

# Beta wave of sleep electroencephalogram analysis based on sign series entropy

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**Abstract.** Sleep and wake EEG have some differences. After studying their brain waves and calculating the sign series entropy, we use the T test for the detection of sleep and wake EEG data to figure out whether they are different. After beta waves being filtered out by the filter, we calculate the entropy of the sign series. The results of T test show that the beta waves in the state of sleep and wake are different.

## Introduction

When a person is awake, the frequency of the brain is basically in the state of beta waves [1-4]. With the enhancement of the beta waves, the body gradually gets more nervous. In the body, the proper beta waves have a positive effect on the development of attention and cognitive behavior. When people sleep, beta waves weakened, people gradually show the state of relaxation. Through the study of the beta EEG analysis, we can distinguish that people are awake or asleep [1-4].

## Method of sign series entropy

The calculation of sign series entropy [5] is first to carry out symbolic sequence. In order to represent the potential changes of the original EEG signals, its symbolic process is :

$$r(j) = \begin{cases} 0, & z(j+1) < z(j), \\ 1, & z(j+1) = z(j), \\ 2, & z(j+1) > z(j), \end{cases} \quad j = 1, 2, 3 \dots (L_m - 1)$$

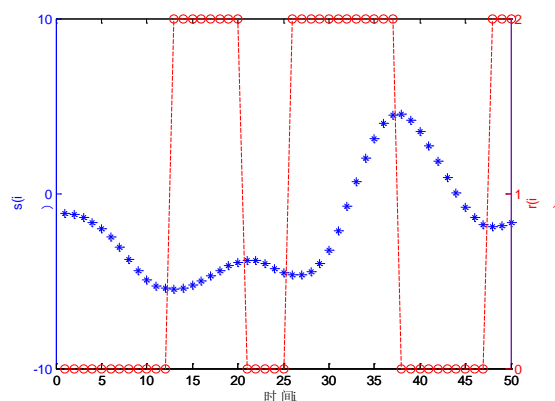


Figure 1: symbolic process of EEG signals

$R(J) = 0, 1, 2$  represent the electric potential. The three numbers in the sign series do not have a numerical value, but are the symbols of the three directional information. In order to show the regularity of the sign series, we construct vector sequence with the width  $d$ :

$$R(j)=[r(j),r(j+1),\dots,r(j+(d-1))], \quad j=1,2,3\dots L_m-d$$

When the width is  $d$ , the models of continuous change are  $3^d$ . For example, when  $d$  is 2, the models are 00、01、02、10、11、12、20、21 and 22.  $D_k$  indicates the number of times that the models appear and the probability of each model is  $P_k$ , which are shown in the following formula and figure:

$$P_k = \frac{D_k}{L_m-d}, \quad k=1,2,3\dots D$$

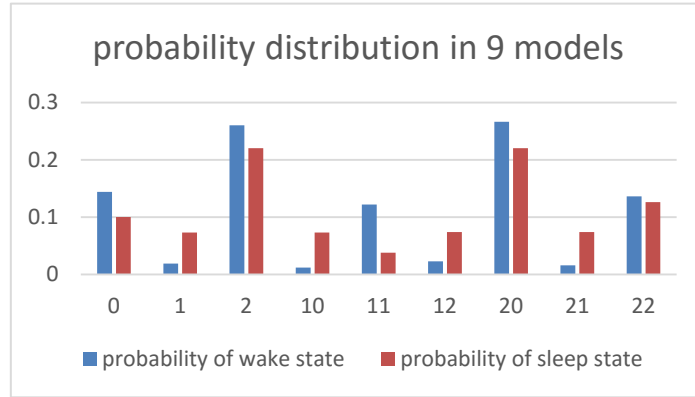


Figure 2: probability distribution of 9 models

According to the probability of each model, we can calculate the entropy:

$$MSSE(d) = -\sum_{k=1}^D (P_k \cdot \log_2 P_k)$$

## Numerical analysis

We divide collected EEG signals into 8 groups of sleep and 8 groups of wake. The width is 2. We apply sign series entropy to the original EEG signals data for research.

