Spinal cord fMRI: functional response and linear model assessment

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Introduction

Functional magnetic resonance imaging (fMRI) has emerged during the last decade as the main non-invasive technique for the investigation of human brain function. More recently some studies have been conducted also to reveal the activation in the human spinal cord [1-2], albeit the characteristics of functional contrast are still debated [3] (even its BOLD origin has been challenged). Although performing fast imaging in the spinal cord still remains a technical challenge (motion-effects and susceptibility artifacts, related to local inhomogeneities, do impair the quality and the spatial resolution of the images), such kind of investigation provides promising perspectives for the study and follow-up of spinal cord injuries.
In this study we report the results obtained applying an fMRI block-design motor paradigm of the upper limb to identify the hemodynamic response function (HRF, i.e. the impulse response function) in the human cervical spinal cord and to test the linearity assumption of fMRI response.

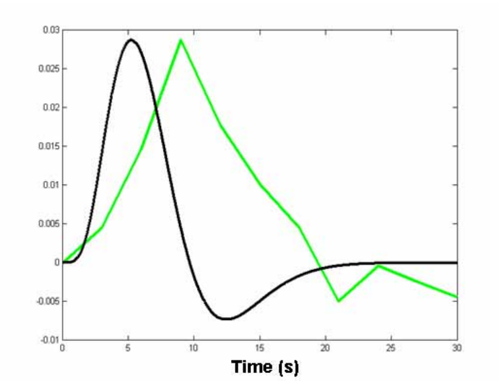

Fig.1 Comparison between Glover's double gamma model of the brain HRF with respect to motor task [4] (black) and spinal cord HRF as assessed in our experiment (green).

Methods

Five right-handed healthy subjects were examined at 1.5 T (GE NV/i) at Neuromed institute. A circular 3-inches receive surface coil and the body transmitter coil were used. Gradient-echo, echo-planar functional images (TR/TE 3000/40 ms, flip-angle 90°, 12x12 cm2 FOV, 128x64) were collected. Five slices (thickness/spacing 9.0/1.0mm) spanned from the fifth to the last cervical vertebra. Six presaturation regions were used. Stimulation of the spinal motor areas was obtained by squeezing a rubber bulb with the dominant hand, synchronously with 1 Hz cued tone pulse. The experiment was block-designed. A single block consisted of 30 s rest condition and presented different durations of the ON periods of 3, 6, 9, 15, 21, 27 and 42 seconds according to the trial. In the 30s/42s trial postprocessing, images were cropped to a subregion containing the spinal cord, realigned using rigid body rototranslations, and smoothed (FWHM=2.0mm). Functional analyses were performed by computing the deconvolution between the time course of each pixel and the task paradigm [5]. Voxels with $p<0.0025$ were considered activated. A mask was defined from these voxels, and applied to the remaining data-sets, previously realigned to the same reference. Time-locked averaging was computed for each voxel in the functional mask for each data-set, then the inter-voxels, inter-subjects averages of the time courses were computed. Finally, the time course of the 30s/42 s task was deconvolved with the relevant stimulation paradigm to obtain the HRF, and this HRF was convolved with all the stimulation paradigms.

Results

The obtained impulse-response function (Fig.1) appears slower than in the brain, peaking around 10s after onset. The observed contrast is generally larger than in the brain, about 5% of baseline signal at 1.5T, but smaller than previously reported works. By means of this HRF we were able to rebuild the functional response evoked by motor tasks between 15 and 42 seconds long (Fig.2), thus suggesting a linear behavior of the phenomenon in this interval. Conversely, with stimuli durations ranging between 3 and 9 seconds, the functional signal was under the level predicted by the linear model, suggesting deviation from linearity during such shorter stimulations.
These findings suggest that the physiological origin of the signal is similar in the spinal cord and in the brain.

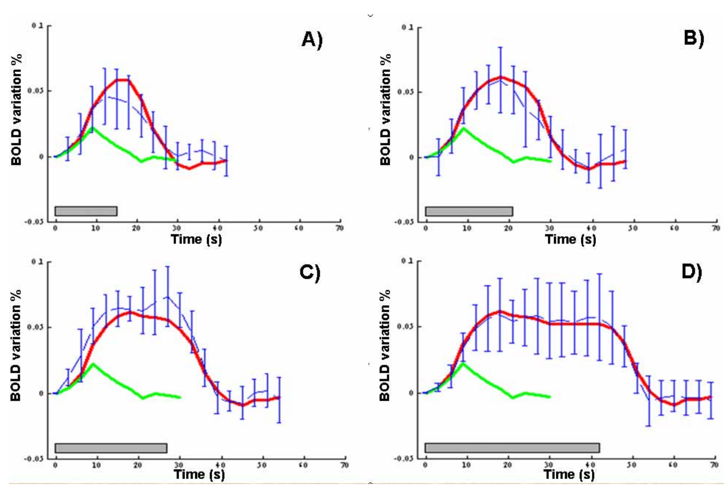

Fig.2 Average time-course (blue), hrf deconvolved from the 30s/42s task (green) and reconvolved hrf for the **A)** 15, **B)** 21, **C)** 27 and **D)** 42 seconds tasks (red). The experimental time-courses of the four tasks can be fairly reconstructed with the same HRF.

References
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