Wavelet Leader Based Multifractal Analysis of Sleep Electroencephalogram

Yan Li
Huaqiao University College of Information Science and Engineering
Chi Tang
Air Force Medical University
Juan Liu
Air Force Medical University
Wei Han
Ninewells Hospital Department of Medical Microbiology
Siqi Yang
Air Force Medical University
Erping Luo
Air Force Medical University
Zheng Yan
Huaqiao University College of Information Science and Engineering
Ruimin Huang
Huaqiao University College of Information Science and Engineering
Kangning Xie (tocooper@hotmail.com)
Air Force Medical University https://orcid.org/0000-0002-6031-8489

Research

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Abstract

Background: Conventional manual sleep stage classification is time-consuming and relies on the knowledge and experience of the specialists. The emergence of automatic sleep stage classification greatly improves the classification efficiency. The feature extraction in automatic sleep stage classification is particularly important, which usually uses the linear methods based on techniques in the time domain, frequency domain, or time-frequency domain. Electroencephalograms (EEGs) contain a wealth of physiological information, have been widely used for the classification of sleep stage. Due to the nonlinear, non-stationary, and multifractal characteristics of EEGs, some nonlinear methods have been used to extract features of sleep stages in recent years, such as complexity, multifractal theory, and chaos theory. The Wavelet Leader Multifractal Formalism (WLMF) of the multifractal theory is widely applied to different physiological signals. The current researches focus on discussing the mean H¨older exponent (h0) and the width of the multifractal singularity spectrum (WD(h)) estimated by the WLMF method. However, in the field of sleep staging, a number of researches focused on h0, but few studies on WD(h).

Results: This paper aims to assess the multifractal characteristic for sleep EEG time series from the Sleep-EDF Expanded Database by the WLMF method. In the young group, the mean h0 increased from the Wake stage to the S3 stage ($p<0.01$). So did the elderly group ($p<0.001$). WD(h) of the Wake stage was less than that of the S3 stage for the young group, and this relationship was reversed for the elderly group($\chi2=13.769$, df=1, $p<0.001$). Gender did not affect, with statistical significance, WD(h) of the Wake stage and the S3 stage ($\chi2=0.085$, df=1, $p=0.608$), nor did the brain region ($\chi2=3.137$, df=1, $p=0.078$).

Conclusions: The result shows that WD(h) was influenced by aging. The gender and location of brain regions did not show significant influence on the multifractal characteristics of wakefulness and sleeping. This finding extends the application of the multifractal singularity spectrum on sleep staging, and raises a fundamental question on what might be the underlying mechanisms of the WD(h) reversion.

