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Can "Quality of Sleep" Be Evaluated from Hypnogram? -Estimation of Factor Score of Oguri-Shirakawa -Azumi Sleep Inventory by Artificial Neural Network-

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ABSTRACT

The connection between the psychological evaluation of "quality of sleep" and the physiological one was considered by matching Oguri-Shirakawa-Azumi sleep inventory (OSA-SI) with hypnogram. Eight healthy men (aged 22-23 years old) participated as subjects. They were instructed to go to bed at 0 o'clock (midnight), and to wake up at their own rhythm. As recordings, polysomnography (PSG) was measured during sleeping and OSA-SI was assessed after getting up. This task was performed for three nights by each subject. As analyses, hypnogram was produced from PSG for each night/subject, and then 39 sleep parameter values were calculated from each hypnogram. On the other hand, 5 standardized factor score (convert mean score into 50 for each factor score) were computed from OSA-SI, which was consisted of 16 question items. Finally, artificial neural network (ANN), which was designed to input sleep parameter values and to output factor score (0 means less than 50 points; 1 means more than or equal to 50 points) was employed to estimate "quality of sleep. As results, the best estimation accuracy (71%) was obtained for factor #1 and #2 of OSA-SI. Therefore, it is suggested that factor score of OSA-SI, i.e. "quality of sleep," can be estimated from hypnogram.

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1. INTRODUCTION

Sleep is not only a mere shutdown period but also an adaptation behavior supported by a high order physiology and defense mechanism. Especially, for us (human being endowed with developed cerebrum), sleep property affects the quality of life. In other words, hyposomnolence or sleep shortage or sleep disorder brings fatigue, emotional instability or blunting of judgment and causes a decrease of quality of life. Particularly, sleep apnea syndrome (SAS) becomes a social problem not only a factor of apoplexy or ischemic heart disease but also background of accident in recent years. Hence, it can be said that to evaluate "quality of sleep" is extremely beneficial.

The psychological evaluation of sleep custom or hypnagogic feeling has been performed numerously. Many sleep evaluation indices also have been proposed such as Pittsburgh sleep quality index (PSQI)[1], mini sleep questionnaire (MSQ)[2], Leeds sleep evaluation questionnaire (LSEQ)[3] and so on. However, there are some indications that it is hard to appear the difference about "quality of sleep" with these indices in the case of the person who has no sleep disorder.

For the physiological inspection of sleep, it is indispensable to record polysomnogram (electroencephalogram (EEG), electrooculogram (EOG), electromyogram (EMG), etc.) and to make hypnogram. However, on the polysomnogram inspection, it is necessary to stick many electrodes and sensors. It is considered to give the subject hardness for sleeping and high stress. Further, it cannot be said simple for making hypnogram because of requirement of expert knowledge. Furthermore, by hypnogram, we can know sleep amount or sleep depth, but we cannot know "quality of sleep" directly.

Hence, we aimed to reveal the relationship between "quality of sleep" and hypnogram [4]. In this study, whether the factor score of Oguri-Shirakawa-Azumi sleep inventory (OSA-SI)[5] could be estimated from hypnogram by artificial neural network (ANN) was investigated.

2. METHODS

a. Subjects

Eight healthy male, 22-23 years old, participated in the following experiment. Before the experiment, informed consent was obtained from each subject.

b. Task

The experiment consisted of four nights. Every night, each subject entered the electromagnetic shielded room at 11 p.m. for the preparation. Then, the subject was directed to go to bed at 0 a.m. and to get 7 hours' sleep at least. In addition, since two days before the experiment, the subject was instructed to go to bed at 0 a.m. and to rise at 7 a.m. Furthermore, since one day before the experiment, the subject was prohibited to drinking alcohol, taking medicine and taking excess exercise.

