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Examination of the wavelet-based approach for measuring self-similarity of epileptic electroencephalogram data

Key words: Self-similarity, Power-law behavior, Wavelet analysis, Electroencephalogram, Epilepsy, Seizure

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Introduction

- The mathematical concept of a fractal is commonly associated with irregular objects that exhibiting a property called self-similarity or scale-invariance (Mandelbrot, 1982; Goldberger, 2006)
- An important class of statistical scale-invariant or self-similar random processes is the 1/*f* process (Wornell, 1995)
- In general, models of 1/*f* process are represented using a frequency domain characterization
- The dynamics of 1/*f* process exhibit power-law behavior (Watters, 1998) and can be characterized in the frequency domain .
- Wornell (1993; 1995) developed a wavelet-based representation for 1/*f* process
- In this study, a computational method based on a wavelet-based representation of 1/*f* process is used to estimate the spectral exponent which characterizes the self-similarity of a signal
- The application of the wavelet-based approach to epileptic EEG data analysis is demonstrated

Wavelet-based self-similarity measure

- According to the theorem developed by Wornell (1993), the spectral exponent of a $1/f$ process can be determined from a linear relationship between $\log_2 \mathrm{var}(d_{m,n})$ and the level m

- The wavelet-based approach for estimating the spectral exponents can be performed in the following steps:

    1. Normalized a signal

    2. Decompose the normalized signal into M levels using the wavelet-basis expansions to obtain the wavelet coefficients $d_{m,n}$ where m=1,2,...,M

    3. Compute the variance of wavelet coefficient corresponding to each level m

    4. Compute the logarithm to base 2 of the corresponding variances of wavelet coefficients

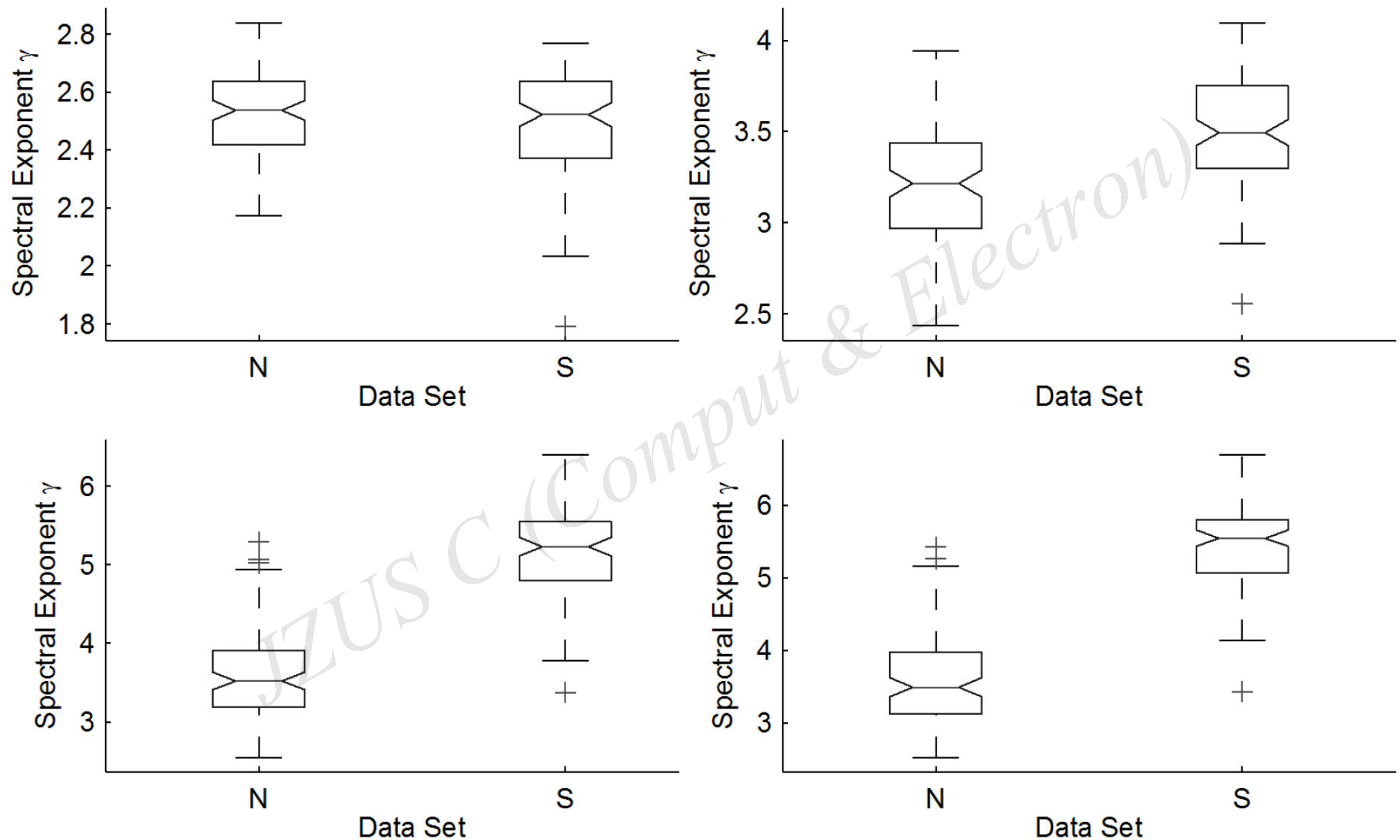
    5. Estimate the slope of the $\log_2 \mathrm{var}(d_{m,n})$-$m$ graph to obtain the spectral exponent

