Chapter 42
Phase-Dependent Alteration of Functional Connectivity Density During Face Recognition in the Infra-slow Frequency Range

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Abstract Infra-slow fluctuations have been observed in electrophysiological recordings, psychophysical time series, and blood-oxygenation-level-dependent (BOLD) signals. The physiological significance of infra-slow fluctuations, however, is rarely understood. The phase of infra-slow fluctuations has been demonstrated to be associated with behavioral performance. In the present study, we aimed to examine whether the phase is related to short- or long-range neural synchronizations. We extracted phase information about steady-state BOLD responses and found that the alteration of local functional connectivity density during a face recognition task occurred at the ascending and descending phases, rather than at the crest and trough. Therefore, the dynamic neural synchronization in the infra-slow frequency range is phase-dependent. These results shed light on the physiological significance of infra-slow fluctuations and highlight the relationship between infra-slow fluctuations and neural synchronization.

Keywords Face recognition · Infra-slow fluctuations · Neural synchronization · Phase-dependent functional connectivity density

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42.1 Introduction

Infra-slow (<0.1 Hz) fluctuations have been widely observed in psychophysical time series, electrophysiological recordings, and blood-oxygenation-level-dependent (BOLD) signals [1]. These fluctuations are mutually correlated and supported by neural activities [1, 2]. Recently, the phase of infra-slow fluctuations has been demonstrated to be associated with neural synchronization and behavioral performance [3].

Steady-state brain response (SSBR), as a typical proxy of neural synchronization, is evoked by exogenous stimuli and is widely investigated in studies of cognitive and clinical neurosciences [4–7]. Nevertheless, how the neural synchronization in the infra-slow frequency range is modulated by exogenous stimuli is largely unknown.

In the present study, we explored short- and long-range neural synchronizations at different phases of infra-slow fluctuations. SSBRs were used to extract different phases of infra-slow fluctuations: the ascending, descending, crest, and trough. Short- and long-range functional connectivity densities (FCDs) were obtained from these four phases. The short-range FCD was found to be phase-dependent with increased synchronization at ascending and descending phases rather than at crest and trough.

42.2 Methods

42.2.1 Subjects and Procedure

Twenty-nine participants (13 females, 18–27) took part in the experiment. All subjects had normal or correct to normal vision, were right-handed, free from any medication, neurological, and psychiatric disorders. Written informed consent, approved by the university research ethical committee, was obtained from each subject. The data of three participants were removed from the final analysis due to large head motion (translation >2 mm or rotation >2°) in any runs.

A 10 min 20 s task and a resting scan of the same length were counterbalanced between subjects. During the task run, participants were asked to perform a face recognition task (all faces were neutral) with a judgment of whether a face is a neutral expression (right finger response) or not (left finger response). Stimuli were presented once every 20 s (0.05 Hz) and lasted for 2 s. During the resting scan, participants were required to remain motionless, focus their eyes on a white crosshair, stay awake, and not think of anything in particular.

42.2.2 Data Acquisition and Preprocessing

MRI data were acquired using a 3.0T GE 750 scanner (General Electric, Fairfield, Connecticut, USA) equipped with high-speed gradients. An 8-channel prototype quadrature birdcage head coil fitted with foam padding was applied to minimize the head motion. Functional images were acquired using a gradient-recalled echo-planar imaging (EPI) sequence. The parameters were as follows: repetition time/echo time = 2000 ms/30 ms, 90° flip angle, 43 axial slices (3.2 mm slice thickness without gap), 64 × 64 matrix, 22 cm field of view.

All images were preprocessed using the Data Processing Assistant for Resting-state fMRI (DPARSF 2.2, http://restfmri.net/forum/DPARSF). The preprocessing steps included: discarding the 1st 10 scans, slice-time correction, spatially alignment, normalizing to Montreal Neurological Institute (MNI) EPI template, resampling to 3 × 3 × 3 mm^3 isotropic voxels, smoothing with a 6 mm full width half maximum Gaussian kernel, and linear de-trend. Afterwards, six head motion parameters, white matter signal and cerebrospinal fluid signal were further regressed out.

