Changes in interhemispheric motor connectivity after muscle fatigue

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ABSTRACT

Synchronized oscillations in resting state timecourses have been detected in recent fMRI studies. These oscillations are low frequency in nature (< 0.08 Hz), and seem to be a property of symmetric cortices. These fluctuations are important as a potential signal of interest, which could indicate connectivity between functionally related areas of the brain. It has also been shown that the synchronized oscillations decrease in some spontaneous pathological states. Thus, detection of these functional connectivity patterns may help to serve as a gauge of normal brain activity. The cognitive effects of muscle fatigue are not well characterized. Sustained fatigue has the potential to dynamically alter activity in brain networks. In this work, we examined the interhemispheric correlations in the left and right primary motor cortices and how they change with muscle fatigue. Resting-state functional MRI imaging was done before and after a repetitive unilateral fatigue task. We find that the number of significant correlations in the bilateral motor network decreases with fatigue. These results suggest that resting-state interhemispheric motor cortex functional connectivity is affected by muscle fatigue.

Keywords: functional connectivity, functional MRI, muscle fatigue, maximal voluntary contraction

1. INTRODUCTION

Low frequency (< 0.08 Hz) synchronized oscillations in resting state timecourses have been detected in recent fMRI studies[1-3]. These low-frequency oscillations have been shown to exist in the motor, auditory, visual, and sensorimotor systems, among other brain networks. These fluctuations are important as a potential signal of interest, which could indicate normal connectivity between functionally related areas of the brain. It has also been shown that these synchronized oscillations decrease in some pathological states (such as multiple sclerosis[4], or Alzheimer's Disease[5]). Therefore, detection of these functional connectivity patterns may help to serve as a gauge of normal brain activity.

The effect of muscle fatigue on the brain is not well understood. Several recent studies have demonstrated that the activity in the associated brain networks can dynamically change during the task, in response to the increasing demands in the fatigue state[6,7]. A sustained task can thus alter the connectivity in the brain during the task, but it is unknown what effect this will have on the baseline state after the fatigue task.

In this work, we examined the resting-state interhemispheric correlations in the left and right primary motor cortices to see how they change with muscle fatigue. We find that the number of significant correlations in the bilateral network decreases with fatigue. This extends the investigation of resting-state connectivity to fatigue studies, and can help to explore the effects of muscle fatigue on the brain.

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2. METHODS

1.1. Acquisition

A series of fMRI experiments were performed on a 3 T Siemens Trio scanner. Following informed consent, ten subjects were scanned using an EPI sequence to acquire resting state data before and after a fatigue task, described below. Resting state data were acquired using ten oblique slices (parallel to AC-PC), with an in-plane resolution of 3.44 mm x 3.44 mm, with 5 mm slice thickness. Pulse sequence parameters were TR/TE/FA/FOV of 750 ms/35 ms/50°/22 cm. Resting state data were acquired while the subjects were inactive (lying still, with fixation cross being presented), with a total scan time of 200 seconds.

1.2. Motor task

Subjects performed repetitive right handgrips at 50% maximal voluntary contraction (MVC) level by gripping a bottle-like device[8]. Handgrip force was measured by a pressure transducer connected to the device through a nylon tube filled with distilled water. The target level (50% MVC) was calculated based on the maximal grip force measured at the beginning of the experiment. Subjects performed the contractions by following visual cues projected onto the screen above the subjects' eyes. Each visual cue was a rectangular pulse that matched the profile (amplitude and duration) of the handgrip contraction. The duration of each contraction was 3.5 s, followed by a 6.5-s inter-trial (rest) interval. The fatigue task lasted 20 minutes, with a total of 120 contractions performed by each subject. The MVC handgrip force was recorded at the beginning and the end of the force task to assess fatigue.

1.3. Connectivity Analysis

Two subjects were excluded due to gross head motion. The remaining resting state data was first low-pass filtered < 0.08 Hz preserving those frequencies contributing to functional connectivity[1,9] and to avoid unwanted artifacts caused by physiological noise (due to the respiration or cardiac cycles). Then, the motor cortices of each slice were anatomically delineated by identifying the "knee" of the primary motor cortex[10]. The motor cortex timecourses were then extracted and cross-correlated to all other ROI timecourses in the same slice.

