# Test-Retest Reliability of fMRI using SmartPhantom

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## Introduction

FMRI uses blood oxygenation level dependent (BOLD) contrast to construct task-related activation maps for the human brain. Different statistical models and methodology have been developed to provide reliability estimates for such maps [1][2]. However, repeatable estimates are difficult to obtain because of many sources of variability, such as human subjects' anatomical differences, physiological variations, irreproducible motion artifacts, etc. SmartPhantom [3] is a device that eliminates those sources of variability from reliability tests because it generates reproducible simulated BOLD activation signals.

## Data Acquisition & Analysis Methods

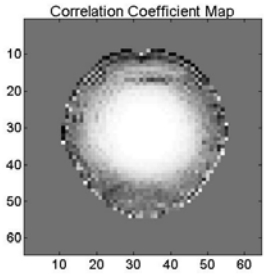
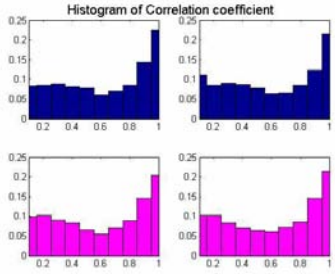
The fMRI data were acquired with a Siemens 3T Allegra head-only scanner. Twenty-four sessions of data were acquired in a period of about 3 months. The scan parameters were: TR=1700ms, TE=25ms, 25 slices with 5mm thickness and no gap between slices. The SmartPhantom is a 7 inch (in diameter) sphere ($NiCl_2$*$H_2O$ in solution of $H_2O$), having a pair of coils, one attached at each end in the z-direction. Direct current flowing in the coils induces a de-phasing effect analogous to that of paramagnetic deoxyhemoglobin, and thus simulates the basis of BOLD signal changes. The SmartPhantom generates reproducible simulated BOLD signals in this way. In the present experiment, a time series of current flows was controlled by a remote computer. A triangle waveform was generated to roughly approximate the temporal frequency content of a hemodynamic response, with an amplitude approximating a 3% signal change. In each session of a human subject study, separate scans of the SmartPhantom were performed before and after the human subject was scanned. By examining the similarity of activation patterns in the SmartPhantom within-session (pre-subject scan vs. post-subject scan in the same session), or across-sessions, one can gauge reliability absent the sources of variability arising from the subject. Because magnetic field homogeneity at the center of phantom is much better than near each end, the center five slices (#11-#15) were selected for data analysis for greater consistency. The fMRI analysis package AFNI was employed for data processing, including volume registration, auto-masking, and cross correlation calculations. Specifically, cross-correlation of each voxel time course with the pre-determined triangle waveform time series was calculated to obtain a correlation map. To measure the reliability, the similarity of correlation maps within-session and across-session were calculated using mutual-information based divergence measurements, the Integrated Squared Error (ISE) [4]:

$$d_{ISE} = \int (f_{X1}(x) - f_{X2}(x))^2 dx \qquad D_{ISE} = 1 - d_{ISE} / \sqrt{Var(d_{ISE})}$$

where $f_X(x)$ is an estimated probability density function of correlation coefficients in a correlation map.

## Results and Discussions

Figure 1, *left side*, shows a sample correlation map from the center slice of one SmartPhantom scan. Higher correlation is represented by higher brightness. Figure 1, *right side*, presents histograms of correlation coefficients from four SmartPhantom scans. The upper graphs show the proportions of voxels falling into each range of correlation for data collected before (left) and after (right) scanning a human subject. The lower graphs also depict data collected before (left) and after (right) scanning a human subject but in a session one month later.

| Figure 1 (left) | Figure 1 (right) | |
|---|---|---|
|   |   | Figure 1 *Left side:* Correlation coefficient map (center slice, brighter = higher correlation) from a single SmartPhantom scan. *Right side:* Histograms of correlation coefficients, showing the fraction of voxels exhibiting the indicated range of coefficient values The upper histograms are from scans of the SmartPhantom performed before (left) and after (right) scanning a human subject. The lower histograms are similar but from a scanning session done one month later. |

Mutual information based integrated squared error divergence ($D_{ISE}$) was calculated to gauge reliability. Table 1 presents each within-session (before, after human scans) and the averaged across-session divergences for five middle slices. For all five slices of Session I, SmartPhantom correlation maps before/after the human scan were less similar than the corresponding maps of Session II. We believe this reflects less precision in repositioning the SmartPhantom for Session I's scans. Within-session similarity was higher than across-session. Variation in positioning the SmartPhantom in the scanner across scans and across sessions reduces map similarity, although software image registration, which was done within session but not across sessions, may also contribute to reduced across-session reliability.

| Slice # | Session I | Session II | Across-session |
|---|---|---|---|
| 11 | 0.82 | 0.96 | 0.77 |
| 12 | 0.89 | 0.95 | 0.84 |
| 13 | 0.91 | 0.95 | 0.84 |
| 14 | 0.89 | 0.94 | 0.80 |
| 15 | 0.88 | 0.95 | 0.79 |

Table 1 Similarity of correlation maps within-session and across-session, as indexed by integrated squared error divergence, $D_{ISE}$

In summary, the SmartPhantom provides a means of measuring test-retest reliability of fMRI with a reproducible simulated BOLD signal that eliminates many sources of variability. Reliability studies using human subjects, or multi-site or cross-platform studies, could profit from SmartPhantom evidence that their imaging is repeatable and consistent.

## REFERENCE:

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