A Comparison of the Effectiveness of 3 T and 1.5 T MRI Scanners in a Multi-Subject fMRI Study of Visual Memory

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INTRODUCTION

Use of higher field strength in fMRI studies of cortical functional organization is becoming rapidly more popular. The expected gain in SNR with magnetic field strength is well demonstrated. At 1.5 T, given typical scanner stability and SNR, many activations are only marginally observable, particularly for cognitive paradigms, and many stimulus repeats may be required to give usable data. Several studies (1,2,3,4,5) have shown BOLD signal increases with field strength. However, the parametric statistical maps generated by standard imaging neuroscience multi-subject studies at 1.5 T and 3.0 T have not often been compared. In widely used methods for fMRI data analysis, such as SPM, time course data for each subject are realigned to remove motion artefact, normalized to a standard template reference brain, and then spatially smoothed to facilitate averaging across brains. The data are analyzed by means of the General Linear Model, to obtain estimates of the experimental effects, expressed as values of 'Beta' for each experimental condition. Together with estimates of variance, Betas are combined to derive t-scores relating to the various contrasts of interest. They are also used in the computation of group mean data, at the second level, in which a mixed effects model uses an estimate of variance across subjects to provide results valid for populations. In SPM, Beta has units of percentage image intensity change, normalized by the global mean image intensity. The fractional signal change in each voxel is given by the ratio between the Beta for the condition of interest and the Beta that provides an estimate of the mean intensity in each voxel.

BOLD theory (5,6,7) suggests that the relaxation rate R2* for a given vascular deoxyhaemoglobin concentration varies quadratically with field strength for water protons near capillaries ('tissue'), and linearly with field strength for protons within or near larger venules ('vein'). The fractional signal change ΔS in a gradient-recalled echo image caused by a change of relaxation rate $\Delta R2^*$ is given by $\Delta S = S_0$ TE. $\Delta R2^*$, with corresponding predicted dependences of tissue or vein activations on field strength. Thus measuring $\Delta S/S_0$ provides an estimate of $\Delta R2^*$. Maximum BOLD signal change occurs when TE = T2*. In grey matter, T2* is about 70 ms at 1.5 T , and 50 ms at 3 T. However, using these values for TE with EPI or spiral sequences entails unacceptable levels of image dropout, caused by through-slice field gradients due to magnetic susceptibility variations within the head. In practice, even with a very thin slice of 2 mm, use of TE of 50 ms at 1.5 T and 30 ms at 3 T gives much better image quality, while maintaining good BOLD sensitivity (8). These values were used to make a realistically pragmatic comparison across field strengths.

We considered two questions regarding the effect of static field strength in functional neuroimaging studies. The first question is, how much does the use of 3 T increase the extent, number, or significance level of brain activations at the single subject level? The second question relates to the most usual type of imaging neuroscience study, the group study of 12 subjects or more, investigating brain areas typically involved in a particular cognitive task. In group average data, does the use of a 3 T field reveal activity in brain areas that do not reach significance at 1.5 T?

METHODS

fMRI data were obtained during the encoding phase of a visual memory experiment, performed twice using the same 16 subjects, at field strengths of 1.5 T (Siemens Sonata) and 3 T (Siemens Allegra), using standard head rf receiver coils. Subjects viewed either pictures of objects or their written names, making a semantic decision by key press for each stimulus. Stimuli were arranged in blocks of 24 s duration, interleaved with 16 s fixation. The EPI acquisition used a 64 x 64 image matrix, with voxel dimensions 3 mm x 3 mm x 2 mm slice thickness. At 3T, TE was 30 ms, with an EPI acquisition window of 21 ms; while at 1.5 T TE was 50 ms, with acquisition window of 32 ms. The shorter acquisition window at 3T, made feasible by the fast-switching head gradient coils of the Allegra scanner, resulted in nearly identical image distortion and dropout at the two field strengths. With these imaging parameters, for a gel phantom with T2 of 80 ms, single voxel SNR was 60 at 1.5 T and 120 at 3 T.

All brain images were realigned and normalized to the same template brain. Using SPM and 6 mm spatial smoothing, we estimated the main effect of the memory encoding task for each subject and field strength. For each subject, we calculated the mean of $\Delta S/S_0$ for all encoding conditions (Figure 1), then masked the data to retain only voxels that showed statistically significant activation for both field strengths, at the $p<0.05$ level (corrected). The mean ratio of fractional signal change between field strengths was evaluated, for each subject, and then averaged across subjects. The data were group-averaged, and statistical comparisons were made of the group main effects between field strengths.

RESULTS AND CONCLUSIONS

For each subject, the number of significantly activated voxels was larger at 3 T than at 1.5 T, and the grand mean t-score for all activated voxels across subjects was 40% greater at 3 T. The grand mean ratio of fractional signal change was 1.01 ± 0.20, giving a ratio of $\Delta R2^*$ of 1.7, somewhat lower than the linear tissue dependence predicted (6). However, there were no significant differences between field strengths in the group-averaged data, after correction for family-wise error. We conclude that for this cognitive task and choice of echo times the variance of the activations between subjects dominates the variance between field strengths. This suggests that increased field strength mainly increases sensitivity in single-subject studies, and enables improved fMRI spatial resolution (9).

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Figure 1. Main effect of memory task for all voxels (subject 2) at each field.