The development of the bio-feedback system to support the good sleep and daily life

Naoya Nisizuka, Kazuhiro Nakagawa
Department of Electrical Engineering and Computer Science
National Institute of Technology, Fukui College, Geshi-cho, Sabae-shi, Fukui, 916-8507, Japan
Tel: +81-778-62-8280, Email: nishizuka_1997@yahoo.co.jp

Sakiko Ogoshi†
Department of Electrical Engineering and Computer Science
National Institute of Technology, Fukui College, Geshi-cho, Sabae-shi, Fukui, 916-8507, Japan
Tel: +81-778-62-8280, Email:ogoshi@fukui-nct.ac.jp

Yasuhiro Ogoshi
Graduate School of Engineering,
University of Fukui, 3-9-1 Bunkyo, Fukui 910-8507, Japan
Email: y-ogoshi@u-fukui.ac.jp

Yotu Saitou,Takahiro Komatsu
Department of Electrical Engineering and Computer Science
National Institute of Technology, Fukui College, Geshi-cho, Sabae-shi, Fukui, 916-8507, Japan
Tel: +81-778-62-8278, Email: t-saitoh@ei.fukui-nct.ac.jp
Tel: +81-778-62-8264, Email:komatsu@fukui-nct.ac.jp

Akio Nakai
Hyogo Children's Sleep and Development Medical Research Center
Akebono-cho 1070, Nishi-ku, Kobe, 651-2181, Japan
Phone: +81-78-927-2727, FAX : +81-78-925-9203

Yoshinori Mituhasi
Faculty of Education and Regional Studies,
University of Fukui, 3-9-1 Bunkyo, Fukui 910-8507, Japan
Email: mituhasi@u-fukui.ac.jp

Abstract. The average amount of sleep for Japanese people is the lowest in the world, underscoring the need to develop more advanced tools to study sleep behavior. Electroencephalography (EEG) is widely utilized in neurological research. The objective of this investigation is to create a database of sleep EEG recordings to examine the stages, rhythm, and quality of sleep. Our study includes EEG analysis of both rapid eye movement (REM) and non-REM sleep, with a focus on theta, alpha, and delta waves. In total, we believe our approach will provide advancement toward the goal of high-quality deep sleep, with future research aiming to discern a relationship between sleep and the daily rhythm of life.

Keywords: EEG, sleep, bio-feedback, daily behavior

1. Introduction

According to recent studies of sleep behavior, the average amount of sleep time for Japanese citizens is the least in the world. To address this critical issue, additional research on sleep patterns is warranted.

EEG recordings are commonly used in medical research, and a collection of EEG data during sleep would greatly benefit future studies. Thus, the objective of this research is to develop a biofeedback EEG system to monitor human sleep behavior and ultimately improve the quality of sleep.

2. Development of a feedback system using sleep EEG recordings

2.1 Outline of the feedback system

To observe the stages and rhythm of sleep behavior, we developed a biofeedback system to obtain and analyze human EEG recordings during sleep.

Figure 1 shows an overview of the system.

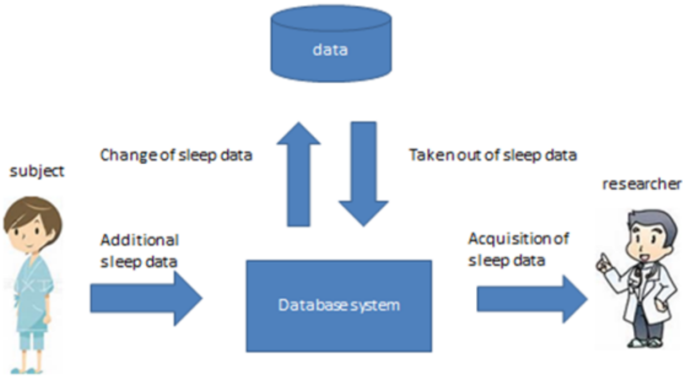

Figure 1. Overview of the biofeedback system

Using this system, we first obtain sleep EEG measurements and next divide them into θ (theta), α (alpha), and δ (delta) waves. The properties of these brain waves help to classify our data into sleep stages, as described below.

2.2 Classification of sleep stages

There are many studies utilizing EEG signals to automatically classify sleep stages and conditions (Sheng-Fu et al., 2012; Masaaki et al., 2001; Mohammed et al., 2016; Arnaud et al., 2013; Ishii et al., 1978; Ueda et al., 1987; Nakai et al., 2000; Hanaoka et al., 2001; J)(Sheng-Fu et al., 2012)(Jose et al., 2002). A classification study using the technique of the artificial intelligence is conducted flourishingly.

Table 1 shows the particular criteria that we used for classification of sleep stages.

Figure 3 is a representative histogram of each sleep stage.

