Journal Club

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fMRI Detection of Spinal Activity during Voluntary Movements

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Review of Maieron et al. (http://www.jneurosci.org/cgi/content/full/27/15/4182)

The neural basis of voluntary motor control in humans has been extensively investigated at the brain level using noninvasive techniques such as functional magnetic resonance imaging (fMRI). In contrast, this approach has rarely been used in the spinal cord to study its role in motor functions. Although it is well known, notably from electrophysiological work in animals and humans, that the spine is not an innocent bystander of the CNS (Wolpaw and Tennissen, 2001), the functional imaging community has directed the major focus of interest on the relationship between cerebral activity and voluntary motor output. One main reason is that functional imaging of the spinal cord has been plagued by technical difficulties greatly exceeding those at the brain level (Stroman, 2005), thus discouraging functional imagers from pursuing this endeavor.

In support of early findings from electrophysiological and neuroanatomical work, the blood-oxygen-level-dependent (BOLD) signal measured with fMRI has revealed qualitative and quantitative relationships between brain activity and willed motor actions. Qualitatively, distinct cerebral territories have been shown to control movements of different parts of the body (Gerardin et al., 2003) or to have specific functions in relation to movements. Quantitatively, fMRI measurements have also been found to be proportional to different parameters of motor output such as movement quantity or velocity (Taniwaki et al., 2003). Although all motor commands generated in the brain ultimately go through the spinal cord before reaching the effectors, this intermediate neural layer has been largely ignored in functional imaging studies. Unlike their electrophysiological and neuroanatomical counterparts, fMRI studies have yet to demonstrate that the spinal cord does not merely relay commands from the cortex, but also plays a modulatory role during willed movements.

In a study recently published in *The Journal of Neuroscience*, Maieron et al. (2007) attempt to overcome the methodological hurdles specific to spinal fMRI BOLD imaging and to record activity in the cervical spinal cord while volunteers perform a finger-opposition sequence task either at a fixed frequency, alternating between the left and right hands (experiment 1), or at two different frequencies with the right (dominant) hand only (experiment 2).

The methodological innovations in this work are as important as the functional results, given that artifacts from numerous sources tend to degrade the BOLD signal associated with spinal activity (Stroman, 2005). Multiple receive-only coils functioning in parallel and a custom-made MRI device that amplified, filtered, and reconstructed the data were used to allow for a reduction in image acquisition and reconstruction times, as well as for a significant increase in the signal-to-noise ratio. A high-resolution echo planar imaging stimulation sequence was combined with a sensitivity encoding technique that enhanced the BOLD sensitivity and reduced the signal dropout as well as the image distortions caused by different magnetic susceptibilities in tissues adjacent to the spinal cord. Finally, functional images were acquired with a high in-plane resolution (1.25×1.25 mm^2) that is appropriate for the small diameter of the cervical cord (12–14 mm) and a large slice thickness (4.5 mm) to further increase the signal-to-noise ratio. However, presentation of the filtered functional data alone (spinal cord segmented from surrounding tissues) does not fully inform on the extent to which the authors achieved the noise reduction and elimination of artifacts.

The functional data showed that the

Received June 6, 2007; revised June 22, 2007; accepted June 23, 2007.

O.L. was supported by a grant from the Multidisciplinary Team in Locomotion Rehabilitation at the University of Montreal and P.O. is a research fellow at the Belgian National Funds for Scientific Research. We thank Drs. Julien Doyon and James Ashe for comments on a previous draft of this manuscript.

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DOI:10.1523/JNEUROSCI.2565-07.2007

cervical spinal cord was predominantly activated in the most caudal slices of the volume, concordant with the anatomical location of the cervical roots that contribute to the median nerve, which controls finger–thumb opposition movements. In experiment 1, clusters of activation were detected on both sides of the spinal cord during the execution of finger taps with either hand [Maieron et al. (2007), their Figs. 2 (http://www.jneurosci.org/cgi/content/full/27/15/4182/F2), 3 (http://www.jneurosci.org/cgi/content/full/27/15/4182/F3)]. However, the intensity of activation was higher on the side ipsilateral to the performing hand. The spatial extent of activation showed a similar effect as additional neural populations were recruited on the ipsilateral side [Maieron et al. (2007), their Figs. 2 (http://www.jneurosci.org/cgi/content/full/27/15/4182/F2), 4 (http://www.jneurosci.org/cgi/content/full/27/15/4182/F4)]. This lateralization effect convincingly demonstrates that neural activity in the spinal cord follows similar qualitative rules to those of the brain in relation to motor output. In experiment 2, the spatial extent of the BOLD signal remained constant, whereas the intensity of activation became higher in the ipsilateral spinal cord as the level of several movement parameters increased [Maieron et al. (2007), their Figs. 6 (http://www.jneurosci.org/cgi/ontent/full/27/15/4182/F6), 7 (http://www.jneurosci.org/cgi/content/full/27/15/4182/F7), 8 (http://www.jneurosci.org/cgi/content/full/27/15/4182/F8)]. Because the velocity, quantity and error rates of the movements were not dissociated, it is unclear with which of these motor parameters the BOLD signal variation was correlated. Yet, these results provide credible evidence for a quantitative relationship between neural activity in the spinal cord and voluntary motor control.

Although BOLD spinal cord activity that corresponds to stimulated dermatomes or myotomes has been reported previously (Stroman, 2005), the present findings provide compelling evidence regarding the lateralization and the modulation of the spinal neuronal activity as a function of different movement characteristics. The predominant activation of the spinal cord ipsilateral to the hand performing the motor task as well as the greater intensity of the signal at higher levels of voluntary movement parameters indicate that the spinal BOLD signal measured using fMRI results from physiological activity of spinal neurons. The experimental setup of the parameters and imaging devices used in this work offers a technical recipe for use of fMRI in the spinal cord. Although there are several imaging techniques capable of measuring physiological processes in the spinal cord, BOLD fMRI has a major advantage. Indeed, this tool allows for a direct comparison of novel findings at the spinal level with the extensive fMRI data already reported at the brain level. The experiments by Maieron et al. (2007) thus serve as a springboard for future imaging studies of the spinal cord. It is now conceivable to use fMRI to evaluate the function of the spinal cord in relaying or modulating signals from the brain. Of particular interest is also the potential use of fMRI to show spinal learning-dependent plasticity during more complex voluntary activities such as motor learning.

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