Full Text

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Figures

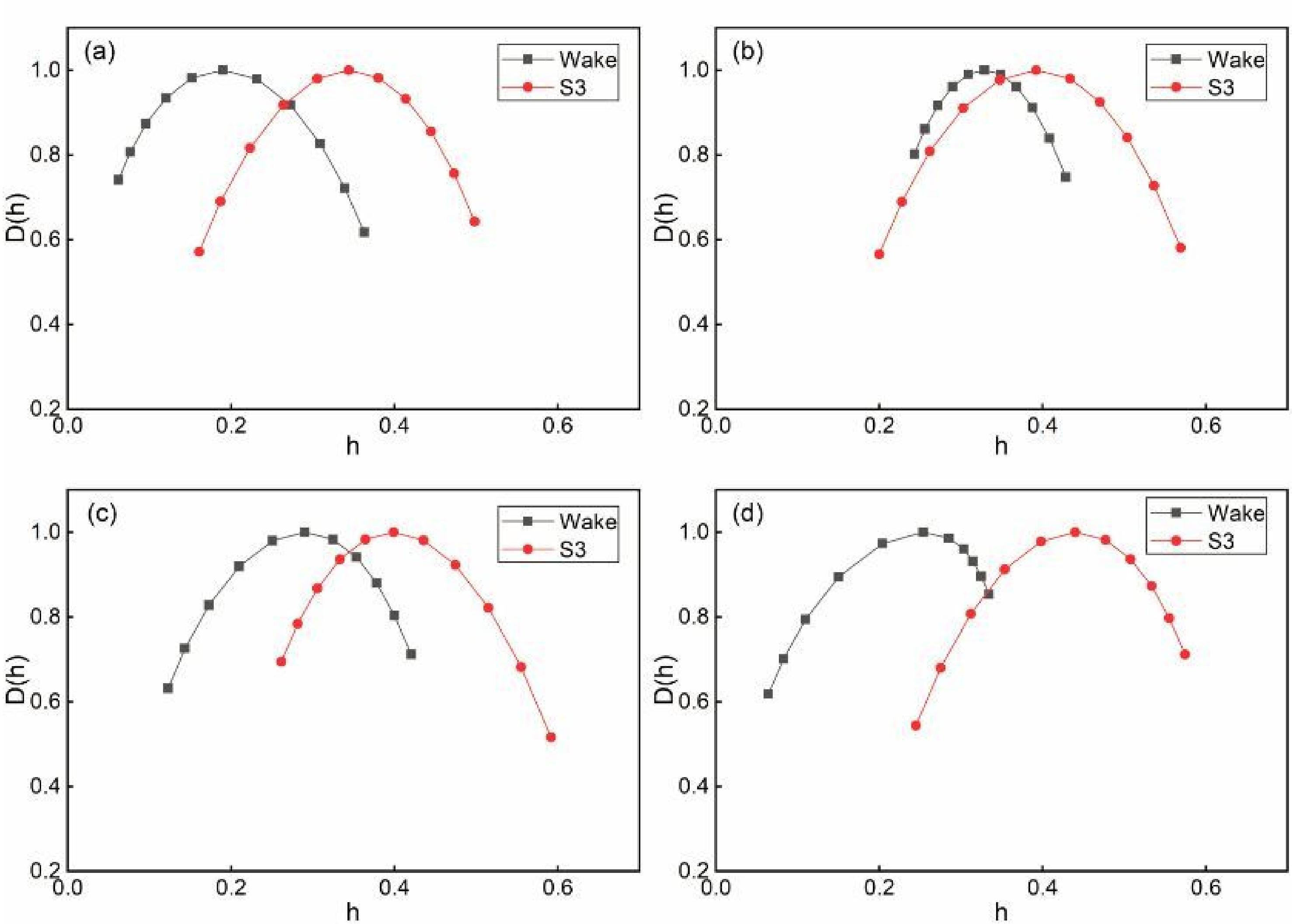

Figure 1

The multifractal singularity spectra of Wake stage and S3 stage from the young group. (a), (b), (c) and (d) are respectively subject SC4051E0, SC4121E0, SC4151E0 and SC4182E0. Wake: denotes the subject is awake; S3: sleep stage 3.

