An fMRI Phantom Based on Electric Field Alignment of Molecular Dipoles

Innovative Graduate Student Proposal

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Abstract
Multi-center fMRI research has been carried out in many institutes and universities because it has many advantages such as larger sample size, more disease cases, and so on. But the differences between magnetic imaging systems setup at different sites makes the data hard to combine and difficult to interpret. Some groups have made their own phantoms to address this problem but there are still some questions left. We proposed to build a new phantom based on electric field alignment of molecular dipoles. This phantom not only simulates the $T_2^*$ change during the fMRI experiments but also eliminating the metallic effect and moving parts. This proposal seeks funds for partial support of the principal investigator to carry out the project.

Dollar Request: $5,000.00

Desired Funding Dates: January 1 through May 30, 2011
**Scientific justification**

Function magnetic resonance imaging (fMRI) opens a new window for us to explore how the brain works without cutting it open. The magnetic susceptibility difference caused by the change of $T_2^*$, which is the combination of the spin-spin relaxation time ($T_2$) and the effect due to magnetic field inhomogeneities, between oxygenated hemoglobin and deoxygenated hemoglobin makes it possible for fMRI to detect the active functional region or find the connectivity among the active regions when people perform a specific task like tapping fingers or reading books. However, this blood-oxygenation-level dependent (BOLD) effect is quite small. When buried in non-uniform noise and various physiological fluctuations, these weak and valuable signals are quite hard to obtain via subtracting the average image of the control task from the average image of the active task.[1] Therefore, the commonly employed method at present is to get statistical maps from the fMRI data. Statistical knowledge tells us that the larger the sample size, the more approximate the result is to the real answer. Unfortunately, the number of subjects who are willing to do the fMRI experiment is always limited for every research site. Sometimes even though the sample size is not a problem, the misunderstanding of the tasks and motion during the experiment would ruin the data and result in unreliable results. In order to reduce the influence brought by these circumstances, it is ideal to strengthen the collaboration of fMRI research sites, hence every site can take advantage of the data acquired from other sites. This measure is particularly useful for some rare diseases. Some research institutes and universities have begun to build such an organization and carried out many meaningful experiments. [2]

But are all the data coming from different sites comparable and able to use the same software to do the statistical analysis? This question is not easy to answer. Nowadays there are three major MRI whole-body manufacturers (GE, Siemens, and Philips) set up at most research sites. They have different magnetic field strength (1.5T, 3T, or 4T), are equipped with different head coils, and employ different pulse sequences, and reconstruction methods. Casey et al. [3] found the reproducibility of fMRI results from multicenter research but also observed the differences among the sites. At this moment, quality assurance seems quite important. Usual quality control ways involve resolution and RF homogeneity test via special constructed phantoms, [4] which are aimed at relative static signals, while fMRI signals are changing during the experiment. It will be better if there is a phantom capable of simulating signal changes between the control and active task.

Some groups have thought about the idea of designing a special phantom for fMRI quality control and two types of phantom have been made. One (Type I) is to fill the phantom with special material which has similar spin-lattice relaxation time ($T_1$) and $T_2$ to that of the gray matter of the brain. What Friedman et al. [5] and Olstrud et al. [6] constructed is such kind of phantom. The difference between these two groups is that Friedman only designed a static phantom to test the stability of the system performance and Olstrud’s purpose was to mimic the active and control status of the brain. He concocted two solutions with only a tiny disparity in $T_1$, $T_2$, and $T_2^*$. When doing the experiment, the “control part” or the active part is physically moved into the center of the coil. This kind of phantom is easy to make and the mixture of agarose is homogeneous and will not lead to magnetic field inhomogeneities. However, it is not convenient to switch the control status to active or vice versa during the experiment. In addition, for
different strength of magnetic field, the relaxation times ($T_1$, $T_2$ and $T_2^*$) are different, which means for every system with different magnetic field, an exclusive phantom should be made. Last but not the least, agarose may degrade over time, so some preservative should be added or the phantom should be checked regularly. The other type of phantom (Type II) did not use the same mechanism to mimic the BOLD signal. Researchers employed electronic properties to alter the signal but not through the relaxation time changes. Renvall et al. [7] utilized a current-induced magnetic field to change the local applied magnetic field ($B_0$) near an electric conductor. Cheng et al. [8] utilized a radio frequency (RF) resonant circuit to change the RF magnetic field ($B_1$) so that different signals were obtained. These kinds of phantoms contain metallic parts within the field-of-view (FOV) which will affect the magnetic field homogeneity. Their strength is that it is easy to synchronize the signal change to the fMRI experiment.