c. Recordings

i. Psychological measurement

At the end of the experiment from the second night to the fourth night, the subject was indicated to assess OSA-SI. OSA-SI is a psychological measure to evaluate the sleep inspection at the time of rising. The inventory consists of sixteen items (choosing of one out of four alternatives for each item) into five factors: (1) sleepiness on rising, (2) initiation and maintenance of sleep, (3) frequent dreaming, (4) refreshing, (5) sleep length. In addition, the mean of standardized score is regarded as 50 points for each factor. Furthermore, the better a feeling of sleep is, the larger the score becomes.

ii. Physiological measurement

Polysomnography (PSG) signals of the subject were recorded during sleeping. The recorded signals were amplified and band-pass filtered via the bio-amplifier (Nihonkohden Neurofax EEG-9100) then stored in PC with 1 kHz sampling frequency.

d. Data Processing

i. Psychological measurement

A score of each factor of OSA-SI was termed GOOD for larger than or equal to 50 points. Whereas the score was termed POOR for less than 50 points.

ii. Physiological measurement

According to the Rechtschaffen and Kalen standard[6], each sleep stage (awake, non-REM sleep (stage I, stage II, stage III or stage IV) or REM sleep) was estimated from recorded signals by a sleep analysis software package (Nihonkohden Polysmith sleep system) and was plotted into hypnogram every epoch (consisted of 30 seconds). Then, following indices (thirty-nine in all) were evaluated from each hypnogram.

(1) Whole sleeping duration: total of sleeping time length from falling-asleep time to the last awakening time except halfway awakening.
(2) Halfway awakening duration: total of awakening time length from falling-asleep time to the last awakening time.
(3) Latency to each sleep stage (5 indices): time length from bedtime to occurring time of each sleep stage.
(4) Sleep induction latency: time length from bedtime to occurring time of sleep stage I or deeper sleep stage with more than 5 minutes' duration.
(5) Sleep latency (4 indices): time length from occurring time of sleep stage I to that of each sleep stage.
(6) Appearance duration of each sleep stage (5 indices): total of appearing time length of each sleep stage.
(7) Appearance ratio of each sleep stage (5 indices): ratio of appearing time length of each sleep stage.
(8) Transition frequency of sleep stages (unused in this study): number of transition of sleep stages from falling-asleep time to the last awakening time.
(9) Mean sleep stage: mean sleep stage during non-REM sleep.
(10) Appearance duration of each sleep stage in the first half of sleep (5 indices).
(11) Appearance ratio of each sleep stage in the first half of sleep (5 indices).
(12) Ratio of appearance duration of each sleep stage in the first half of sleep to that in whole sleep (4 indices).
(13) Mean sleep stage in the first half of sleep.
(14) Difference between mean sleep stage in the first half of sleep and that in whole sleep.

iii. Artificial Neural Network

ANN used in the present study is a feed forward neural network composed of input, hidden and output layers. The number of units is 39, 6, and 1 for the input, hidden and output layers, respectively. According to the leave-one-out cross-validation (LOOCV)[7], the normalized values of 39 indices from hypnogram were inputted to the ANN as a training dataset. The ANN was trained using standard back propagation algorithm with teaching signals 1.0 and 0.0 for GOOD and POOR, respectively. In addition, the training was repeated until the mean square error of the output of ANN reached 10^{-3} or less.

3. RESULTS

i. Psychological and physiological measurement

Fig. 1 shows the hypnogram on the third night for subject Y.N. and that on the second night for subject Y.O. For the subject Y.N., it was confirmed that the deepest sleep (sleep stage IV) appeared at 60–90 minutes after falling asleep onset. Further, it was also confirmed that approximately 90 minutes' sleep cycle was repeated 3–5 times. On the third night, his factor scores of OSA-SI were assessed as 57, 63, 45, 66 and 59 for factor #1, #2, #3, #4 and #5, respectively (evaluated all good except factor #3). However, for the subject Y.O., it was observed that he could not fall asleep easily depending on the ambient environment, such as noise. On the second night, his factor scores of OSA-SI were assessed as 36, 25, 31, 23 and 35 for factor #1, #2, #3, #4 and #5, respectively (evaluated all poor).

