QUANTITATIVE REPRESENTATION FOR EEG INTERPRETATION AND ITS AUTOMATIC SCORING

Masatoshi Nakamura*, Hiroshi Shibasaki**, Kaoru Imajoh*
Shigeto Nishida*, Ryuji Neshige***

*Department of Electrical Engineering, Saga University, Honjomachi, Saga 840, Japan
**Department of Brain Pathophysiology, Faculty of Medicine, Kyoto University, Sakyo-ku, Kyoto 606, Japan
***Department of Internal Medicine, Saga Medical School, Nabeshima, Saga 840-01, Japan

ABSTRACT

A new system for automatic interpretation of the awake electroencephalogram(EEG) was developed in this work. We first clarified all the necessary items for EEG interpretation in accordance with an analysis of visual inspection of the rhythms by a qualified electroencephalographer (EEGer), and then defined each item quantitatively. Concerning the automatic interpretation, we made an effort to find out specific EEG parameters which faithfully represent the procedure of visual interpretation by the qualified EEGer. Those specific EEG parameters were calculated from periodograms of the EEG time series. By using EEG data of 14 subjects, the automatic EEG interpretation system was constructed and compared with the visual interpretation done by the EEGer. The automatic EEG interpretation thus established was proved to be in agreement with the visual interpretation by the EEGer.

1. INTRODUCTION

The electroencephalogram (EEG) is the summation of the electrical activity of nerve cells in the cerebral cortex and is recorded from the human scalp. As the EEG reflects at least a part of the functional status of the subject's brain, the EEG interpreted by electroencephalographers (EEGers) is used as a diagnostic aid of the diseases affecting brain. Usually, qualified EEGers visually inspect the time and spatial features of the EEG record. Automatic analyses of the EEG have been attempted by many researchers. Out of many kinds of automatic EEG interpretations, spike detections for EEG in epilepsy have been actively investigated (Gotman and Gloor 1976, Gotman 1985, Frost 1985). Automatic detections of sleep stages of a subject by using EEG data were also implemented and about 80 % accuracy in the recognition was achieved (Inoue et al. 1981). Automatic diagnosis of EEG has been investigated by Kowada et al. 1971, Yamamoto et al. 1975. However, those studies were restricted only to a certain aspect of the EEG characteristics. As there are many complex items involved in the interpretation of awake EEG, full automatic EEG interpretation has not yet been achieved. The authors, in the previous works (Nakamura et al. 1985, Nakamura, Shibasaki and Nishida 1989), attempted an automatic scoring of EEG "organization" which is one of the most essential items for EEG interpretation.

In this study, we further advanced the previous "organization" scoring method and accomplished a total automatic interpretation, except for paroxysmal abnormalities, of the awake EEG recorded with subjects' eyes closed. We first clarified all the necessary items for EEG interpretation in accordance with the analysis of the procedure of an EEGer whose interpretation was based on the visual inspection of the following EEG rhythms: dominant rhythm, beta rhythm, alpha rhythm other than the dominant rhythm, theta rhythm and delta rhythm. After having completed the clarification, all items were defined quantitatively and the threshold values for the degree of abnormality were determined. According to the threshold values, each item was graded into 4 degrees: normal, mildly abnormal, moderately abnormal and markedly abnormal. Concerning the automatic interpretation, we made an effort to find out specific parameters which faithfully represent the technique of visual interpretation by the qualified EEGer. Those specific parameters were calculated from periodograms of the EEG time series. The automatic EEG interpretation was made on EEG data of 14 subjects and was compared with the visual interpretation done by the EEGer. The automatic EEG interpretation proved to be successful and gave the similar results to those obtained by the visual interpretation. This system can be used clinically as an assistant tool for neurologists and even for EEGers themselves, and may be the first step for its clinical application at hospitals.

2. QUANTITATIVE REPRESENTATION FOR EEG INTERPRETATION

2.1 Data acquisition

Subjects of this study were 14 adults aged 20-64 years, free from personal and family history of any neurologic or psychiatric diseases and other illnesses. Recording of EEG took place in a quiet, dimly lit room and the subject was placed in a sitting position with the eyes closed. Exploring cup electrodes were fixed to the scalp at points Fp_1, F_3, C_3, P_3, O_1, Fp_2, F_4, C_4, P_4, O_2, F_7, T_3, T_5, F_8, T_4, T_6 of the international 10 – 20 system, and referred to the ipsilateral ear electrode (A_1,A_2). The EEGs were recorded by an electroencephalograph with the time constant of 0.3 sec and the high frequency cut-off at 120 Hz. The artifact-free EEG record of 50 sec duration altogether, divided into 5 separate parts, was selected for each subject, and was visually inspected by a qualified EEGer.