Table 1: SSE of the data sample

| SSE of the data sample |           | Data41 | Data411 | Data45 | Data451 | Data48 | Data481 | Data59 | Data591 |
|------------------------|-----------|--------|---------|--------|---------|--------|---------|--------|---------|
| Wake                   | 1~2000    | 2.586  | 2.872   | 2.610  | 2.521   | 2.176  | 2.743   | 2.784  | 2.647   |
| Sleep                  | 1~2000    | 2.960  | 2.911   | 2.707  | 2.768   | 3.113  | 2.831   | 2.932  | 2.413   |
| Wake                   | 2000~4000 | 2.535  | 2.931   | 2.630  | 2.460   | 2.146  | 2.178   | 2.747  | 2.699   |
| Sleep                  | 2000~4000 | 2.824  | 2.857   | 2.804  | 2.820   | 3.087  | 2.770   | 2.925  | 2.701   |

According to independent sample T test, we can draw the obvious difference between the sleep entropy and wake entropy. Then we divid the 8 groups of sleep and 8 groups of wake EEG data into 3 data segments whose length is 2000. After filtering out the beta component of each data segment by the filter ,we return it to the time domain.We apply sign series entropy to the beta component again. Results are shown in the following table:

Table 2: sign series entropy of the beta wave

| 1~2000 | Beta wave | 2001~4000 | Beta wave | 4001~6000 | Beta wave |
|--------|-----------|-----------|-----------|-----------|-----------|
| 41     | 1.2783    | 41        | 1.2868    | 41        | 1.2764    |
| 45     | 1.2781    | 45        | 1.2823    | 45        | 1.2606    |
| 48     | 1.2588    | 48        | 1.2695    | 48        | 1.2868    |
| 59     | 1.2693    | 59        | 1.2770    | 59        | 1.2731    |
| 411    | 1.3034    | 411       | 1.2950    | 411       | 1.2946    |
| 451    | 1.2908    | 451       | 1.2605    | 451       | 1.2867    |
| 481    | 1.2949    | 481       | 1.2939    | 481       | 1.3118    |
| 591    | 1.2953    | 591       | 1.2944    | 591       | 1.2952    |
| 1~2000 | Beta wave | 2001~4000 | Beta wave | 4001~6000 | Beta wave |
| 410    | 1.2865    | 410       | 1.2782    | 410       | 1.2868    |
| 450    | 1.2587    | 450       | 1.2782    | 450       | 1.2739    |
| 480    | 1.2866    | 480       | 1.2865    | 480       | 1.2694    |
| 590    | 1.2607    | 590       | 1.2867    | 590       | 1.2780    |
| 4110   | 1.2952    | 4110      | 1.2692    | 4110      | 1.2780    |
| 4510   | 1.2736    | 4510      | 1.2852    | 4510      | 1.2781    |
| 4810   | 1.2649    | 4810      | 1.2472    | 4810      | 1.2950    |
| 5910   | 1.2782    | 5910      | 1.2605    | 5910      | 1.2604    |

By using the independent samples T test for the data in the table above, we can conclude that there is a certain difference between the sleep beta component and wake beta component.

Table 3: independent samples T test for beta waves

|    | V2                  | N  | average  | standard deviation                  |            | Standard error average |                    |                   |  |                |
|----|---------------------|--|----------|-------------------------------------|------------|------------------------|--------------------|-------------------|--|----------------|
| V1 | 1.0000              | 24   | 1.283896 | .0139667                            |            | .0028509               |                    |                   |  |                |
|    | 2.0000              | 24   | 1.275654 | .0122863                            |            | .0025079               |                    |                   |  |                |
|    |                     | Levene's<br>equivalent test of<br>variance |          | For the average value of the t test |            |                        |                    |                   |  |                |
|    |                     | F  |          | T                                   | df         | significance           | Mean<br>difference | Standard<br>error | 95%<br>Confidence<br>interval of<br>difference<br>number |                |
|    |                     |  |          |                                     |            |                        |                    |                   | lower<br>limit   | upper<br>limit |
| V1 | Equal<br>variance   | .693                                       | .409     | 2.171                               | 46         | .035                   | .008               | .004              | .0006  | .016           |
|    | Unequal<br>variance |  |          | 2.171                               | 45.2<br>64 | .035                   | .008               | .004              | .0006  | .016           |

Therefore, we can get the result that beta waves based on sign series entropy can effectively distinguish sleep and wake state .

## Conclusions

In this paper, we propose sign series entropy and apply it to sleep and wake EEG analysis. The studies of this paper are based on each group whose length is 2000. We can calculate SSE values from 8 groups of sleep and 8 groups of wake EEG data. The SSE values are analyzed and the independent sample T test is carried out by filtering. The result of the studies shows that the values of SSE are different and it can effectively distinguish the EEG signals of beta waves in the state of sleep and wake.

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