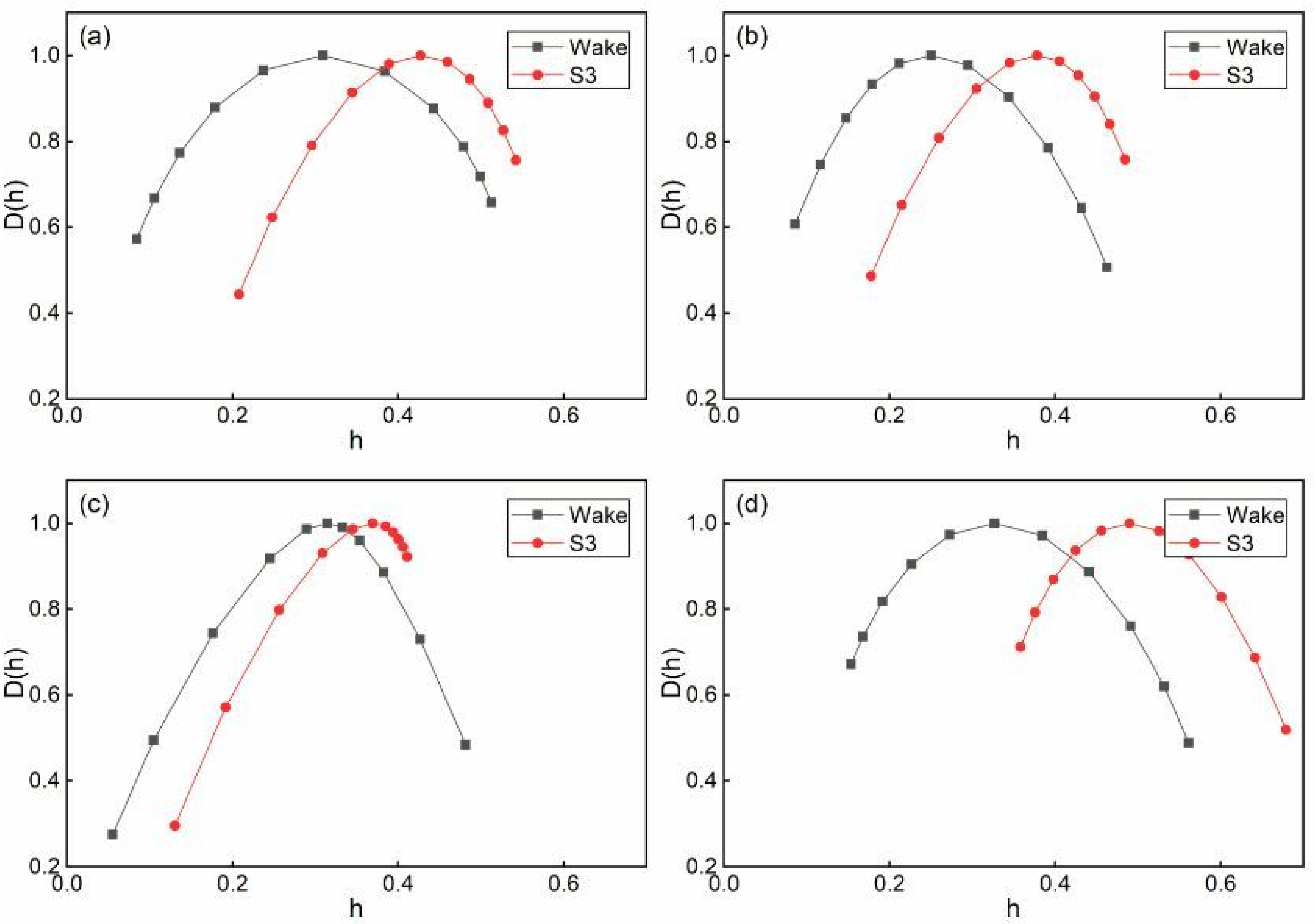

Figure 2

The multifractal singularity spectra of Wake stage and S3 stage from the elderly group. (a), (b), (c) and (d) are respectively subject SC4221E0, SC4382F0, SC4402E0 and SC4481F0. Wake: denotes the subject is awake; S3: sleep stage 3.

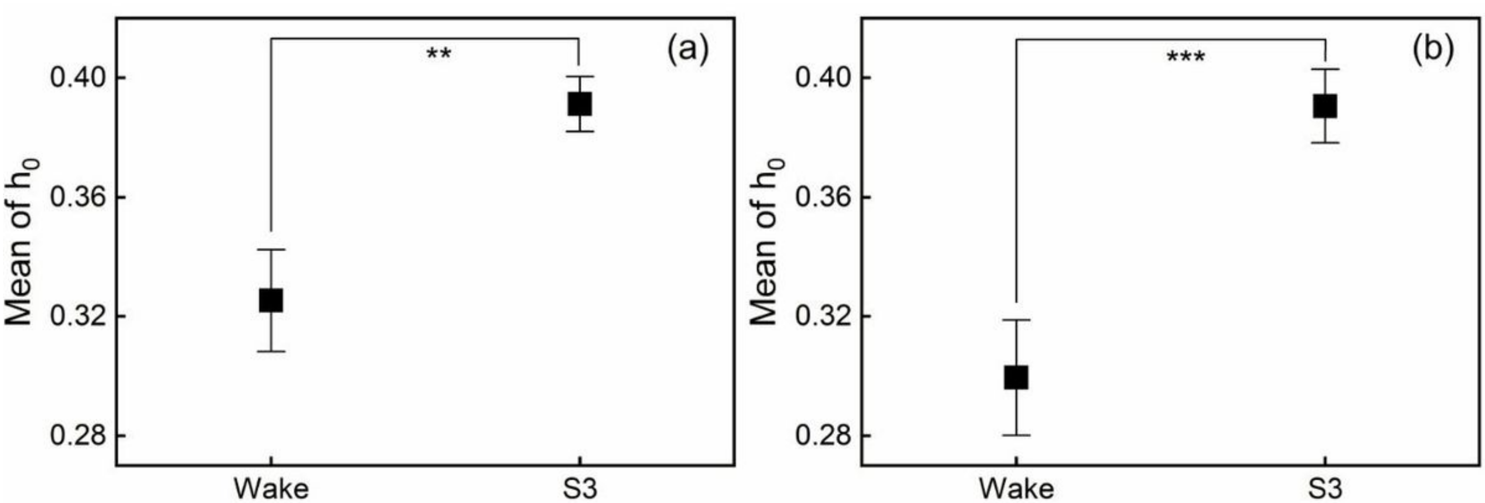

Figure 3

Means and standard derivations of the h0 H¨older exponents for Wake and S3. (a) 16 subjects from the young group. (b) 23 subjects from the elderly group. Wake: denotes the subject is wake; S3: sleep stage 3. ** ($p<0.01$) and *** ($p<0.001$) denote there is a significant difference between the 2 stages respectively.

