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An Analysis of Brain and Muscle Activity in Arousal Maintenance State against Sleepiness

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***Abstract*— Recently, we have developed a new method to analyze brain activity from electroencepharogram (EEG) based on a concept of instantaneous equivalent bandwidths (IEBWs). The essence of the method using the IEBW is to track bandwidths changes of EEG signals. Arousal maintenance state against sleepiness can be considered to be in a different physiological state compared to the normal sleep onset. The method was therefore applied to the EEG signals in the wakefulness maintenance state against sleepiness in order to capture the feature of the EEG signals. As a result, we have revealed that EEG signals while the subjects were trying to maintain wakefulness state against sleepiness had wide bandwidth compared to the EEG signals in normal sleep onset because of the EEG desynchronization. It can be considered that neuron activities from the frontal association area which coordinates behavior to hypothalamus which coordinates wakefulness and sleep were raised in order to maintain wakefulness state against sleepiness. Meanwhile, it is considered that EEG activity in γ band is influenced by muscle activity. We therefore measured electromyograms (EMG) at mentalis muscle and trapezius muscle in order to evaluate the influence of the EMGs for the EEGs. The results showed that the EMG and the EEG were not correlated each other.**

***Index Terms*— EEG analysis, wakefulness maintenance state, EMG, desynchronization, Instantaneous Equivalent Bandwith**

I. INTRODUCTION

An electroencephalogram (EEG) has been used in the clinical and engineering fields to explore the brain activity. In particular, sleep EEGs have been widely analyzed to characterize sleep stage[1] . As far as we know, however, there has been little research done for analyzing arousal maintenance state against sleepiness.

When we look at analyzing methods in the clinical field, visual analysis of raw EEG traces is still the major tool and point of reference for other methods, in spite of its inherent limitations. For the engineering field, the time-frequency analysis has been extensively applied to not only EEG but also other biomedical signals, such as electromyogram (EMG) and phonocardiogram (PCG), in order to achieve precise characterization and classification[2].

Recently, the authors have unified a large class of equivalent bandwidths (EBWs) for a stationary random process by using Rényi entropy[3], [4]. We also defined instantaneous equivalent bandwidths (IEBWs) for non-stationary random signals and applied them to the biosignal analysis[5], [7], [8], [9].

In this paper, we first introduce a concept of EBWs and IEBWs of stationary or non-stationary random signals briefly. Then, we discuss application to the IEBWs to the EEG analysis in the wakefulness maintenance state against sleepiness and relationship between γ frequency band of the EEGs and muscle activity of mentalis and trapezius. Finally, we summarize our dicussion and make mention of our future work.

II. METHODOLOGY

A. EEG Data Acquisition

Twelve channel EEG and two channel EMG recordings were made on five normal healthy subjects. The electrodes for EEG were selected 12 positions of the international 10/20 system and electrodes for EMG were placed on mentalis and trapezius muscle, which is shown in Figure 1.

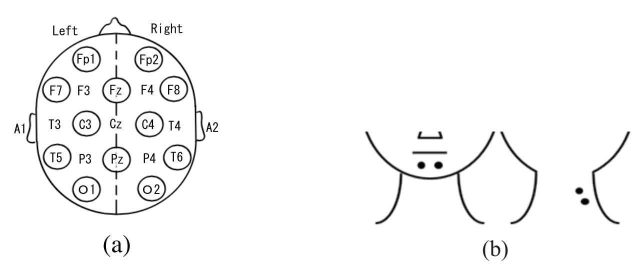

Fig. 1. (a) The electrodes placement by international 10/20 system. Circled channels were used in this study. (b) The electrode for EMG were placed on mentalis and trapezius muscle, respectively.

