Applying Nonlinear Time Series Analysis Methods to Functional Magnetic Resonance Imaging

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Functional magnetic resonance imaging (fMRI) has emerged as a useful and noninvasive technique for studying brain function. This method of functional mapping indirectly detects neural activity by measuring changes in blood oxygenation in the brain in response to stimulus. By acquiring multiple MR images over time during activated and non-activated states, it is possible to construct a time series of the signal from each volume element of the brain. This thesis first discusses the background information needed to understand magnetic resonance imaging in Chapter 1 and then explains the method of functional magnetic resonance imaging in Chapter 2. Sophisticated statistical methods have been developed in order to accurately analyze fMRI data to determine activated regions during a task and to assess the significance of results obtained. Chapter 3 of this thesis presents a study that compares the usefulness of several nonparametric methods of resampling the data used to determine the statistical significance of experimental results.

Nonlinear time series methods have recently improved in their usefulness in analyzing deterministic, nonlinear systems, and the feasibility of their application to fMRI data is investigated. Before proceeding with the use of these methods, it is necessary to justify their use by formal testing. Results are discussed in Chapter 4 of several tests using the method of surrogate data which allows us to verify that the data are nonlinear and to conclude that we may proceed with these advanced techniques.

Next, results of several studies that apply the theory of phase synchronization, a nonlinear phenomenon, are detailed. A novel method is proposed in Chapter 5 in which the phase locking condition is investigated between a voxel time series and the reference waveform of the task performed. In addition, it is shown in Chapter 6 how the phenomenon of cluster synchronization can be detected in fMRI activation data. Lastly, a method of determining the direction of coupling between the motor cortex and the cerebellum using an algorithm based on the theory of dynamics of interacting, nonlinear oscillators is introduced in Chapter 7.