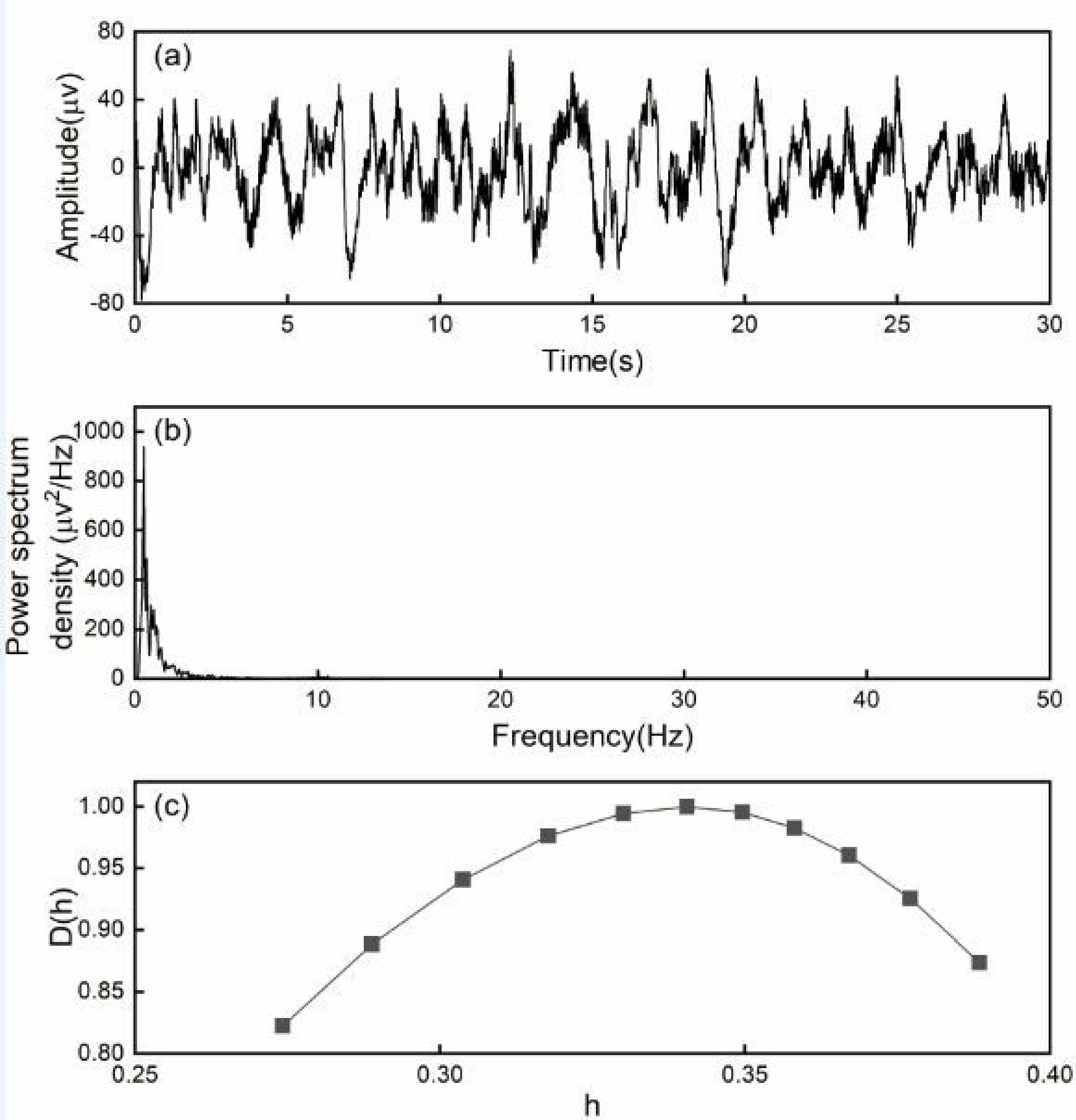

Figure 4

An example of sleep EEG, power spectrum density, and multifractal singularity spectrum from subject SC4492E0 (Fpz-Cz). (a): EEG (Fpz-Cz) of the sleep stage. (b): The power spectrum calculated by the Pwelch method. (c): The multifractal singularity spectrum D(h).

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