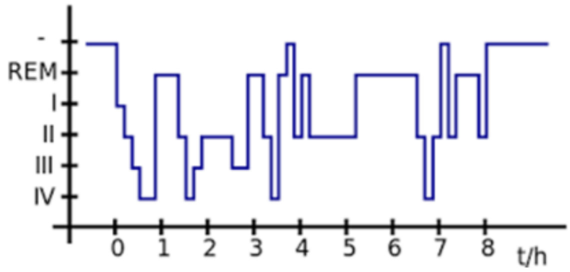

Figure 3. Example histogram of time spent in sleep stages

Table 1. Criteria for sleep stage classification

Depth	International classification decision criteria	
Stage W	・α-wave, low amplitude speed wave ・Rapid eye movement, high amplitude EMG	
Stage 1	・α-wave less than half, mixed. It is the wave of low amplitude and various frequencies. ・Slow eye movement, marginally reduced muscle tone	
Stage2	・Low-amplitude irregular, not a high-amplitude slow wave ・vertex sharp wave, spindle, K composite	NON-REM sleep
Stage3	・Less than 2 Hz, more than 75 μV, θ–δ-wave 20–50% ・Spindle frequency is late and More widespread emergence	
Stage4	・Less than 2 Hz, more than 75 μV and θ–δ-wave 50% ・Spindle	
Stage REM	・equal to Stage1 but no muscle tone ・Rapid eye movement, lowered obvious tension	REM sleep

2.3 Input/output data and analysis

Our feedback system receives input in the form of brain waves and human actions and analyzes this information to produce an output.

Table 2 displays the parameters used when obtaining EEG input data from experiments.

Table 3 shows how the parameters from Table 2 are utilized to obtain values for sleep state analysis.

Table 2. Parameters used for sleep EEG recordings

Parameters	
RS	Recording start time
BI	Bedridden instant
SO	Sleep onset
LSP	Last specific point
RE	Recording end

Table 3. Calculations for sleep state analysis

Data	Value	Formula
SPT	Sleeping period time	LSP-SO
TST	Total sleeping time	SPT REM + NREM
TIB	Time in bed	RE-RS
SE	Sleep efficiency	TST/SPT
SL	Sleep latency	SO-RS
REM latency		Latency from SO

Table 4 is the template used to determine the total amount of time spent in each sleep stage.

Table 4. Total time spent in each sleep stage

Stage total time	Formula	Total time
Wake time	Stage Wake	
REM time	Stage REM	
NREM time	NREM	
Shallow sleep time	Stage1 + Stage2	
Deep sleep time	Stage3 + Stage4	

Our study thus obtains three major pieces of data for sleep state analysis: total sleeping time, time in bed, and sleep efficiency.

3. Method

3.1 Analysis to recognize the sleep state

The following parameters are recorded: recording start time (RS), bedridden instant (BI), sleep onset (SO), last specific point (LSP), and recording end (RE).

3.2 method of deriving the stage 4

NREM is divided further into 4 stages, stage 4 non-REM sleep is the deepest. Figure4 shows flowchart for determination of sleep stages.

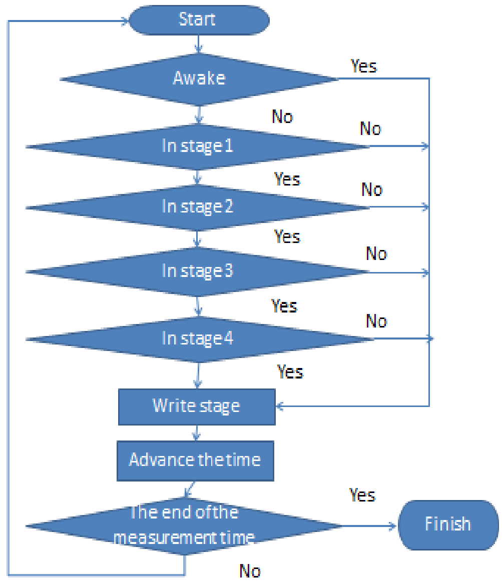

Figure 4. Flowchart for determination of sleep stages

4. Data analysis method

4.1 Analysis of Daily behavior

4.1.1 System for accumulate the daily behavior

We propose system to store and management of the daily behavior and the quality of sleep.

Table5 Show the item to be stored in the system.

Table5. item of the daily behavior and the quality of sleep

Daily behavior item
Date and time
When
Where
Who
What Why How Evaluation during the day action

4.1.2 Analysis and Discussion

We analyze using the data of the 13 days of the 19-ye ar-old male stored in the system.

4.1.3 Evaluation of behavior

We investigate the relationship by using the correlatio n of the behavior and sleep evaluation during the day.

Table6. the quality evaluation of the daily behavior and sleep

id	koudou_e	sleep_e
1	3	4
2	4	5
3	4	4
4	5	4
5	5	5
6	4	4
7	3	3
8	3	2
9	5	5
10	5	4
11	1	3
12	5	5
13	4	4

* Id represents a unique value for each data.
* Koudou_e shows the evaluation of the action during the day.
* Sleep_e shows the evaluation of the quality of sleep.

The correlation of Koudou_e and Sleep_e date it can be seen that there is a relationship is 0.69 .

Next we analyze by the evaluation of the behavi or to change as any evaluation of the quality of sleep.

Figure5 show the relationship of evaluation and e valuation sleep quality behaviors.