42.2.3 Data Analysis

The Fast Fourier Transform (FFT) in gray matter constrained by the Automated Anatomical Labeling (AAL) template without cerebellum [8] revealed that the face recognition task evoked steady-state BOLD responses at the fundamental frequency of stimuli and three harmonics (Fig. 42.1a). According to previous studies [5–7, 9], we further superimposed all preprocessed data every 20 s time-locked to the onset of faces in the right fusiform face area (FFA). These time-locked phases were used to ensure that they are associated with SSBRs. A sinusoidal function was shown in the task scan rather than in the resting scan (Fig. 42.1b). The small standard errors in Fig. 42.1b indicate low variability of the phase among subjects or trials. Hence, four phases of the 0.05 Hz fluctuation were extracted from unsmoothed data, undergoing linear de-trend and noise regression on each phase. Of note, data points between the phases were overlapped to recruit as many time points as possible to improve statistical power.

The local and global FCDs were computed using the method proposed by Tomasi and Volkow [10]. The short-range FCD is equated to the local FCD, and the long-range FCD is defined as global FCD–local FCD [10].

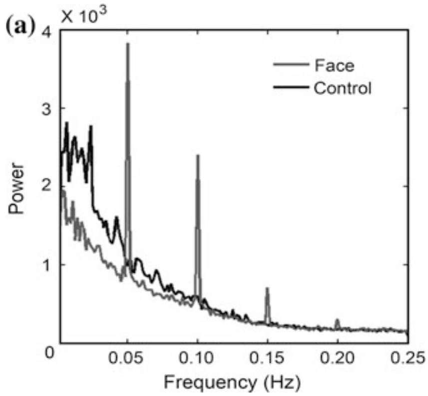

Fig. 42.1 Mean power in gray matter (**a**) and mean waveforms of task and resting conditions in the *right* FFA time-locked to the onset of face pictures (**b**). The waveforms were obtained from the fundamental frequency (0.045–0.055 Hz). *Error bars* show the standard errors. Time points for ascending: 1, 2, 9, 10; descending: 4, 5, 6, 7; crest: 1, 2, 3, 4, 5; trough: 6, 7, 8, 9, 10

42.3 Results

Repeated measures analysis of variance (ANOVA) was performed for both short- and long-range FCDs with task and phase as within-subject factors. Widely changed synchronizations were induced by the task (FDR correction, $p < 0.05$). No effect of phase was observed. The interaction of task × phase was significant in the right FFA for the short-range FCD only (Fig. 42.2). Paired-sample t-test revealed that the synchronization was changed by the task at ascending [t (25) = 5.45, $p < 0.001$] and descending [t (25) = 5.46, $p < 0.001$] phases (Fig. 42.3).

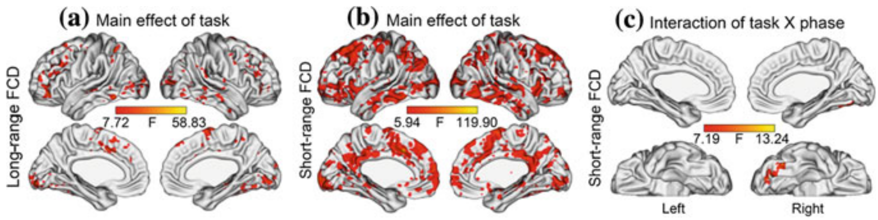

Fig. 42.2 Main effects and interaction of FCD. The main effects of task are significant for **a** long- and **b** short-range FCDs. The interaction of task × phase is significant for short-range FCD (**c**). There is no main effect of phase

