A double-excitation approach is the optimal strategy for whole-brain ASL/BOLD acquisitions

Vincent Schmithorst[1,2], Luis Hernandez-Garcia[3], Jennifer Vannest[2], Akila Rajagopal[2], Gregory Lee[2], and Scott Holland[2]

[1]*Radiology, Children's Hospital of Pittsburgh of UPMC, Pittsburgh, PA, United States,* [2]*Radiology, Children's Hospital Medical Center, Cincinnati, OH, United States,* [3]*Functional MRI Laboratory, University of Michigan, Ann Arbor, MI, United States*

Target Audience

Researchers interested in combined ASL/BOLD acquisitions covering the whole brain and/or development of the child connectome.

Introduction

Changes in BOLD signal may result from changes in hemodynamics as well as changes in neuronal activity. This confound is of particular relevance[1] to developmental task-based or intrinsic-connectivity fMRI studies investigating the child connectome. A simultaneous ASL/BOLD acquisition technique covering the whole brain provides a method to investigate changes in blood flow contemporaneously with changes in BOLD signal. We investigate the optimal method to acquire simultaneous ASL/BOLD through the whole brain.

Methods

We compared three possible simultaneous ASL/BOLD acquisition strategies: a single-excitation single-echo technique (e.g. the same images are used for ASL and BOLD contrast); a double-excitation technique (images with a short TE are acquired for ASL contrast immediately after application of the ASL tagging pulse; afterwards, images with a longer TE are acquired for BOLD contrast); and a double-echo technique.

We simulated the ASL and BOLD signals in order to determine relative CNRs of the proposed acquisition schemes using routines written in IDL (Exelis, Boulder, CO). The signal change due to application of the CASL tagging pulse was estimated using a theoretical model derived from a general kinetic model[2]. Temporal SNR (tSNR) was estimated using image SNR and physiological noise constants taken from the literature[3]. A typical value of 700 ms was used for post-inversion delay. Other parameter values chosen for the simulation were either typical literature values or typical values used for implementation of the sequence on our Philips Achieva 3T scanner. For the simulated double-excitation or double-echo scans we used the following parameters as typical values for use of the sequence at 3T: TE_{ASL} = 11 ms; TE_{BOLD} = 35 ms; TA (time to acquire a slice) = TE + 7 ms; # slices acquired = 30; T2* = 40 ms. For the simulated single-excitation single-echo scan, the echo time was allowed to vary; we used echo times of 15 ms, 20 ms, 25 ms, and 30 ms. For all sequences, we used TR = 4000 ms.

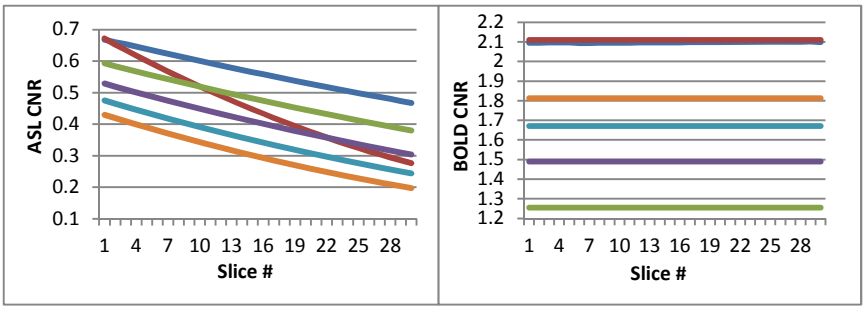

Figure 1. Comparison of relative ASL CNR **(left)** and BOLD CNR **(right)** for various approaches for simultaneous ASL/BOLD acquisition: double-excitation **(dark blue)**, double-echo **(red)**, and single-excitation single-echo sequences with TEs of 15 ms **(green)**, 20 ms **(purple)**, 25 ms **(light blue)**, and 30 ms **(orange)**.

We computed the BOLD CNR and the ASL CNR for the double-excitation, the double-echo, and the single-excitation single-echo sequences for the parameters chosen as a function of slice number. For the double-excitation sequence, we optimized the excitation flip angle for the ASL acquisitions by maximizing a figure of merit defined as $4*CNR_{ASL} + CNR_{BOLD}$ (as we are primarily concerned with maximizing ASL CNR).

Results

Comparisons of the double-excitation vs. the double-echo and single-excitation single-echo techniques for ASL CNR as a function of slice number are plotted in Figure 1 (left). Our results clearly show the advantage in using the double-excitation approach: more ASL CNR remains in the brain in the later slices compared to the other acquisition schemes, where the ASL contrast decays due to longitudinal recovery. At the last (30th) slice, the ASL CNR obtained using the double-excitation method shows an almost 70% improvement over that obtained using the double-echo method. The double-excitation method also out-performs all the single-excitation single-echo methods.

Comparisons of BOLD CNR are plotted as a function of slice number in Figure 1 (right). While one would expect reduced CNR in the double-excitation sequence compared to the dual-echo sequence due to the reduced time available for longitudinal recovery, the reduction is minimal (< 1 % for all slices), without significant dependence on slice number. Again the double-excitation method outperforms the single-excitation single-echo sequences, due to the longer TE. For the double-excitation sequence, the optimal excitation flip angle for each slice using our figure of merit ranged from 50 to 60 degrees, indicating that in practice an identical excitation flip angle could be used for all slices.

Discussion

The simulation results clearly show that the double-excitation technique results in improved ASL functional contrast in whole-brain simultaneous BOLD/ASL acquisitions compared to a double-echo method, with minimal reduction in BOLD CNR. Our approach takes advantage of the fact that physiological noise dominates thermal noise for EPI acquisitions at these voxel sizes and TEs[3].

We note that our implementation is not specific to 2D multislice acquisitions, and a possible alternative is a 3-D technique such as single-shot 3-D GRASE or a stack of spirals 3D acquisition.

A technique that simultaneously acquires ASL and BOLD with full-brain coverage using standard RF hardware has immediate applications for studies of the developing child connectome. Our ongoing study (https://research.cchmc.org/c-mind/) uses this method to map growth trajectories of specific cognitive functions, with the goal to understand the relationship between developmental changes in perfusion and changes in neuronal activity associated with neurocognitive development. It is clearly necessary to image the whole brain in order to be able to understand the dynamics within and between brain networks and their impact on the developing brain, as is being investigated in the adult "Human Connectome" project (http://www.humanconnectome.org/), and to investigate the complex relationship between blood flow dynamics and neuronal function.

Conclusion

We have shown that a dual-excitation sequence is the optimal approach for simultaneous ASL/BOLD imaging covering the whole brain. Optimization of the excitation flip angle for the ASL acquisitions results in minimal CNR reduction for the BOLD acquisitions.

References

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