

Functional MRI of Central Motor Drive During Muscle Contractions

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Introduction:

Decreased central motor drive from the primary motor cortex is thought to contribute to muscle fatigue after prolonged repetitive exercise under some conditions (1). However, at present there is no established non-invasive measure of central motor drive at the level of the motor cortex, although decreased supraspinal drive can be inferred if transcranial magnetic stimulation of the motor cortex adds to the force during a nominally maximum voluntary contraction (MVC). Interestingly, BOLD-based functional MRI studies show that activity in the primary motor and somatosensory areas depends on the force of isometric contraction (e.g., 2), suggesting that signal intensity (SI) changes in the primary sensorimotor area might yield a measure of central motor drive. This study tested this possibility by measuring SI in a highly force-correlated sensorimotor area under two conditions: during low-force 3 min duration isometric contractions, and during the same contractions with blood flow occluded. Occlusion of blood flow results in peripheral muscle ischemia and fatigue, and therefore results in increased motor unit recruitment at constant target force, i.e., in increased central motor drive (3).

Methods:

Twelve adult subjects (3 female, age 26 ± 11 years) completed the study after giving informed, written consent. Subjects were supine, with the head firmly fixed within an 8 channel head coil by a neck brace and foam padding. Subjects held a custom-made handgrip ergometer in their right hand, and a pressure cuff was placed around the upper arm. The force of handgrip contraction was recorded at 120 Hz, and the force trace was continuously displayed to the subjects on a monitor, along with a red line indicating the target force for each contraction. Single-shot echo-planar images (3T GE Excite, GE Medical, Milwaukee, WI; TR 2s, TE 35 ms, 22 cm FOV, 4 mm axial slices, 0.5 mm gap, 64×64 matrix, 90° pulse, 29-32 slices) were continuously acquired during 5 tasks, each performed after a 30 s control acquisition period: 1) 30 s duration isometric handgrip contractions at target forces of 20, 40, 10, and 30% MVC, each contraction followed by 30 s rest periods, 2) 3 min occlusion of forearm blood flow by rapidly inflating the cuff to 80 Torr above resting systolic pressure (to 199 ± 11 [SD] Torr), 3) 3 min isometric contraction at 15% MVC, 4) 3 min contraction at 15% MVC with cuff inflated, and 5) 3 min contraction at 15% MVC. Five minute rest periods occurred between tasks 1-3, and 8 minute rest periods between tasks 3-5. T1-weighted anatomical images (Fast SPGR, 256×192 , 1 mm slice, TR 2 s, TE 1.5 ms, TI 500 ms, 15° flip angle) were acquired at the end of the study. Using AFNI software (4), contiguous clusters of highly force-correlated voxels were identified in each subject by correlation of voxel SI vs. target force during the contraction periods of task 1. The SI time course in the same cluster was then extracted for each of the five tasks in each subject.

Results:

Figure 1 shows the Talairach-averaged location of the most highly force-correlated cluster ($n=12$, $r>0.5$, location S55, P23, L37 = left precentral gyrus). In every subject the most highly force-correlated cluster was centered in this region, although typically the cluster included both pre-central (motor) and post-central (somatosensory) voxels. Figure 2 shows the mean force (\pm SE, $n=12$, top) and cluster SI (bottom) during the force-varied contractions of task 1. Figure 3 shows SI in the same clusters during the 15% MVC contraction without (task 3, open circles) and with the cuff inflated (task 4, filled circles). Although cluster SI initially increased similarly during both contractions, by the end of the contractions the increase in SI was 2-fold greater during ischemia (paired t-test, $p=0.0002$). As shown in Figure 4, the mean rate of increase in SI over the last half of the task period was 3-fold greater ($p<0.02$) during ischemic contraction compared to either ischemia alone, or to the non-ischemic contractions.

Discussion:

The increase in fMRI-measured activity in the force-correlated area of the sensorimotor cortex during the ischemic contraction is consistent with the increased central drive needed to maintain the target force as fatigue develops in the peripheral muscles. Thus, fMRI may provide a non-invasive measure of central motor drive under some conditions, and might prove useful for studies of patients with chronic fatigue syndromes.

References:

1. Taylor, JL, et al, Clin. Exp. Pharmacol. Physiol. 33:400-405, 2006
2. van Duinen, H, et al, Hum. Brain. Mapp. 29:281-299, 2008.
3. Moritani, T, et al, Eur. J. Appl. Physiol. 64 :552-556, 1992.
4. Cox, RW, Hyde, HS, NMR Biomed. 10:171-178, 1997.