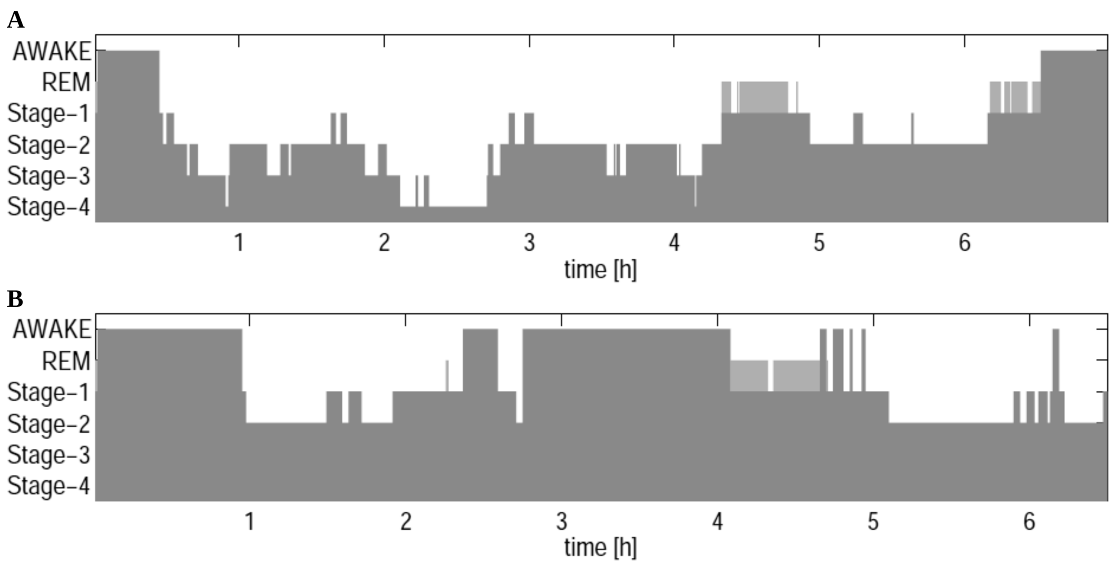

Figure 1. Representative example of the hypnogram. A: on the third night for subject Y.N. (good sleep), B: on the second night for subject Y.O. (poor sleep)

Fig. 2 shows the relationship between values of five selected hypnogram indices and OSA-SI factor scores. Note that plotted points and line represent subjects/nights and regression line, respectively. It was exhibited that both the hypnogram indices "appearance ratio of sleep stage III" and "appearance duration of sleep stage III" had significant positive correlations with OSA-SI factor "initiation and maintenance of sleep" and "sleep length", respectively. Whereas "appearance ratio of sleep stage IV" had a significant positive correlation with "refreshing", however, "appearance duration of sleep stage IV" had a significant negative correlation with "frequent dreaming." For OSA-SI factor "sleepiness on rising," there was no significantly correlated hypnogram indices but tend to be correlated with "appearance duration of sleep stage I."

Table 1 lists hypnogram indices that showed a significant correlation between hypnogram indices values and OSA-SI factor scores ($p<0.05$). It was found that the hypnogram index "appearance duration/ratio of sleep stage III" was significantly correlated with OSA-SI factor "initiation and maintenance of sleep/sleep length." Besides, "appearance duration/ratio of sleep stage IV" was significantly correlated with "frequent dreaming."

