수면박탈이 각성 뇌파의 양수 리아프노프 지수에 미치는 효과에 관한 연구

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Effects of Total Sleep Deprivation on the First Positive Lyapunov Exponent of the Waking EEG

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Abstract

Sleep deprivation may affect the brain functions such as cognition and, consequently, dynamics of the EEG. We examined the effects of sleep deprivation on chaoticity of the EEG. Five volunteers were sleep-deprived over a period of 24 hours. They were checked by EEG during two days, the first day of baseline period and the second day of total sleep deprivation period. EEGs were recorded from 16 channels for nonlinear analysis. We employed a method of minimum embedding dimension to calculate the first positive Lyapunov exponent. For limited noisy data, this algorithm was strikingly faster and more accurate than previous ones. Our results show that the sleep deprived volunteers had lower values of the first positive Lyapunov exponent at ten channels (Fp_1, F_4, F_8, T_4, T_5, C_3, C_4, P_3, P_4, O_1) compared with the values of baseline periods. These results suggested that sleep deprivation leads to decrease of chaotic activity in brain and impairment of the information processing in the brain. We suggested that nonlinear analysis of the EEG before and after sleep deprivation may offer fruitful perspectives for understanding the role of sleep and the effects of sleep deprivation on the brain function.

1. Introduction

Total sleep deprivation is known to cause various degrees of monotonic decrease in performance of a very broad range of variables including vigilance, reaction time, arithmetic computations, short-term and long-term memory, psychomotor tasks, and logical reasoning tasks. The longer the time period of previous wakefulness is, the greater the decrease in the performances is (Horne 1978; Corsi-Cabrera et al., 1996).

Recent progress in the theory of nonlinear dynamics has provided new methods for the study of time-series data from human brain activities. In the dynamical aspect, the brain is assumed to be a dissipative dynamical system. The distinct states of brain activity had different chaotic dynamics quantified by nonlinear invariant measures such as correlation dimensions and Lyapunov exponents (Babloyantz and Destexhe 1987; Babloyantz 1988; Röschke and Aldenhoff 1991; Fell et al 1993). Therefore, we can investigate the brain function by understanding the dynamical properties of the brain using nonlinear analysis of EEG.

In this paper, we investigate the cognitive dysfunction after sleep deprivation using nonlinear analysis of EEG. We estimate the first Lyapunov exponents of the EEG and compare the values in the whole brain region before and after sleep deprivation. The changes of dynamical properties of EEG at different channels may give the fruitful key to understand the role of sleep and the effect of sleep deprivation on the brain function. In Section 2, we explain the procedure for reconstructing brain dynamics from an EEG and for analyzing the EEG by nonlinear methods and algorithm for determining the proper embedding dimension and for compensating for both noise contamination and edge effects. The first Lyapunov exponent is also defined and discussed. Section 3 briefly presents the procedure for recording data. Section 4 shows the differences in the values of the first Lyapunov exponent before and after sleep deprivation. In section 5, we discuss our results in the dynamical and physiological view. Our conclusions are given in Section 6.

2. Theory and Algorithm

Lyapunov exponents estimate the mean exponential divergence or convergence of nearby trajectories of the attractor. We estimate the first positive Lyapunov exponent with minimum embedding dimension method. In our new algorithm, we calculate the first positive Lyapunov exponent L1 in the minimum embedding dimension. We determine the minimum embedding dimension by using the calculation method, presented by Kennel et al. (1992), which is based on the idea that in the passage from dimension d to dimension $d+1$, one can differentiate between points on the orbit that are "true" neighbors and those on the orbit which are "false" neighbors. A false neighbor is a point in the data set that is a neighbor solely because we are viewing the orbit (the attractor) in too small an embedding space ($d < d_{\min}$). When we have