Our idea is inspired by Jone’s paper [9] which showed that with the application of an electric field, some polar liquids undergo a change in their $T_1$ value. If these liquids are used as the filling of our phantom, we can simulate the changes between control and active status during the fMRI experiments by changing the strength of the electric field. Compared to the Type II phantom, our phantom only has small metallic parts that can be placed outside the FOV. In other words, our phantom possesses the advantages of both Type I and Type II phantoms, which simulate the BOLD signal through the same mechanism and is simple to alter the intensity of the signal.

To pursue this research, we first need to determine the change in $T_1$, $T_2$, and $T_2^*$ of different polar liquids with an applied electric field. Only by knowing this information can a proper polar liquid be selected. These values will be measured on RIT’s 300 MHz NMR spectrometer with a to be constructed sample holder across which an electric field can be applied. The specific pulse sequences are:

1) Inversion Recovery pulse sequence to measure $T_1$,
2) Multi-echo spin-echo sequence to measure $T_2$, and
3) Gradient-echo echo-planar imaging sequence to measure $T_2^*$.

After appropriate polar liquid is determined, a phantom will be constructed. The additional tasks which will be performed are:

1) Use an echo planar imaging sequence to acquire the fMRI images, and
2) Optimizing acquisition parameters.

When the data are collected from the imager, they will be transferred to and stored in one of the CIS computer for processing. SPM and AFNI are popular in fMRI filed and both of them are free. [10] We will use these two software packages to analyze the data acquired from our phantom and validate its effectiveness.

In summary, by constructing this phantom, we will gain a deeper understanding of the data acquisition procedure from the fMRI experiment and how it can vary from site to site or machine to machine. By becoming familiar with the SPM and AFNI data processing software, we will be able to incorporate a phantom into a patient/volunteer imaging protocol and provide a new method to ensure the stability of the systems used in multi center studies. This should promote the collaboration of the institutes and get more reliable results from the fMRI data.
Budget Request

The proposed project is expected to take several years to complete. This proposal only covers the PI’s effort for a portion (5 months) of this period. During this period, the PI will devote 100% of her time to this research and thus the requested funds will be used to support her stipend. The advisor will provide the polar liquids and material to make the phantom. The total funds requested are $5,000.

<table>
<thead>
<tr>
<th>Category</th>
<th>Item</th>
<th>Period</th>
<th>Effort</th>
<th>Amount</th>
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<tr>
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<td>Graduate Stipend</td>
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<td>$5000</td>
<td>$5000</td>
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Total $5000

Table 1. Proposed budget for phantom research

Project plan

The goal of this project is to make an fMRI phantom to do the quality control to ensure the reproducibility of the results and comparableness of the data acquired from the multi-centers. The proposed job is expected to take two years to complete. The timeline, outcome and milestone are listed in Table 2. The first three milestones are expected to achieve during the funded period, while the others will be fulfilled in two years. The NMR spectrometer and MR imager will be made an appointment when needing to use.

Table 2. Project Plan

<table>
<thead>
<tr>
<th>Milestone</th>
<th>Time Line</th>
<th>Outcome</th>
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<tbody>
<tr>
<td>Measure $T_1$ and $T_2$ of some polar liquids using NMR spectrometer</td>
<td>Jan</td>
<td>Feb</td>
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<tr>
<td>Add electric potentials and measure these $T_1$ and $T_2$ using different current levels</td>
<td>x</td>
<td>x</td>
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<tr>
<td>Design and build a phantom for use on an MRI</td>
<td>x</td>
<td>x</td>
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<tr>
<td>Measure $T_1$, $T_2$, and $T_2$ of the phantom at 1.5 and 3.0 T.</td>
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<tr>
<td>Acquire real fMRI experiment data on a magnetic resonance imager</td>
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<td>Analyze the experimental results using SPM and AFNI</td>
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References