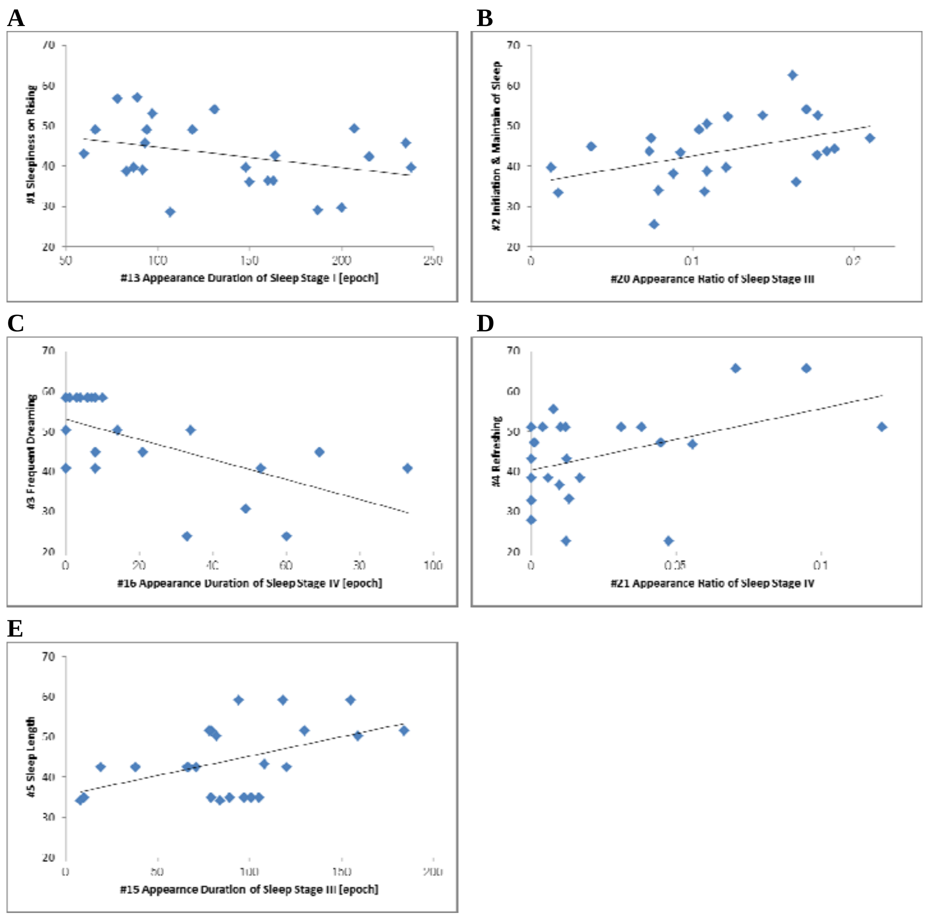

Figure 2. Relationship between hypnogram index value and OSA-SI factor score. A: appearance duration of sleep stage I vs. "sleepiness on rising" (r=–0.338, p=0.106), B: appearance ratio of sleep stage III vs. "initiation and maintenance of sleep" (r=0.445, p=0.029), C: appearance duration of sleep stage IV vs. "frequent dreaming" (r=–0.588, p=0.003), D: appearance ratio of sleep stage IV vs. "refreshing" (r=0.434, p=0.034), E: appearance duration of sleep stage III vs. "sleep length" (r=0.495, p=0.014)

Table 1. Significant correlated hypnogram index value with OSA-SI factor score

hypnogram Index	OSA-SI factor	*r*	*p*
#15 appearance duration of sleep stage III	#2 initiation and maintenance of sleep	0.432	0.035
	#3 frequent dreaming	-0.430	0.036
	#5 sleep length	0.495	0.014
#16 appearance duration of sleep stage IV	#3 frequent dreaming	-0.588	0.003
#19 appearance ratio of sleep stage II	#3 frequent dreaming	0.455	0.025
#20 appearance ratio of sleep stage III	#2 initiation and maintenance of sleep	0.445	0.029
	#5 sleep length	0.446	0.029
#21 appearance ratio of sleep stage IV	#3 frequent dreaming	-0.521	0.009
	#4 refreshing	0.434	0.034

ii. Artificial neural network

Table 2 shows the result of the estimation of OSA-SI factor term by ANN. It was found that the sensitivity (GOOD OSA-SI factor was successfully estimated as GOOD by ANN) of factor #1, #2 and #4 indicated lower value, however, the specificity (POOR OSA-SI factor was successfully estimated as POOR by ANN) of each factor tended to be indicated higher value. Finally, the best accuracy (71%) was obtained for factor #1 and #2.

