# Finger-Tapping Modulates Functional Synchrony in the Motor Cortex Network

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**Introduction:** Spontaneous low-frequency fluctuations (SLF) detected by functional MRI (fMRI) techniques have been utilized to investigate functional synchrony in human brain networks. We have demonstrated that the functional synchrony during a memory task can be modulated [1]. It is not clear if a similar modulation effect exists in the motor cortex network during finger-tapping tasks. Also uncertain is whether there is an intrinsic frequency component (IFC) in the SLF signal to determine the functional synchrony within or between brain regions in the motor cortex networks. In the present study, we hypothesize that there is a dominant IFC at around 0.025Hz in SLF signals to determine the functional synchrony in the motor cortex network. The functional synchrony either within a brain region or between brain regions in the motor cortex network can be modulated by the finger-tapping task.

**Theory:** The IFC $\hat{f}_c$ of SLF signal is identified as the maximum peak of the regional cross-spectrum of pair-wised voxel time courses from a given region of interest (ROI). Assume that the phase delay of each voxel time course to the detected IFC within the ROI is Gaussian distributed $N(\tau_0, \sigma_\tau)$, then the standard deviation of the phase delay distribution can be obtained as $\hat{\sigma}_\tau$ [2], which is defined as the within-region functional synchrony. If we have two regions, each with Gaussian-distributed phase delays to the input IFC as: $N(\tau_{0A}, \sigma_{\tau A})$ for region A (with $K_A$ voxels), and $N(\tau_{0B}, \sigma_{\tau B})$ for region B (with $K_B$ voxels), then the between-region phase delay reaches following equation approximately when both $K_A$ and $K_B$ are large enough:

$$\frac{1}{K_A K_B}\sum_{\substack{1\le i\le K_A \\ 1\le j\le K_B}} \tau_{ij} \approx \sqrt{2/\pi}\,\sigma_d \cdot \exp\left(-\tau_d^{\,2} \big/ 2\sigma_d^{\,2}\right) + \tau_d \cdot erf\left(\tau_d \big/ \sqrt{2}\sigma_d\right) \quad (1)$$

where $\tau_{ij}$ is the phase delay between the pair of voxel time courses (*i*th voxel from region A and *j*th voxel from region B), $\sigma_d$ is the combined standard deviation of the phase delay $\sigma_d^{\,2} = \sigma_{\tau A}^{\,2} + \sigma_{\tau B}^{\,2}$, *erf( )* is the error function, and $\tau_d$ is defined as the between-region phase delay: $\tau_d = |\tau_{0A} - \tau_{0B}|$, which is used to measure the between-region functional synchrony. The larger $\hat{\sigma}_\tau$ or $\hat{\tau}_d$, the less synchronized the IFC becomes within or between regions.

**Materials and Methods**: The fMRI experiments were conducted on a GE 3T scanner. Ten healthy young subjects were recruited for the experiments, and informed consent was obtained from all the subjects for this IRB-approved study. The fMRI parameters were: axial EPI, TE/TR=30/2000 ms, slice thickness 4mm, matrix 64*64, FOV 240mm. For each subject, three fMRI scans were included in this study: steady-state resting-state scan with 180 equilibrium repetitions, steady-state finger-tapping scan with 180 equilibrium repetitions, and block-designed finger-tapping vs. resting scan with 180 equilibrium repetitions (30s on, 30s off, 6 blocks). Three activated regions were selected as the backbone of the motor cortex network with the block-designed scan ($P$<0.05 with Bonferroni correction): left primary motor cortex (LM), right primary motor cortex (RM), and supplementary motor cortex (SM). Cardiac and respiration cycle data were also recorded by using a pulse-oximeter and pneumatic belt. For preprocessing, all the voxel time courses within the ROIs were processed by RETROICOR method [3] to regress out unwanted cardiac and respiration noise. Then, those voxels susceptible to respiration variation [4] were excluded. The voxel time courses were interpolated to sampling frequency 2Hz, and filtered with a band-pass filter 0.015~0.1Hz. The cross-spectrums were computed using the Welch method. The intrinsic low-frequency components, within-region phase delays, between-region phase delays were obtained.

**Results and Discussion**: The motor network is illustrated in Figure 1, and the measurements of the functional synchrony are presented in Table 1. For all the steady-state fMRI scans (finger-tapping and resting state scans), the detected IFC shows up consistently at around 0.025Hz. Within-region phase delays are consistent within each type of tasks, but they are significantly different between different types of tasks. Fewer phase delays in selected motor regions are demonstrated with the continuously performed finger-tapping task than the resting state, creating more synchronization at the IFC. A similar result was obtained for the between-regions analysis. The phase delays in the between-region analysis for the finger-tapping task are significantly less than those in the resting state, and less than those within the brain region. These results demonstrated that the IFC plays a dominant role in determining functional synchrony and that the functional synchrony is significantly stronger between the motor regions than within a motor region. Moreover, these results further suggest that finger-tapping task induces more synchronized tonic activity and functional connections between the motor networks. It is suggested that these modulation effects can be applied in investigating a disease state in which patients may have lost the ability to modulate the functional synchrony during performing specific tasks.

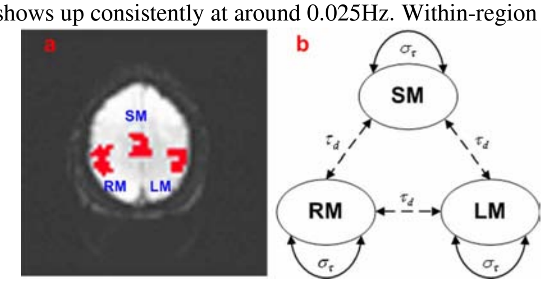


Fig. 1a representative motor cortex network
Fig. 1b within and between region functional synchrony

Table 1. Measurements of functional synchrony (Mean±SD) (* denotes that there is statistical difference between two tasks)

| | $\hat{f}_c$ (Hz) | $\hat{\sigma}_\tau$ - LM (seconds) | $\hat{\sigma}_\tau$ - RM (seconds) | $\hat{\sigma}_\tau$ - SM (seconds) | $\hat{\tau}_d$ - LM vs. RM (seconds) | $\hat{\tau}_d$ - LM vs. SM (seconds) | $\hat{\tau}_d$ - RM vs. SM (seconds) |
|---|---|---|---|---|---|---|---|
| Finger-tapping | 0.0237±0.0044 | 4.09±0.87* | 3.94±0.77* | 3.62±0.87 | 1.35±0.81* | 1.34±1.19* | 1.35±0.99* |
| Resting State | 0.0218±0.0048 | 5.65±1.03* | 5.62±0.81* | 4.82±1.15 | 2.06±0.76* | 2.72±1.97* | 2.50±1.35* |

**References**: 1. Xu G et al. MRM 2006;56:41-50. 2. Xu Y et al. ISMRM 2007; in submission. 3. Glover GH et al. MRM 2000;44:162-167. 4. Birn RM et al. NeuroImage 2006;31:1656-1668.

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