Investigating BOLD signal intensity changes in fMRI of the human spinal cord

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Introduction

MRI detection of neurological activation (fMRI) in the human cervical spinal cord has been demonstrated by us to be feasible at 3 T and at 1.5 T, with both sensory stimulation and a motor task [1,2]. Moreover, we have shown that spinal fMRI can be done with both spin-echo and gradient-echo techniques, and that these two yield similar BOLD intensity changes. While the prospect of being able to do spinal fMRI with a spin-echo technique is attractive because of its much higher image quality in the spinal cord, this finding raises many questions. The primary question is whether or not the intensity changes we detect with spin-echo techniques is truly the BOLD effect and what other factors may be contributing to the signal changes to cause them to be as large as those detected with gradient-echo techniques. We therefore carried out a series of experiments at 1.5 T using a spin-echo technique while subjects were either subjected to a sensory stimulus, or performed a motor task with one hand. FMRI time courses were obtained with different echo times so that we could compare our observations with current models of the BOLD effects, and data were analyzed parametrically with different correlation thresholds.

Methods

MR images of the spinal cords in healthy volunteers were obtained using a single-shot fast spin-echo (SSFSE) sequence on a 1.5 T GE Signa Horizon LX. A phased-array spine coil was employed as a receiver. Activation of the motor and sensory neurons involved with the transmission of nerve impulses to and from the fingers, hand and forearm was achieved by having the subjects repeatedly squeeze a rubber bulb with one hand and alternating between rest and exercise conditions (5 conditions: 3 rest + 2 exercise). For sensory stimulation experiments the subjects were asked to remain relaxed and a plastic pack containing cool water (5 – 8 °C) was placed on one palm during stimulation periods. Imaging parameters were as follows: 12 cm FOV, 7.5 mm thick slices, 128 x 128 matrix, 5 slices were acquired sequentially, TR = 8 sec, 54 time points/slice. The image plane was chosen to show transverse sections of the cord and the slice spacing was adjusted to align each slice with either an inter-vertebral disc or with the center of a vertebra to provide the high through-slice field homogeneity. The effective echo time was chosen to be 38, 64, or 95 msec in separate experiments. Effects of cardiac motion, CSF pulsation and blood flow were minimized by averaging pairs of sequential images, resulting in a net 27 time points per slice location.

Time course data was analyzed on a pixel-by-pixel basis by computing the correlation with the exercise paradigm as described by Bandettini [3]. Analysis was repeated with correlation thresholds, R, of 0.5 and 0.3. Prior to analysis images were registered to correct for any in-plane translation between time points.

Results

Areas with significant intensity changes during periods of exercise or sensory stimulation were observed in SSFSE time course images at all three echo times. There was a linear relationship between the fractional signal change, $\Delta S/S$, and the echo time in all cases. With a motor task linear fits yielded (TE in seconds):

$\Delta S/S = 0.50\,TE + 0.020$, ($r^2 = 0.92$, n=10) with R = 0.3

$\Delta S/S = 0.68\,TE + 0.023$, ($r^2 = 0.93$, n=10) with R = 0.5

With a sensory stimulus:

$\Delta S/S = 0.34\,TE + 0.024$, ($r^2 = 0.92$, n=5) with R = 0.3

$\Delta S/S = 0.39\,TE + 0.033$, ($r^2 = 0.81$, n=5) with R = 0.5

Discussion

The linear relationship between the fractional signal change and echo time supports the conclusion that we are indeed observing changes arising from the BOLD effect in the spinal cord. The slope of these curves should equal the change in transverse relaxation rate, $\Delta(1/T_2)$. The values we observed, 0.34 to 0.68 sec^{-1}, are reasonable compared to the value of 1.3 sec^{-1} determined for $\Delta(1/T_2^*)$ within capillary beds at 4 T [4], because T_2 values depend only very weakly on field strength. The fact that we observed significantly lower signal intensity changes with a lower correlation threshold indicates that our data are affected by partial volume effects [5], and also suggests that at the higher threshold we are preferentially selecting only those pixels undergoing the highest intensity changes. This effect may have biased our previous results to make the BOLD change with spin-echo techniques appear more similar to those observed with a gradient-echo. Nonetheless, because our data were acquired at a relatively high resolution (0.9 mm) we are still able to detect a significant BOLD intensity change with spin-echo imaging [5], with a higher average value than that predicted by current models of the BOLD effect. The intercepts of linear fits are considerably above zero, however, indicating that other factors such as motion and flow are contributing to the intensity changes we detected. Nonetheless, the slopes of the linear fits reflect the true relaxation rate change in the spinal cord upon neural activation.

References

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