Table 2. Result of the estimation of OSA-SI factor term by ANN. For OSA-SI factor, GOOD and POOR were designated from factor score of OSA-SI (GOOD indicates larger than or equal to 50 points, POOR indicates less than 50 points). For ANN output, GOOD and POOR were designated from output value of ANN (GOOD indicates larger than or equal to 0.5, POOR indicates less than 0.5).

		OSA-SI factor									
		#1		#2		#3		#4		#5	
		GOOD (4)	POOR (20)	GOOD (6)	POOR (18)	GOOD (13)	POOR (11)	GOOD (10)	POOR (14)	GOOD (9)	GOOD (15)
ANN output	GOOD	0	3	2	3	9	4	4	3	6	6
	POOR	4	17	4	15	4	7	6	11	3	9
Accuracy [%]		71		71		67		63		63	

Table 3 shows hypnogram indices which indicated the most significant weight of the connection from the input layer to the hidden layer of ANN for each OSA-SI factor. For example, it means that OSA-SI factor term of "#1 sleepiness on rising" strongly depends on hypnogram indices of "#02 halfway awakening duration" and "#32 appearance ratio of sleep stage IV in the first half of sleep." Furthermore, it represents that the more the value of "#02 halfway awakening duration" (negatively weighted index) decreases, the more OSA-SI factor score may increase. On the other hand, it implies that the more the value of "#32 appearance ratio of sleep stage IV in the first half of sleep" (positively weighted index) increases, the more OSA-SI factor score may also increase.

Table 3. Most significant weighted hypnogram index of ANN

OSA-SI factor	hypnogram index	
	most negatively weighted	most positively weighted
#1 sleepiness on rising	#02 halfway awakening duration	#32 appearance ratio of sleep stage IV in the first half of sleep
#2 initiation and maintenance of sleep	#19 appearance ratio of sleep stage II	#32 appearance ratio of sleep stage IV in the first half of sleep
#3 frequent dreaming	#02 halfway awakening duration	#07 latency to sleep stage REM
#4 refreshing	#19 appearance ratio of sleep stage II	#12 sleep latency to sleep stage REM
#5 sleep length	#31 appearance duration of sleep stage II in the first half of sleep	#01 total sleeping time

4. DISCUSSION

Lewandowski, *et al.*[8] proposed the probabilistic sleep model (PSM) to represent sleep profile (not only sleep stage but also sleep quality) by processing 3 seconds EEG then correlated with psychometric tests, physiological variables and questionnaires. Rosipal, *et al.*[9] applied the PSM then found significant correlations between sleep architecture and daytime variables of sleep quality. These two reports shown many significant correlation coefficients between the PSM parameters and sleep quality variables, however, their methods were not based on hypnogram but based on EEG.

This study investigated the relationship between "quality of sleep" and hypnogram. Each subject was asked to sleep and evaluate OSA-SI, which consisted of five factors. Simultaneously, PSG of each subject was recorded, from which a hypnogram was produced. Effective indices were then extracted from the generated hypnogram, correlations with evaluating each OSA-SI factor score were assessed. By statistical analysis, it was found that appearance duration/ratio of sleep stage II/III/IV showed a significant correlation with each OSA-SI factor score. By ANN, we could estimate OSA-SI factor terms from hypnogram indices with maximum accuracy 71%. At the same time, we could abstract effectual indices by observing connection weights from the input layer to the hidden layer. For example, OSA-SI factor term of "#3 frequent dreaming" can be estimated by hypnogram indices of "#02 halfway awakening duration" and "#07 latency to sleep stage REM." Here, the weight of the former index takes negative value, and that of the latter index takes positive value. It implies that less "halfway awakening duration" and long "latency to sleep stage REM" is necessary for the evaluation of good quality of "frequent dreaming".

5. CONCLUSIONS

Thus, it is suggested that factor score of OSA-SI, i.e. "quality of sleep," can be estimated from hypnogram by ANN. For the future works, to increase the number of subjects/nights and improve the classification accuracy of ANN should be expected. It is also required to compare with other classifiers such as SVM or Bayesian Networks to assess "quality of sleep." The direct evaluation of "quality of sleep" from physiological signals (not through hypnogram) will be also investigated.

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