Calibration of fMRI by Simulating BOLD Contrast in the Living Human Brain

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Introduction

Calibrations of fMRI instruments have been done using *static* phantoms filled with water or gel, digital phantoms [1], and the *dynamic* SmartPhantom [2][3]. However, it is difficult to establish a calibration standard for *in vivo* data. Repeatable data are necessary for calibration, but living human participants introduce multiple sources of variance into the measurements. In this study, we reduce these sources of variance by substituting for the endogenous hemodynamic response a controlled electronic simulation of the BOLD contrast signal. A pair of coils is placed near a subject's head, one coil above the scalp and the other below the chin, aligned with the main magnetic field. Direct current flowing through these coils distorts the main field causing a de-phasing effect similar to that caused by the susceptibility difference of oxy- vs deoxyhemoglobin. The simulated BOLD signal is computer-controlled and highly reproducible, unlike the endogenous response. Acquired images contain (1) a small amount of instrument noise, (2) the known simulated BOLD signals, and (3) the relatively large "physiological noise" due to magnetic inhomogeneities within the brain, head motions, respiration, heart rate, etc. The simulated signals, generated by the SmartCoils device, are extracted from this noise by analytic procedures. Success in extracting signals of known sizes from the noise provides an index of the sensitivity of the system (instrument plus human) for detecting BOLD-like signals. Such knowledge could potentially be applied to the interpretation of endogenous hemodynamic responses.

Methods

The SmartCoils consist of a radio-frequency (RF) coil pair. The coils are placed near a subject's head in the z-direction, as shown in Figure 1(left side). Direct current flowing in the coils induces local magnetic field distortion, which simulates BOLD susceptibility effects. There are two ways to manipulate the current in the coil pair. The coils with co-rotating current form a Helmholtz pair, and the coils with counter-rotating current form a Maxwell pair. The Maxwell pair is typically used because the current flow gives rise to no distortion of the magnetic field at the center as well as a uniform z gradient over a wide range. The coils are decoupled during proton spin excitation (RF transmission). With SmartCoils placed on the ends of a spherical phantom filled with $NiCl_2$ in H_2O (Figure 1 middle), the magnetic gradient is quite linear near the center of the phantom (Figure 1 right). A time series of current flow was controlled by computer. In the present experiment, a rectangular waveform was generated to roughly approximate the temporal frequency content of a prolonged hemodynamic response, with amplitudes approximating a few percent signal change. Two levels of direct current (5mA or 10mA) were injected into the coils during the "on" periods of the rectangular waveform, in order to check the "simulated activation" levels induced in the subject's brain. Preliminary data were obtained from two human participants (the authors). The scanning parameters were: TR=1700ms, TE=25ms, 32 axial slices with 5mm thickness (no gap).

Figure 1 (left) SmartCoils above the scalp and below the chin, aligned with the main magnetic field

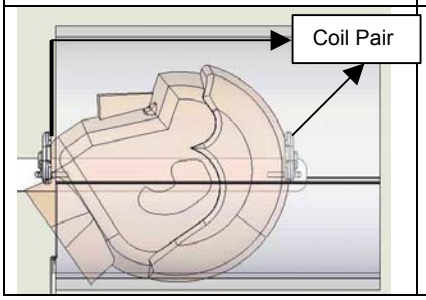


Figure 1 (middle) SmartCoils placed on a 7 inch diameter spherical phantom filled with $NiCl_2$ in H_2O

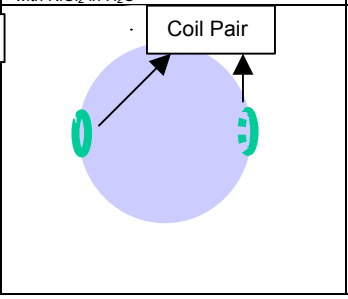
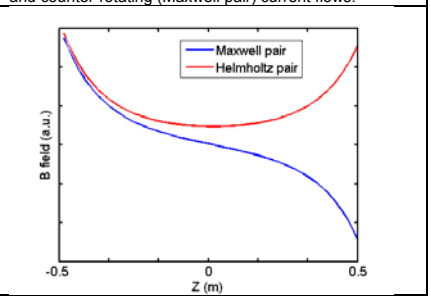


Figure 1 (right) Magnetic gradient (arbitrary units) in the phantom produced by co-rotating (Helmholtz pair) and counter-rotating (Maxwell pair) current flows.



Data analysis and Discussion

BrainVoyager and AFNI were employed for data processing, including volume registration, auto-masking, and cross correlation calculations. Each voxel time course was cross-correlated with the driving waveform to obtain "activation" maps A sample map is shown in Figure 2. Figure 3 shows sample voxel time courses for the two subjects, comparing percent signal change induced by the two DC levels. As the DC current doubled, the induced "simulated activation" also roughly doubles. Surprisingly, it was observed that the simulated BOLD signals are mainly evident near the cortical surface, and not as much deeper into the brain as expected from the phantom's magnetic gradient (Figure 1 right). Perhaps this results in part because while the phantom has spatially homogeneous susceptibility and dielectric constant, the brain does not. In summary, preliminary data acquired using SmartCoils shows potential as a means for calibrating sensitivity to detect BOLD contrast in the presence of "physiological noise" produced by a living human brain.

Figure 2. Sample "activation" map.

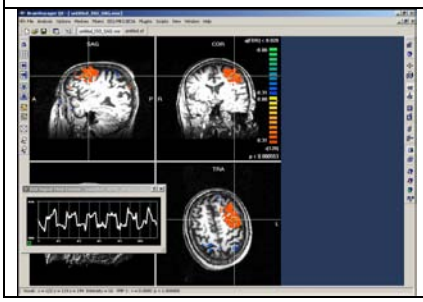


Figure 3(left) Sample voxel time courses of simulated BOLD contrast in living human brains from subject #1.

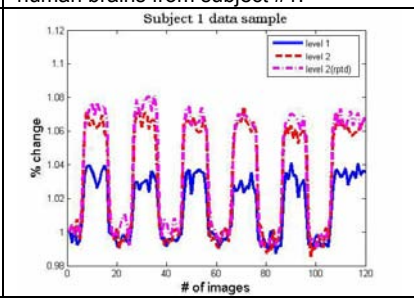
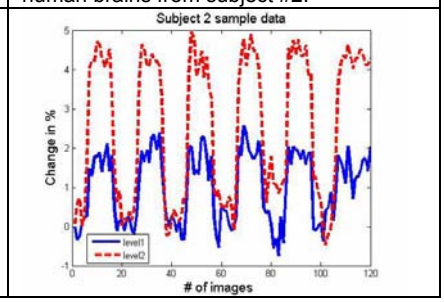


Figure 3 (right) Sample voxel time courses of simulated BOLD contrast in living human brains from subject #2.



References

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