Results

Wavelet bases	$\log_2$ var	
	N	S
Db1	2.5261 ± 0.1396	2.4979 ± 0.1767
Db2	3.2260 ± 0.3125	3.5166 ± 0.3122
Db10	3.6292 ± 0.6003	5.1918 ± 0.5559
Db30	3.6121 ± 0.6667	5.4487 ± 0.5886

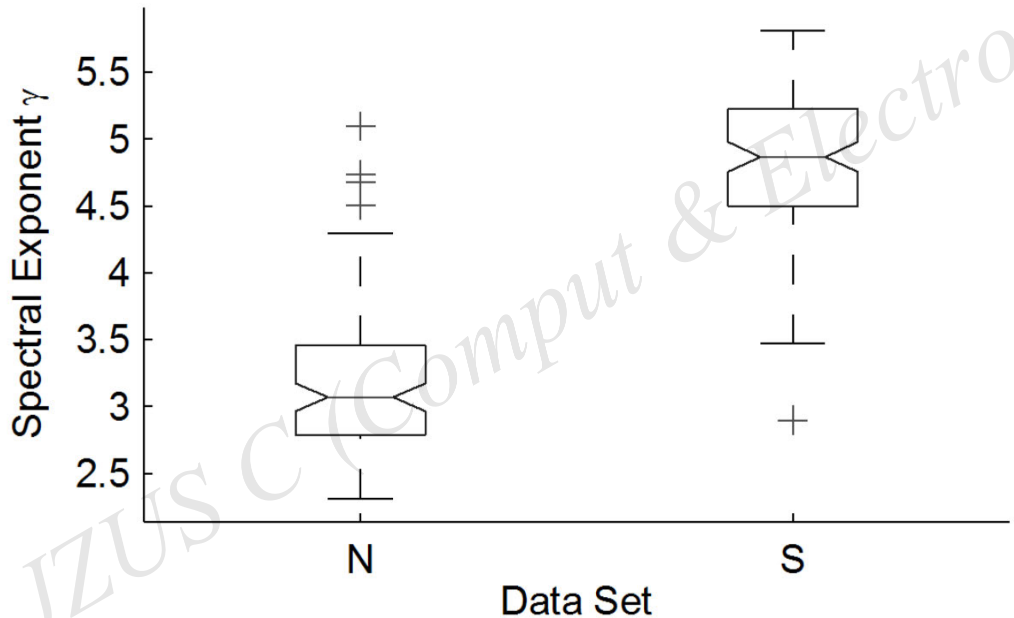
The statistical values (mean±standard deviation) of the intracranial EEG data

Results



Comparison of the spectral exponents of the intracranial EEG data sets N and S using Daubechies wavelet bases Db1 (a), Db2 (b), Db10 (c), and Db30 (d)

Results



Comparison of the spectral exponents of the intracranial EEG data sets N and S using the power spectrum method

Conclusions

- The computational results show that an approach based on a wavelet-based representation of 1/*f* process can be used successfully to estimate the spectral exponent which characterizes self-similarity
- The spectral exponents of the intracranial EEG signals estimated using the wavelet-based approach were generally comparable to those estimated using the power spectrum method
- However, the wavelet transform method is naturally suited for manipulating self-similar or scale-invariant signals
- The computational results suggest that intracranial EEG signals obtained during epileptic seizure activity tend to be more self-similar than those obtained during non-seizure periods
- A significant difference between the spectral exponents obtained during epileptic seizure activity and those obtained during non-seizure periods can be observed
- This is sufficient to reveal the characteristics of the underlying neuronal dynamics of the brain corresponding to different pathological states, i.e., ictal and interictal states