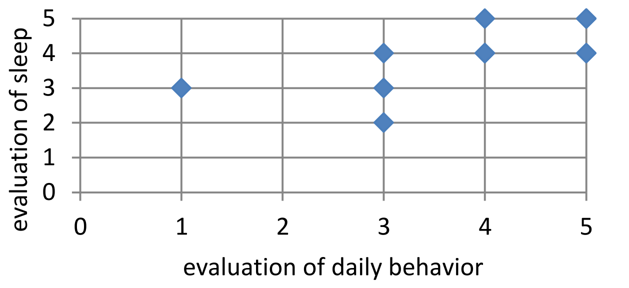

Figure5. relationship of daily behavior and the fatigue degree

The higher the rating of the action during the da y can be seen that the high evaluation of the quality of sleep. On the contrary, the lower the evaluation of the action during the day can be seen the evaluation of the quality of sleep also low value.

It is seen that the daily behavior will affect the quality of sleep.

Next, the action during the day if there is any ki nd of relationship between the evaluation of the actio n.

We analyze the behavior in the case of when Rat ing evaluation is 5 point (max value) and 1 point (mi nimum value). The behavior at the time of the evaluati on 5 it can be seen often move the body. In addition, it can be seen doing the action with someone rather than the actions of one person.

It can be seen that there is a relationship to the fatigue of the evaluation and the body of the action d uring the day. Therefore, to evaluate the fatigue degre e of the body 5 stages, Figure 6 shows the relationsh ip between the evaluation of the behavior during the day.

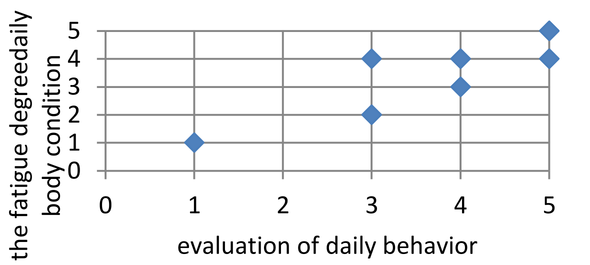

Figure6. The relationship of daily behavior and the f atigue degree

As can be seen in Figure 6, the evaluation of the a ction during the day it can be seen that is proportional t o the tired degree of behavior during the day.

4.2 Sleep EEG Analysis

We culcurate total sleep time in stage 4 sleep, for analysis of -quality sleep as first step.

Data are collected from five electrodes attached to scalp positions (either frontal, central, or parietal) Fz, C3, Cz, C4, and Pz, using the International 10–20 method of electrode placement (Figure 5). We collect data sets every four seconds.

The electrode specifications are as follows:

- material: Ag/AgCl, Nihon Kohden Corp., Japan, NE-113A
- geometry: discs
- size (diameter): 7 mm
- used gel or paste, alcohol applied to cleanse skin, skin abrasion
- interelectrode distance: 13 mm

The following analog/digital converter and amplifier was used to obtain EEG measurements:

- converter/amplifier: Polymate AP1532, Digitex Lab Co., Ltd., Japan
- sampling rate: 500 Hz
- A/D card: 32 channel, 16 bit
- EEG bandpass filter: 0.1–30 Hz

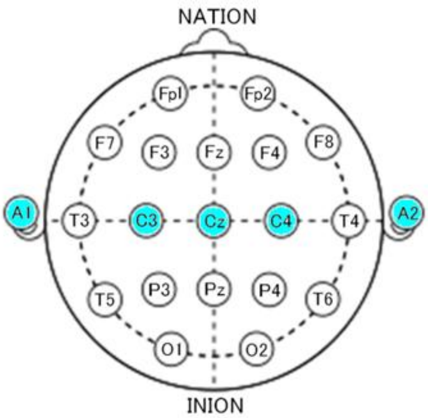

Figure 5. The 10–20 method of electrode placement

To determine sleep stage classification from EEG recordings, the frequency of each type of brain wave is calculated. For example, an EEG recording from a particular data point is divided into α-, β-, θ-, and δ-waves using a bandpass filter, and the percentage of each wave is determined. Table 5 shows the frequency of each class of brain wave for the first five minutes of a preliminary experiment.

Table 5. EEG brain wave frequencies for a preliminary experiment

Time (min)	δ-wave (%)	θ-wave (%)	α-wave (%)	β-wave (%)
1	66.73	24.57	5.50	2.06
2	66.92	24.74	5.31	2.00
3	66.38	24.71	6.03	2.11
4	66.86	24.70	5.81	1.87
5	68.59	25.46	3.69	1.60

We will discriminate sleep stage using this EEG brain wave frequencies data.

5. Consideration

We propose a system of daily behavior and sleep condition .And we propose a feedback system to monitor sleep EEG recordings and are currently engaged in the development of a prototype. Future studies will collect and analyze human EEG data with the goal of gaining a better understanding of high-quality sleep.

Future work we analysis between daily data and sleep data. We will develop a feed back system accoding to the situation of each individual. If there is a problem with behavior during the day, we will provide feedback on the behavior during the day.If it is difficult to sleep deep, we will develop a Brain Machine Interface for comfortable sleep.

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