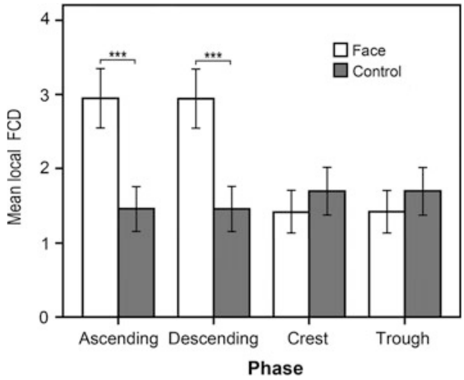

Fig. 42.3 There are differences of short-range FCD between task and resting conditions at the ascending and descending phases

42.4 Discussion

The task effect is pervasive throughout the brain, which is similar to the phenomenon of BOLD variability but not the activation [11], indicating a whole brain modulation pattern during face recognition. The ascending and descending phases of SSBR regulate short-range FCD in the right FFA, consisting of the view that phase indexes the state transitions [3]. Monto et al. [3] reported that the ascending and descending phases are related to the highest and lowest hit rates, indicating the association of these phases with neural synchronization and desynchronization, respectively. However, whether the monotonic (i.e., ascending and descending) and non-monotonic (i.e., crest and trough) changes affect the FCD warrants future investigations. Our results, therefore, shed light on the physiological significance of infra-slow fluctuations by showing the phase-dependent neural synchronization.

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References

1. Palva, M., Palva, S.: Infra-slow fluctuations in electrophysiological recordings, blood-oxygenation-level-dependent signals, and psychophysical time series. NeuroImage 2201–2211 (2012)
2. Pan, W.-J., Thompson, J., Magnuson, E., Jaeger, D., Keilholz, S.: Infraslow LFP correlates to resting-state fMRI BOLD signals. NeuroImage 288–297 (2013)
3. Monto, S., Palva, S., Voipio, J., Palva, M.: Very slow EEG fluctuations predict the dynamics of stimulus detection and oscillation amplitudes in humans. J. Neurosci. 8268–8272 (2008)
4. Vialatte, F.-B., Maurice, M., Dauwels, J., Cichocki, A.: Steady-state visually evoked potentials: focus on essential paradigms and future perspectives. Prog. Neurobiol. 418–438 (2010)
5. Wang, Y.-F., Liu, F., Long, Z.-L., Duan, X.-J., Cui, Q., Yan, J. H., Chen, H.-F.: Steady-state BOLD response modulates low frequency neural oscillations. Sci. Rep-UK 1–7 (2014)

6. Wang, Y.-F., Dai, G.-S., Liu, F., Long, Z.-L., Yan, J.H., Chen, H.-F.: Steady-state BOLD response to higher-order cognition modulates low-frequency neural oscillations. J. Cogn. Neurosci. 2406–2415 (2015)
7. Wang, Y.-F., Long, Z.-L., Cui, Q., Liu, F., Jing, X.-J., Chen, H., Guo, X.-N., Yan, J.-H., Chen, H.-F.: Low frequency steady-state brain responses modulate large scale functional networks in a frequency-specific means. Hum. Brain. Mapp. (2015). doi:10.1002/hbm.23037
8. Tzourio-Mazoyer, N., Landeau, B., Papathanassiou, D., Crivello, F., Etard, O., Delcroix, N., Mazoyer, B., Joliot, M.: Automated anatomical labeling of activations in SPM using a macroscopic anatomical parcellation of the MNI MRI single-subject brain. NeuroImage 273–289 (2002)
9. Thompson, J., Pan, W., Billings, C., Grooms, K., Shakil, S., Jaeger, D., Keilholz, D.: Phase-amplitude coupling and infraslow (<1 Hz) frequencies in the rat brain: relationship to resting state fMRI. Front. Integr. Neurosci. 1–17 (2014)
10. Tomasi, D., Volkow, D.: Aging and functional brain networks. Mol. Psychiatr. 549–558 (2011)
11. Garrett, D., McIntosh, R., Grady, L.: Brain signal variability is parametrically modifiable. Cereb. Cortex 2931–2940 (2014)