All the subjects were asked to behave the way as in the following agenda(TABLE I) from the day before the experiment. On the day of experiment, EEG recordings were made after checking if the subjects followed the agenda and were in good physical condition. The subjects were seated in a relaxed position on a reclining bed. Figure 2 shows

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Period of hours	Action
22:00 — 08:00	About 7 hours of sleep.
08:00 — 09:00	Breakfast
09:00 — 12:00	Free[1]
12:00 — 13:00	Lunch
13:00 — 14:00	Preperation for EEG recording
14:00 — 15:00	EEG recording

TABLE I

THE AGENDA FROM THE DAY BEFORE TO ON THE DAY OF THE EXPERIMENT

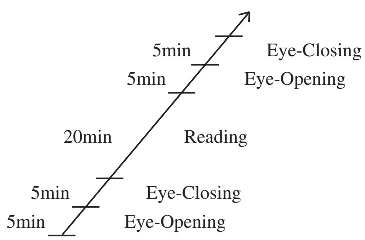

Fig. 2. Time Table of EEG recording

the time-table of the experiment. In the first and the last ten minutes, we measured control data of resting state with eye-opening and eye-closing for five minutes each. During the experiment, the subjects were asked to read a book and to maintain wakefulness state if they felt sleepy.

For the purpose of the present study, the EEG and EMG data were digitized with the sampling rate of 100Hz. The data of natural onset of sleep and wakefulness maintenance state against sleepiness with 10 seconds duration were extracted by monitoring the video recording which was taken in the experiment so that subject's face was brought into view.

B. Instantaneous Equivalent Bandwidth

In this section, we describe briefly a method for analyzing the EEG signals by using Instantaneous Equivalent Bandwidth (IEBW). Details are described in the literature[7], [9]. The idea of the method using the IEBW is to track bandwidths changes of random signals. Let $x(t)$ be a stationary random signal with the power spectrum $p(f)$, the EBW $W^{(\alpha)}$ of order α is defined by

$$W^{(\alpha)} = \frac{1}{2}\left(\int p^{\alpha}(f)df\right)^{1/(1-\alpha)}, \tag{1}$$

where the power spectrum $p(f)$ is normalized as $\int p(f)df = 1$. If we consider $p(f)$ as a probability density function, the EBW can be rewrite using Rényi's entropy as

$$W^{(\alpha)} = e^{H^{(\alpha)}} \Big/ 2, \tag{2}$$

where $H^{(\alpha)}$ is Rényi's entropy of order α [10],

$$H^{(\alpha)} = \begin{cases} \dfrac{1}{1-\alpha}\log\left(\displaystyle\int p^{\alpha}(f)df\right) & (\alpha \geq 0 \text{ and } \alpha \neq 1), \\ -\displaystyle\int p(f)\log p(f)df & (\alpha = 1). \end{cases} \tag{3}$$

It is natural that EBWs of random signals are defined on the basis of information theory because the EBWs indicate the effective number of uncorrelated variables per unit time [11] or the coefficient rate of a random signal [12]. For nonstationary random signals, we have defined the IEBWs using time-frequency distributions. We assume that a nonstationary random signal, i.e. EEG signal $x(t)$ has a time-frequency distribution $p(t,f)$. In analogy with (1), if we consider $p(t,f)$ as a joint probability function, i.e., $\int\int p(t,f)df dt = 1$ and $p(t,f) \geq 0$, we can define IEBW at time t as,

$$W^{(\alpha)}(t) = \frac{1}{2}\left(\int p^{\alpha}(f|t)df\right)^{1/(1-\alpha)}, \tag{4}$$

where the conditional density $p(f|t)$ is defined as

$$p(f|t) = \frac{p(t,f)}{p(t)} \tag{5}$$

and where

$$p(t) = \int p(t,f)df. \tag{6}$$

Therefore, if we obtain a nonnegative time-frequency distribution (TFD) satisfying the marginals for a signal, i.e., the distribution can be considered as a probability density function, we can track the IEBW changes of the EEG signal. The IEBW can provide us the method which can quantify the synchro-desynchronization of brain activity.

III. RESULTS

Fig. 3 and Fig. 4 show typical examples of the positive time-frequency distributions of the EEG signals (O1) in the period of natural onset of sleep and wakefulness maintenance state against sleepiness, respectively. Both periods were extracted by monitoring the video recording which was taken in the experiment so that subject's face was brought into view. The plots in row represent successive periods of 30 seconds.

Along the top and the second of each plot are EMGs of mentalis and trapezius muscle respectively. The third plot is the observed EEG data $x(t)$. The forth top of plot is the IEBW of the EEG data, to the left is the power spectrum of the signal (i.e. $E[|X(f)|^2]$), where $X(f)$ is Fourier transform of $x(t)$), and along the bottom panel of each plot is the energy distribution in time (i.e. $E[|x(t)|^2]$). The positive time-frequency distribution $P(t,f)$ satisfies the marginal conditions.

