BOLD Contrast-to-Noise Ratio across Field Strengths under Global Stimulus

C. Triantafyllou[1,2], L. L. Wald[2], and R. D. Hoge[3]

[1]A.A. Martinos Imaging Center at McGovern Institute for Brain Research, Brain and Cognitive Science, MIT, Cambridge, MA, United States, [2]A.A. Martinos Imaging Center for Biomedical Imaging, Radiology, MGH, Charlestown, MA, United States, [3]Unite de Neuroimagerie fonctionelle, Montreal, QC, Canada

Introduction

It is well known that BOLD effects increase in amplitude at higher field strength, due to the general enhancement of susceptibility-related effects. Recent studies have demonstrated that the temporal signal-to-noise ratio (SNR) in fMRI time series reaches a plateau that is dictated by the inherent level of physiological variation over time in the subject being studied [1, 2]. Since increases in susceptibility effects that occur with field strength [3, 4] affect both these background changes and the functional responses that are of interest, it is important to determine the net increase in the contrast-to-noise ratio (CNR) that occurs with field strength as it is this latter ratio that is the ultimate determinant of the image *sensitivity*. In addition, a second important criterion is the *specificity* of functional imaging. In BOLD fMRI the major challenge in achieving specificity is the large amplitude of responses in venous blood vessels that drain activated tissue regions. In our previous work [5] we quantified the venous and parenchymal responses at 1.5T and 3T over a range of echo times. The goal of the present study was therefore to characterize the contrast-to-noise ratio of responses to a controlled, global stimulus (hypercapnia), compare the performance at 1.5 and 3 Tesla and permit identification of the optimal echo times under the different conditions.

Methods

MR Imaging was performed on four healthy human subjects, on a Siemens Sonata 1.5T and a Siemens Trio 3T system using an 8-channel phased array receive head coil and a whole-body transmit coil for excitation. BOLD measurements were achieved using a multi-echo gradient-echo EPI sequence. The imaging parameters were TR=3000ms, ten 3mm thick slices, inter-slice gap=1.5mm, 200 frames, FOV=192x192mm^2, matrix=64x64, 9 echo times; TE=11, 23, 35, 47, 59, 71, 83, 95, 107 and TE=8, 21, 35, 48, 61, 75, 88, 101, 115 for 1.5T and 3T respectively. To achieve short echo times, the images were acquired and reconstructed using GRAPPA (acceleration factor 2). Increases of CBF in cortical gray matter were achieved using hypercapnia. Scanning runs lasted ten minutes, including two intervals of two minute duration each, during which the gas breathed by subjects was switched from atmospheric composition medical air to a mixture of 7% CO2 with balance air. The block design paradigm alternated between 2 min periods of baseline and 2 min of global stimulus (breathing CO_2 mixture). Within each scanning session, the BOLD protocol was repeated twice for each subject. BOLD sensitivity was determined from the multi-echo data sets, by fitting a General Linear Model (GLM) plus correlated noise after removing motion and linear trends at each echo [6]. The BOLD signal intensity and its effect size were then estimated at ROIs in cortical gray matter and on large (1-2 mm) venous vessels visible in the T_2*-weighted EPI scans.

Results

Figure 1 illustrates the CNR, provided by the plot of t-statistics, as a function of echo time. CNR reaches the maximum at TE near the T2* of the parenchymal within each field strength (65ms±6.93 for 1.5T (Fig. 1A) and 44.75ms±6.5for 3T(Fig. 1B)). At these peak echo times the percent BOLD signal change at 3T appears to be greater than that seen at 1.5T by a factor of 1.92±0.42. Peak venous CNR was observed at earlier TE, (41ms±6.93 for 1.5T(Fig. 1C) and 26.75ms±6.95 for 3T(Fig. 1D)). Figure 2A shows the absolute change of the BOLD signal normalized to the baseline at both 1.5T and 3T. Measurements were estimated from regions of cortical gray matter and veins. Figure 2B demonstrates the averaged CNR at the peak TE at each field strength and tissue compartment. In parenchymal the averaged t-values at 3T were higher than the 1.5T by a factor of 2. In the veins signal changes at both field strengths were higher than the parenchymal tissue, however at the 3T were higher than the 1.5T by a factor of 1.3.

