BOLD signal responses to controlled hypercapnia in human spinal cord

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Introduction

Functional magnetic resonance imaging (fMRI) of the spinal cord has been the subject of intense research in recent years [1]. The principal difficulties arise from the spinal cord's small size, the presence of large physiological movements (cardiac and cerebrospinal pulsation, respiration) and magnetic field inhomogeneities around inter-vertebral disks inducing severe susceptibility artifacts. Because of these challenges, the sensitivity and specificity of BOLD activation maps in the spinal cord has been difficult to assess [2]. Hypercapnia is generally associated with global increases in blood flow throughout the central nervous system [3]. This makes it highly suitable for use as a positive control stimulus for assessing the sensitivity of BOLD fMRI under different conditions. In this study we used a hypercapnic manipulation to characterize the sensitivity of the BOLD method in human spinal cord.

Methods

Functional MRI acquisitions were conducted on two subjects in a Siemens Trio scanner (3T) using an 8-channel neurovascular coil. A single axial slice was positioned at the middle of the C6 vertebral level. Acquisition parameters were: gradient-echo EPI, TR/TE/alpha = 2000/30/70, slice thickness = 10 mm, matrix size = 128x128, in-plane resolution = 1x1 mm^2. A moderate degree of hypercapnia (7.5 mmHg) was induced in a block-design fashion (4 blocks of rest, 4 blocks of hypercapnia, 60 s each). Hypercapnia was induced using a computer-controlled system that allows targeting of specific end-tidal CO_2 values. Data analysis was conducted using SPM [4]. Time series were first realigned within a mask centered in the spinal region to limit the effect of non-linear motions for estimating the transformation matrix [5]. Then, series were smoothed (FWMH = 2 mm) and the general linear model was applied within a mask including the spinal cord (Figure 1a). Physiological-related autocorrelations were partially removed using an autoregressive filter.

Results

Results showed hypercapnia-related signal changes in the spinal cord for both subjects. In subject 1, BOLD signal was detected predominantly on the left side of the cord, with little change in grey matter (Figure 1b). This could be due to the positioning of the slice over a massive draining vein on the left side. For subject 2, small BOLD signal was observed on the dorsal-right side of the white matter, without significant grey matter activation (Figure 1c). Again, this could be explained by the inclusion of a draining vein on the imaged slice. More interestingly, negative BOLD signal was present for both subjects, either on the contra-lateral side of the activation (Figure 1b) or in a region adjacent to the activation (Figure 1c). Possible explanations include a relative decrease of oxygenated blood caused by a blood-stealing effect [6], or increased signal dephasing due to higher flow velocities in large vessels.

Conclusion

Using blood gas manipulation, we were able to induce a vascular reaction in the spinal cord. Preliminary results suggest that BOLD signal is highly dependent on the gross vascular anatomy of the spinal cord, limiting the sensitivity in grey matter since the precise vascular organization may vary among subjects. In-flow effect through adjacent slices was reduced by imaging a single slice. However, it limited our ability to account for the variability of the vascular architecture in the rostral-caudal direction. Moreover, negative BOLD was measured in various regions of the cord, suggesting the importance of small voxels for limiting the impact of partial volume effect on the sensitivity of neurovascular-related signal detection, without canceling it. The framework developed in this study will pave the way for future investigations aiming at characterizing the BOLD signal in the spinal cord and its reproducibility intra- and inter-subject, using a controlled stimulus.

References

[1] Stroman, P.W., 2005. Clin Med Res 3, 146-156. [2] Giove, F. et al., 2004. Magn Reson Imaging 22, 1505-1516. [3] Hoge, R.D. et al., 1999. Magn Reson Med 42, 849-863. [4] Friston, K.J. et al., 1995. Neuroimage 2, 45-53. [5] Cohen-Adad, J. et al., 2007. Conf Proc IEEE Eng Med Biol Soc (in press). [6] Shmuel, A. et al., 2002. Neuron 36, 1195-1210.

Figures

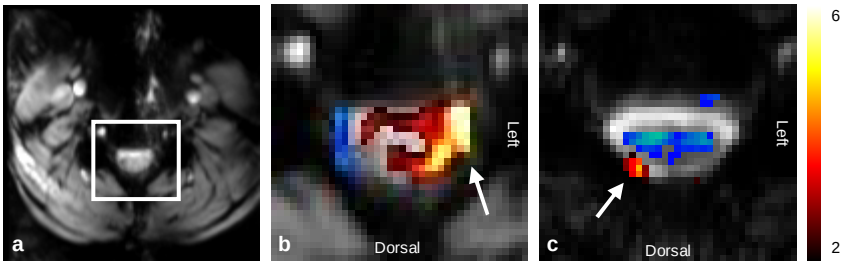

Figure 1. Axial slice showing the mask used for the analysis (a). Mapping of the T-score for subject 1 (b) and for subject 2 (c). For subject 1, BOLD signal was detected predominantly on the left side of the cord (arrow). For subject 2, small BOLD signal was observed on the dorsal-right side of the white matter (arrow).