In Fig. 3, the time-frequency distribution shows that the power of the EEG signal is concentrated in the very low

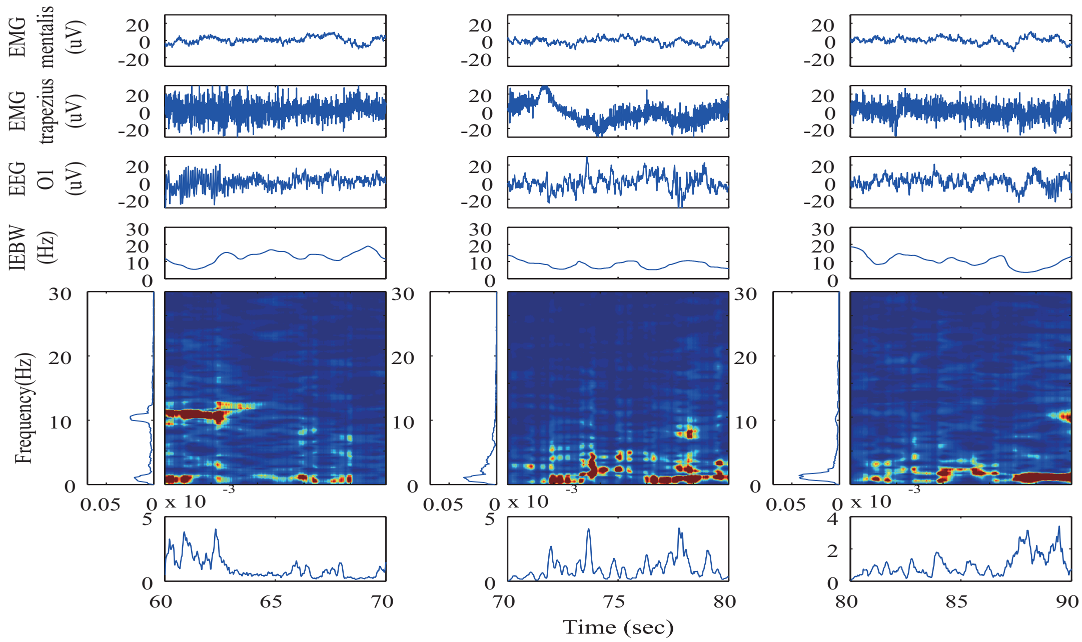

Fig. 3. A typical example of EEG data (O1) in the natural onset of sleep, its IEBW $W^{(2)}$ and its Copula-based positive time-frequency distribution along with its marginals