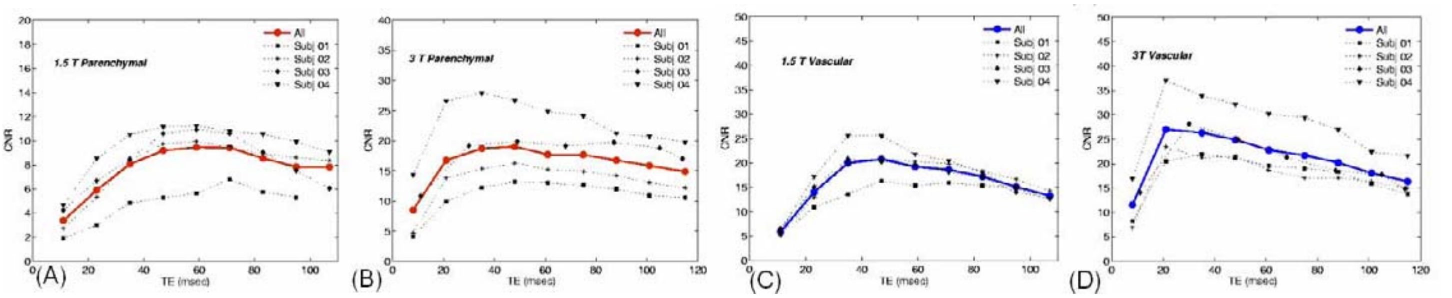

Figure 1. Dependence of CNR on echo time at 1.5T (left) and 3T (right), in regions of parenchymal (A, B) and major vessels (C, D). Measurements are averaged over two scanning sessions for each subject. Red circles and blue squares represent the average data over all subjects for parenchymal and vascular respectively.

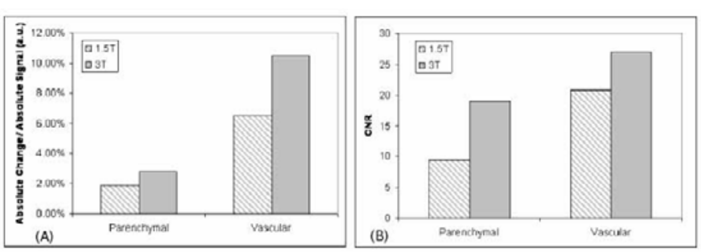

Figure 2. (A) illustrates the absolute change of the BOLD response (as percentage of the baseline) across field strengths for parenchymal ROIs and major veins. In **(B)** CNR measurements derived from the t-statistics maps in areas of cortical gray matter and veins are averaged over two scanning sessions over all subjects. All measurements taken at the respective optimal echo times.

Conclusion

To achieve maximum sensitivity and specificity, functional MRI experiments should be carried out using gradient echo TE values at or above those at which peak parenchymal response was seen to avoid emphasis of venous response components, which can occur even at high field strength. Note that longer echo times will also worsen susceptibility artifacts near air-filled sinuses, so this recommendation only applies when the brain regions of interest are not close to such zones

References

1) Triantafyllou C.,et al, NeuroImage,26:243 50,2005, **2)** Kreuger G.,et al, MRM,46:631-7,2001, **3)** Gati J.S.,et al, MRM,38:296-302,1997, **4)** Turner R.,et al, MRM,29:277-9,1993, **5)** Triantafyllou C.,et al, ISMRM, p1550, 2005, **6)** Hoge R., et al, ISMRM, p1096,2004.

Acknowledgements: NIH P41RR14075, RO1 RR14543, MIND Institute.