Sleep electroencephalogram analysis based on symbolic transfer entropy

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Abstract. The quality of sleep has a great relationship with health. The result of sleep stage classification is an important indicator to measure the quality of sleep. It was found that the symbolic transfer entropy about wake and the first stage of non-rapid eye movement sleep reflect on the changes of sleep stage. And it was confirmed by T test and multi-samples experiments. The symbolic transfer entropy can apply into automatic sleep stage classification. By Multi-parameter analysis it could achieve a higher accuracy of sleep stage classification.

Introduction

Sleep EEG signals are chaotic signals which have a wide range of nonlinear dynamical characteristics [1]. The correlation dimension, Lyapunov exponent, approximate entropy were applied in the field of sleep EEG studies [2]. We know that with the deepening of sleep from the awake state, the brain activity degrees reduction of freedom which suggests that the brain cell is continuing coupling, or the original active part is continuing inacting [3]. Hence the correlation of the EEG signal enhanced.

Human body was in line with three basic characteristics of the dissipative structure. So the symbolic transfer entropy (STE) [4-6] can be use to analyze human sleep stage. Selecting one lead EEG signals from MIT-BIH Polysomnographic Database of PhysioBank, after analyzing awake stages and NREM sleep stages, it was found that the symbolic transfer entropy in the different sleep stages has different characteristic values. The symbolic transfer entropy of wake stages was larger and that of NREM sleep stage was less. It can distinguish different sleep stages. The symbolic transfer entropy [4-6] as a new parameters of sleep stage can be extended to the staging of sleep in REM and NREM sleep period, and accordingly can study the structure of patients with a night's sleep.

Theory

1) Symbolizing time series

Assuming ECG sequence is X, X =$\{ x_0, x_1, x_2, \ldots, x_i, \ldots, x_N \}$, and sequence length is N. Transferring the sequence X into a sequence of symbols S=$\{ s_1, s_2, \ldots, s_i, \ldots, s_N \}$, $s_i \in A$ ($A = 0,1,2,3$). Specific conversion method is as follows:

Calculating differently the mean value of signals greater than zero and signals less than zero of sampled ECG signal, it is denoted by u_1 and u_2.

$$s_i(x_i) = \begin{cases} 0: & u_1 < x_i \le (1+a)u_1 \quad \text{or} \quad (1+a)u_2 \le x_i < u_2 \\ 1: & (1+a)u_1 < x_i < \infty \quad \text{or} \quad -\infty < x_i < (1+a)u_2 \\ 2: & (1-a)u_1 < x_i \le u_1 \quad \text{or} \quad u_2 \le x_i < (1-a)u_2 \\ 3: & (1-a)u_2 \le x_i \le (1-a)u_1 \end{cases} \tag{1}$$

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Where $i=1,2,...,N$. And a is a constant parameter. If the value a is taken too large or too small, it can reduced to the loss of detail in the symbolizing original time series to symbolic sequences, and it cannot well capture dynamic information in the signals. Here we take $a=0.05$.

2) Calculating the symbolic transfer entropy

Supposing $x_i = x(i), y_i = y(i)$, i = 1, ..., N, which represent the two observed time series. The value of y_{i+1} was predicted by history related x_i and y_i. And it was quantified the Markov bias, p($x_{i+1} \mid x_i, y_i$)=p($x_{i+1} \mid x_i$), p is the transition probability density . If not haing Markov bias, it indicates Y having no effect on X. Then transfer entropy can also be seen as the permutation entropy between p($x_{i+1} \mid x_i, y_i$) and p($x_{i+1} \mid x_i$).

The transfer entropy of sequence X and sequence Y is defined as:

$$T_{X \to Y} = \sum p(x_{n+1}, x_n^{(k)}, y_n^{(l)}) \log \frac{p(x_{n+1} \mid x_n^{(k)}, y_n^{(l)})}{p(x_{n+1} \mid x_n^{(k)})} \quad (2)$$

x_n、y_n represent the state of n time and $x_n^{(k)}$ is on behalf of $x_n,\ldots,x_{n-k+1}$, usually k, l taking 1.

Selecting two sets of data of different leads in the same time for the same individual, after a symbolized sequence were S and J respectively. Using the formula, it can be calculated the symbol transfer entropy.

$$T_{S \to J} = \sum p(s_{n+1}, s_n^{(k)}, j_n^{(l)}) \log \frac{p(s_{n+1} \mid s_n^{(k)}, j_n^{(l)})}{p(s_{n+1} \mid s_n^{(k)})} \quad (3)$$

Data analysis

Sleep EEG data used in this paper were from the PhysioBank the MIT-BIH Polysomnographic Database. Records in the Database is a multi-parameter sleep data, including EEG, ECG, EOG, EMG etc. The data sampling frequency is of 250Hz. The paper used one lead EEG signals of multiparameter sleep data from subject slp41 (C4-A1) whose wake stage and NREM I sleep stage signal was extracted. Each stage was of 7500 sampling points. The sleep process is continuous, so the 7500 point may not entirely belong to a sleep stage and we used 2000 sampling points between 2500-5000 points.

When multisample confirming experimental laws, it was randomly selected three samples which were taken in this experiment were slp41, slp48, slp59. The EEG leads were slp41 (C4-A1), slp48 (C3-O1), slp59 (C3-O1) respectively. slp41 (C4-A1) was on behalf of the receiver 41 whose EEG was obtained through the C4-A1. Similarly, slp48 (C3-O1), slp59 (C3-O1) showed that 48th and 59th subjects' EEG were taken from leads C3-O1.

