A fMRI Study of the SMARTPHANTOM

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Introduction: There are many functional MRI (fMRI) software packages currently in use. These generally lack calibration, thereby making the interpretation of results tricky and uncertain. One way to solving this problem is data simulation. This has generally been done by generating fMRI image series numerically. With this approach, errors which may vary from machine to machine are neither fully considered nor correctly modeled. To help improving fMRI accuracy, we have developed an imaging phantom we call the “SMARTPHANTOM™” [1], This phantom can produce a predictable signal enhancement that simulates BOLD signal while being scanned. We performed a simple fMRI study with this phantom and compared the results with numerical simulation.

Methods: **A: SMARTPHANTOM™:** The SMARTPHANTOM™ consists of an rf coil placed in a cylinder (20 cm in length and 10 cm in diameter) filled with agarose gel doped with copper sulfate. The coil acts as a local spin magnetization amplifier and produces regions of variable MR image contrast to noise inside a small cylinder (2cm both in length and diameter) which is integrated into the coil. Signal enhancement of the phantom is accomplished by changing the loop series resistance with a PIN diode circuit controlled by the computer. T1 and T2 of the phantom are designed to be close to those of brain tissues by adjusting the concentration of agarose and copper sulfate. **B: MRI scanning:** 205 Single-slice gradient echo EPI images were acquired in GE 1.5 T Signa scanner with a 4-channel phased array head coil (MRI Devices Corporation, Waukesha, WI, USA). FOV = 16 cm, TR = 3 s and TE = 31 ms. Matrix = 64×64, SLT = 3 mm. The first 5 images were discarded. The remaining images follow the paradigm of alternative off-on states each of which lasts 30 s. The enhancement level of the phantom was set to 3.4 % and 2% respectively. For 3.4%, flip angle (FA) = 30°. For 2%, the exams were repeated 3 times to get different SNR with FA equal to 90°, 30°, and 12°. **C: Simulation and statistics:** We only simulated time courses for the three exams of 2% enhancement level. Each time we duplicated the first image 200 times. Then each image was added Gaussian noise. The magnitude of the noise was estimated from the NEMA approach. Additional signals were added to the ROI of the image corresponding to the ‘on’ state. The magnitudes of the added signals were fine-tuned according to the enhancement values shown in Table 1. Statistical analysis based on GLM was done with BrainVoyager 2000 (Brain Innovation, Maastricht, The Netherlands). Since there is only one slice, no motion correction was performed. No spatial or temporal filtering was done except linear trend removal.

Results: Figure 1 is the EPI image of an axial slice of the phantom. The spin-like signal enhancement is supposed to be localized to the center of the circle and uniform in this region. Therefore, all the analyses are chosen to be constrained on the 9-pixel square ROI. Figure 2 shows the BOLD-similar time course of the mean signal in the ROI for two enhancement levels. Besides signal variation from one time point to another, slight signal drift is also observed in the 10 minutes scan. Table 1 lists the SNR and the mean enhancements of the three 2% enhancement exams and corresponding numerical simulations. T values from GLM analysis for both phantom data and simulation data are also listed in Table 1. It is found that as the noise increases, variation of signal enhancement also increases. The statistics of simulation data seem to be ‘better’ than those from real phantom data provided that there is no motion, i.e., it can detect the same activation with higher P value. This is especially true at lower SNR.

Table 1.

Exam	SNR	Enhancement Phantom (%)	Enhancement Simulation (%)	Mean t value from Phantom	Mean t value from simulation
1	113	1.94±0.18	1.96±0.13	16.56	16.57
2	73	2.07±0.23	2.03±0.14	10.26	11.96
3	34	1.78±0.54	1.76±0.35	3.49	4.45

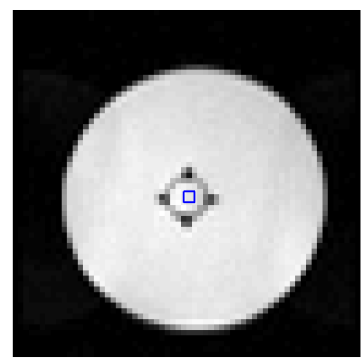
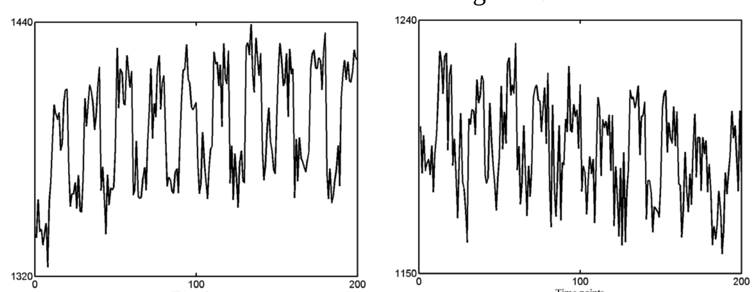


Figure 1. Axial EPI

Discussion: The numerical simulation gives more optimistic results, suggesting that the real time course is noisier. This may be partly due to the fluctuation of the ‘BOLD’ signal, which is also not constant for the brain. Another source of noise could be system drift. Thus, the phantom is better than simple numerical simulation. By adjusting the magnitude of signal enhancement, we are able to model hemodynamic response with current settings. Therefore, the phantom can simulate an ideal fMRI exam. The phantom can do quality control of a MRI system in the sense of fMRI study and provides the lower bound of P values. If we add physiological noise appropriately and introduce motion during data acquisition, the SMARTPHANTOM™ will be able to give excellent threshold estimation for real fMRI studies.



a. 3.4% enhancement b. 2.0% enhancement

Figure 2. Time courses acquired at different enhancement levels (SNR=73)

References:

1. Zhao Q, Duensing GR, Fitzsimmons J. **Proc. ISMRM** (2003) 1834.

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