The number of interhemispheric correlations passing a $p<0.05$ threshold were then calculated, and normalized by ROI area. This normalized bilateral connectivity measure was calculated for all resting state data for all subjects, and examined before and after the unilateral fatigue task for significant change. The mean correlation for each cortex was visually examined to determine change in the interhemispheric resting state correlation patterns before and after the fatigue task.

3. RESULTS

The MVC handgrip force recorded at the end of the experiment was significantly lower than that measured at the beginning, indicating that muscle fatigue had occurred.

The normalized interhemispheric correlations are shown in Table 1. The correlation decreases for almost all subjects after the unilateral fatigue task, except for the fifth subject, who did not perform well during the fatigue task. Using a paired difference t-test, the difference in the interhemispheric correlation before and after the fatigue task was found to be significant ($p < 0.003$).

The change in the interhemispheric connectivity can be seen in the individual mean correlation maps, with a typical subject being shown in Figure 1. It can be seen that the interhemispheric correlation in both cortices decreases after the fatigue task. Note that the mean correlation values after the task do not pass a significance threshold of $p < 0.05$.

4. CONCLUSIONS

We have found that the interhemispheric correlation in the primary motor cortices decreases after a unilateral fatiguing motor task. This suggests that the bilateral motor connectivity network may be disrupted by a taxing unilateral task. This has implications for connectivity network modeling, and in the pathology and rehabilitation of the motor system.

Future work will examine the temporal characteristics of the network changes in more detail. The motor fMRI timecourses before and after the fatigue task will be compared for changes in frequency or phase delays to assess the possible cause of the reduction in interhemispheric correlation. Nonlinear methods[11] will also be applied to assess causes that are not linear in nature.

This study examined the differences before and after the fatigue state, but only assessed these differences for the scans taken as a whole. Methods for examining functional connectivity in a dynamic fashion (including online, allowing near real-time analysis) have been developed by our group[12]. By applying these methods to future fatigue studies, we can assess network changes during the scan, in order to better understand the dynamics of both hemispheric disconnection induced by the fatigue task, and the recovery post-fatigue. Combining this method with concurrent EMG recordings will give us a deeper understanding of the dynamic effects of muscle fatigue on the brain.

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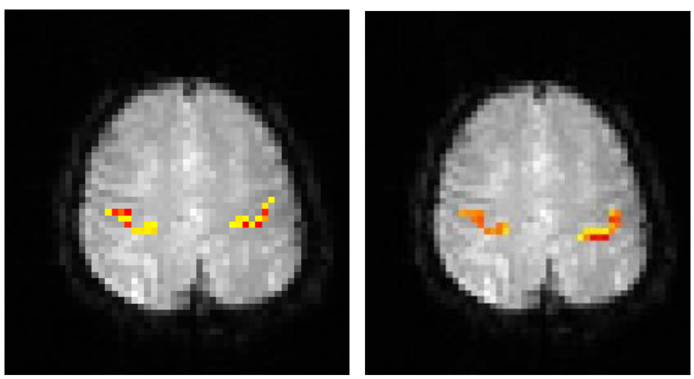
	Normalized interhemispheric correlation	
Subject	Before fatigue task	After fatigue task
1	0.44	0.38
2	0.66	0.44
3	0.52	0.40
4	0.45	0.33
5	0.39	0.43
6	0.57	0.36
7	0.47	0.30
8	0.65	0.47
Mean (Std)	0.52(±.10)	0.39(±.06)

Table 1. Comparison of the amount of significant interhemispheric correlations before and after the unilateral fatigue task. Values are the number of significant ($p<0.05$) interhemispheric correlations normalized by the total number, then averaged across slices.

Mean interhemispheric correlation maps



Before fatigue task **After fatigue task**

Figure 1. Comparison of mean interhemispheric correlation for each voxel in the motor cortex ROIs for a typical subject before and after the unilateral fatigue task.