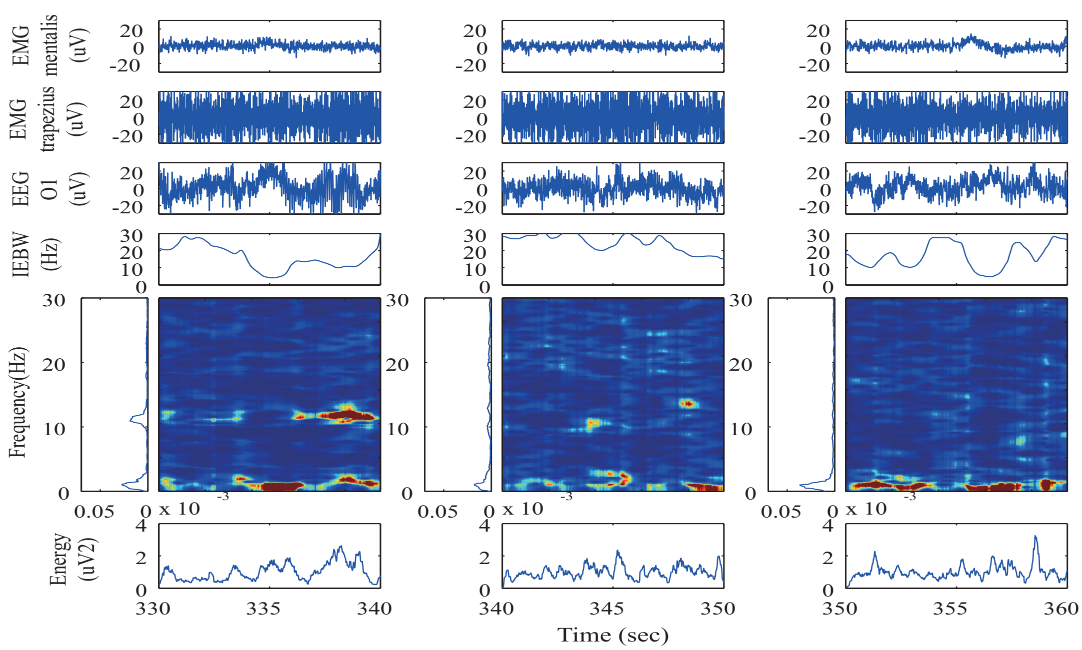

Fig. 4. A typical example of EEG data (O1) in the wakefulness state against sleepiness, its IEBW $W^{(2)}$ and its Copula-based positive time-frequency distribution along with its marginals

frequency range and the range of α rhythm in the period from 60 to 65. The appearance of α wave indicates that the subject is getting sleepy. Then the α rhythm is gradually disappeared and the power of the EEG signal migrate into the lower frequency range only, i.e., θ and δ wave range. This is a typical characteristics of natural onset of sleep.

α rhythm also appeared in the period from 330 to 340 in Fig. 4. Next period (340-350), however, the power of the EEG signal in α range does not migrate into θ or δ range anymore but spread into the range above β rhythm. That is, desynchronization has occured during the period that subject was trying to maintain wakefulness state if they felt sleepy.

TABLE II

THE AVERAGE VALUE OF THE IEBW BEFORE AND DURING THE WAKEFULNESS MAINTENANCE STATE AGAINST SLEEPINESS

	IEBW (Hz)				
Subjects	A	B	C	D	E
30 seconds before wakefulness maintenance state	9.63	7.64	10.64	9.3	11.0
Period of wakefulness maintenance state	20.00	15.26	16.88	14.66	16.80

The desynchronization activity of EEG described above is major feature of the state of which the subject are trying to maintain wakefulness against sleepiness. It can be considered that neuron activities from the frontal association area which coordinates behavior to hypothalamus which coordinates wakefulness and sleep were raised in order to maintain wakefulness state against sleepiness.

The IEBW can track the change of EEG signal, i.e. synchronization and desynchronization. Table II shows the average value of the IEBW before and during the wakefulness maintenance state against sleepiness of each subject. The values of the IEBW in the period of wakefulness maintenace state is significantly large compared to 30 sec. before the period of wakefulness maintenance state.

In order to verify the influence of the muscle activity to the EEG signals, we calculate the correlation coefficient between EMG and EEG which is band-limited β and γ range. The results showed that correlation coefficient of EMG of mentalis muscle and EEG was -0.030, and EMG of trapezius muscle and EEG was -0.058. T-tests with 5 % significance level do not show that both values indicate a significant correlation between EMG and EEG signals.

IV. CONCLUSIONS

We have presented a analysis of desynchronized brain acitivity in wakefulness maintenance state against sleepiness by instantaneous equivalent bandwidth. The essence of the method using the IEBW is to track bandwidths changes of EEG signals. We have introduced a concept of EBWs and IEBWs of stationary or non-stationary random signals. We then discussed application of the IEBWs to the EEG analysis in the wakefulness maintenance state against sleepiness. As a result, desynchronization was shown in the EEG signal while the subjects were trying to maintain wakefulness against sleepiness. The results imply that the IEBW $W^{(2)}$ can track the EBWs change of EEG signals. In addition, simultaneous recordings of EMG and EEG, and correlation coefficient analysis showed that there is no significant correlation between EMG and EEG in this case. Therefore, the desynchronization brain activity can be considered that neuron activities from the frontal association area which coordinates behavior to hypothalamus which coordinates wakefulness and sleep were raised in order to maintain wakefulness state against sleepiness.

Now we are going to apply several methods to remove the artifact from the blinking because people who are trying to maintain wakefulness state against sleepiness blink so many times. We believe that these pre-processing make our method more effective.

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