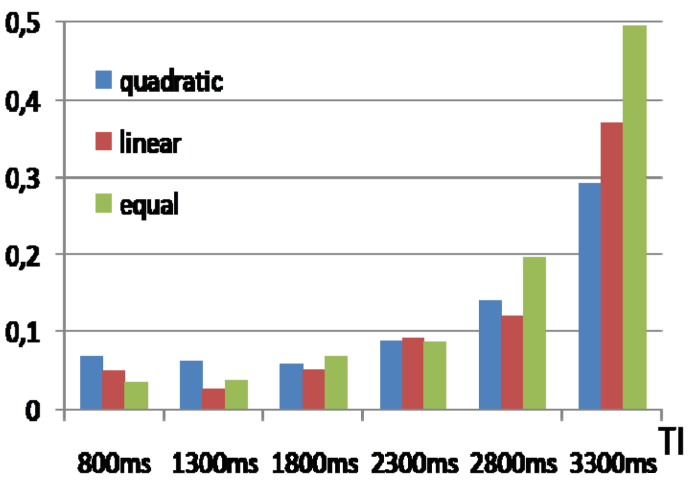


**Figure 2: relative noise of the different imaging modes over TI**

Results: The results shown here were acquired with six averages, but similar results were obtained with three averages. The standard deviation of the noise decreases as expected with $\sqrt{n}$ with a standard deviation of under 10%. The signal intensity depends on physiological parameters and increases up to around 1300ms due to inflow of labeled blood, afterwards it decrease due to T1 relaxation and lack of labeled blood inflow. A SNR level of at least 10 could be achieved for TIs under 2800ms independent of the imaging mode. This is due to the high signal of the labeled blood at these inflow times. A minimum of averages still gives sufficient SNR. For higher inflow times signal intensity decreases due to T1 relaxation and lack of labeled blood inflow. The relative noise can be found in figure 2. The SNR for quadratic and linear mode for high inflow times is raised at least by halve compared to the equal mode. Comparing the theoretical value $\sqrt{n_{quad}} / \sqrt{n_{equal}}$ with the ratio SNR(quadratic)/SNR(equal) shows the expected correlation, displayed in figure 1 (left side).

Discussion and Conclusion: Adaptive averaging can clearly improve the SNR at high inflow times, leading to acceptable scan times for times series above 3000ms. Further improvements especially in the white matter region would be an advantage, as well as the reduction of physiological noise which leads to slightly different results at every scan. Therefore, integrating the SNR of single inflow time points into a real time adaption as shown for the sampling [2] would be beneficial.

References: [1] Xie, J., et al., Optimal design of pulsed arterial spin labeling MRI experiments. Magn Reson Med, 2008. 59(4): p. 826-34.
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