It was randomly extracted 5 wake stage signals and 5 NREM I stage signals from subjects slp41 with data length 2000. The mean and variance of symbolic transfer entropy for these signals when at n=4 were calculated. The experimental results were shown in Tab. 1.

Table 1: slp59 sample,for example,the statistics of the different sampling points the wake (w) and NREM I sleep stage(i)

sampling points / data	500		1000		2000		3000		4000	
	w	**i**	**w**	**i**	**w**	**i**	**w**	**i**	**w**	**i**
1	0.1996	0.1037	0.1050	0.0796	0.0533	0.0484	0.0346	0.0341	0.0256	0.0234
2	0.1467	0.0980	0.0759	0.0583	0.0594	0.0527	0.0351	0.0395	0.0225	0.0306
3	0.1451	0.1748	0.0828	0.0921	0.0517	0.0531	0.0392	0.0406	0.0313	0.0326

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4	0.1435	0.1398	0.1109	0.0863	0.0555	0.0529	0.0353	0.0315	0.0246	0.0364
5	0.1334	0.1313	0.0831	0.0734	0.0585	0.0500	0.0386	0.0350	0.0317	0.0256
6	0.1512	0.1241	0.0853	0.0778	0.0533	0.0501	0.0404	0.0320	0.0297	0.0266
7	0.1533	0.1610	0.0819	0.0720	0.0474	0.0541	0.0385	0.0349	0.0314	0.0252
8	0.1886	0.1181	0.1059	0.0987	0.0536	0.0454	0.0373	0.0405	0.0340	0.0314
9	0.1476	0.0862	0.1204	0.0877	0.0544	0.0611	0.0396	0.0451	0.0245	0.0392
10	0.1672	0.1000	0.0987	0.0829	0.0629	0.0601	0.0407	0.0484	0.0320	0.0292
mean	0.0908	0.1237	0.0950	0.0809	0.0550	0.0528	0.0379	0.0382	0.0287	0.0300
std	0.0370	0.0286	0.0151	0.0115	0.0044	0.0049	0.0023	0.0056	0.0040	0.0051

Further, we analyzed other different individual data, respectively. The analyzed data were 500 sampling points. After the mean-variance table was obtained, it was given the T test.

Table 2: Average of STE values for different individual with 500 sampling points

samples / datas	Slp590	Slp480	Slp410	Slp450	Slp591	Slp481	Slp411	Slp451
Mean w	0.1576	0.0908	0.1118	0.1156	0.1394	0.0961	0.0923	0.1236
Mean i	0.1237	0.0569	0.0625	0.1005	0.1395	0.0582	0.0625	0.0784

The following is the T test results.

Paired Samples Test

	Paired Differences					t	df	Sig. (2-tailed)
	Mean	Std. Deviation	Std. Error Mean	95% Confidence Interval of the Difference Lower	Upper			
Pair 1 Wake stage - NREM1 stage	...	.0161303	.0057029	.0171398	.0441102	5.370	7	.001

According to Tab. 2, the mean and variance of the symbolic transfer entropy for these signals were shown in Figure 1.

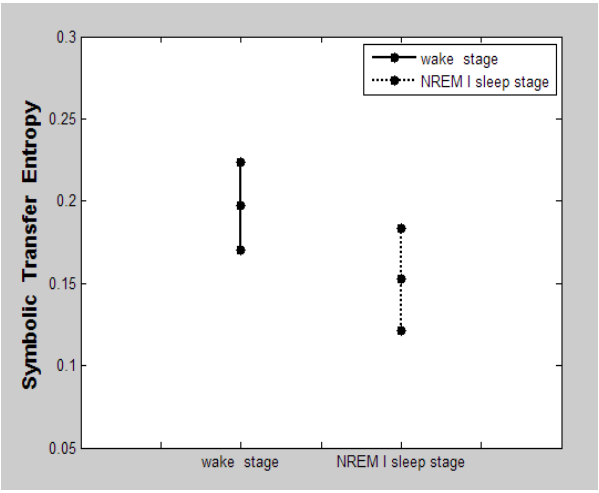

Figure 1: STE range in two sleep stages with 500 sampling points.

Conclusions

STE-based sleep staging method can be further extended to Phase II of NREM sleep, istinguish phase III, IV and REM period. mentioned in this article STE, a quantitative parameters of the

relevance of the two time series, this algorithm reduces the coordination requirements between the parameters calculated easily and quickly, suitable for real-time processing,also reduce the sensitivity to noise, certain anti-jamming capability. These features greatly facilitated the transfer entropy time series analysis.

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References

[1] Q.F. Meng, W.D. Zhou, Y.H. Chen, Y.H. Peng, The feature extraction of epileptic EEG signals based on nonlinear prediction, acta phys. sin. 59 (2010), 123-130.（in Chinese）

[2] L.L. Zhao, Z.Q. Liang, W.Q. Wu, G.S. Hu, Changes of EEG Correlation Dimensions in Epilepsy after Biofeedback Training, Chin. J. Biomed. Eng. 29 (2010), 71-76,85.（in Chinese）

[3] Q.L. Ma, C.H. Bian, J. Wang, Scaling analysis on electroencephalagram and its application to sleep-staging, 59 (2010) 4480-4484.（in Chinese）

[4] T. Schreiber, Measuring information transfer, Phys. Rev. Lett. 85 (2000) 461-464.

[5] M. Staniek, K. Lehnertz, Symbolic transfer entropy, Phys. Rev. Lett. 100 (2008), 158101.

[6] E. Roldan, M.R.J. Parrondo, Estimating dissipation from single stationary trajectories, Phys. Rev. Lett. 105 (2010), 150607.