2.2 Clarification of EEG items

We first clarified the items of EEG based on the EEGer's visual inspection of each identifiable rhythm (dominant rhythm, beta (13 Hz <), alpha (8 - 13 Hz) other than the dominant rhythm, theta (4 - 8 Hz) and delta (4 Hz >) wave components) with an idea of transferring them into an automatic EEG interpretation. Usually EEGers visually inspect an EEG in two steps : first inspect whether there exist wave components in the respective frequency bands, and then estimate the features of those wave components. The features of the dominant rhythm were characterized by frequency, amplitude and organization. The differences of the above three quantities of the dominant rhythm between the corresponding sites of the two hemispheres (asymmetry) and its extension to anterior regions of the head were also taken as factors for the EEG interpretation. For the beta rhythm, the amplitude and amount of the wave components in that band were chosen as the interpretation items. Concerning the alpha rhythm other than the dominant rhythm, theta rhythm and delta wave components, the durations of the respective wave components were measured in percentage, and the electrodes active for each component over the scalp were marked.

Every EEG item was graded into 4 degrees as normal (0), mildly abnormal (1), moderately abnormal (2) and markedly abnormal (3). The threshold values for the degree of each item were quantitatively determined as shown in Table 1.

Table 1 Items for EEG interpretation and the threshold values for each degree of abnormality.

Item		Normal	Abnormal		
			Mild	Moderate	Marked
		Degree 0	Degree 1	Degree 2	Degree 3
DOMINANT	Existence	Yes			No
	Frequency [Hz]	9≦	8< 9>	6< 8≧	6≧
	Asymmetry [Hz]	0.5>	0.5≦ 1.0>	1.0≦ 2.0>	2.0≦
	Amplitude [μV]	100>	100≦ 130>	130≦	
	Asymmetry [%]	50>	50≦ 60>	60≦ 80>	80≦
	Organization	0	1	2	3
	Asymmetry [%]	0.3>	0.3≦ 0.6>	0.6≦ 1.0>	1.0≦
	Extension [%]	till C,MT	till F,AT	till Fp (low)	till Fp (high)
BETA	Amplitude [μV]	50≧	50< 100>	100≦	
	Asymmetry [%]	50>	50≦ 60>	60≦ 80>	80≦
ALPHA	Duration [%]	10>	10≦ 30>	30≦ 75>	75≦
	Electrodes	Active electrodes			
THETA	Duration [%]	0	5>	5≦ 50>	50≦
	Electrodes	Active electrodes			
DELTA	Duration [%]	0	---	50>	50≦
	Electrodes	Active electrodes			

2.3 Quantitative EEG interpretation by EEGer

EEGs of 14 subjects were visually inspected by a qualified EEGer. The EEG record of each subject, consisting of 5 separate parts, 50 seconds long altogether, was inspected quantitatively, without any prior knowledge of the clinical picture, according to the standard criteria determined as shown in Table 1.

3. EEG PARAMETER AND AUTOMATIC SCORING

3.1 Calculation of periodogram parameters

To develop an automatic EEG interpretation which gives an equivalent result to visual interpretation made by the qualified EEGer, we first obtained numeral EEG time series from the actual EEG record. Continuous graphical data of EEG record were transformed into dotted data by using an image scanner (NEC PC-In503G), connected to a personal computer NEC PC-9801 RX, and again transformed into numeral ones by a computer program made by us (Nakamura et al., 1989). The EEG was recorded in the scales of 3cm/1sec and 1cm/50μV, and the image scanner transformed the 2.54 cm length data into 90 dots. Consequently the resolving powers were 9.4 msec of sampling interval and 2.8μV in quantified amplitude. The EEG time series for each subject consisted of 10 segments of 5 sec record, and the digital data of 18.4 msec sampling interval were sporadically adopted.

The digital data of the EEG time series were transformed into the Fourier components by the FFT method (Cooley and Tukey 1965) and the periodogram was calculated as the squares of the Fourier components for each frequency. The Nyquist frequency was 27 Hz and the resolving frequency was 0.2 Hz. Features of the periodogram for each 5 sec EEG record were expressed by the periodogram parameters for each of the 5 bands ; dominant rhythm, beta, alpha, theta and delta bands. The aforementioned parameters are the area of the periodogram within the respective bands (S_d, S_β, S_α, S_θ, S_δ), the mean frequency (m_d, m_β, m_α, m_θ, m_δ), the peak frequency (f_d, f_β, f_α, f_θ, f_δ), and the standard deviation (σ_β, σ_α, σ_θ, σ_δ). Actually, the time and spatial features of the 50 sec, 16 channel EEG record for each subject were condensed into the 3040 (10×16×19) periodogram parameters.

3.2 Construction of EEG parameters

By using the periodogram parameters, we constructed the EEG parameters which followed the features of the visual EEG interpretation done by the qualified EEGer. The quantity 'frequency' inspected by EEGers was expressed by the peak frequency (f) of the periodogram parameter. As the quantity 'amplitude' inspected by EEGers was the voltage of the EEG waves measured peak-to-peak, it was expressed by $8\sqrt{S}$ (see appendix). The quantity 'amount' was expressed by the area (S) of the periodogram in the respective frequency bands. As the quantity 'duration' was the relative appearance rate of the respective wave components, it was expressed by $\{\sum(S'/S_T)/10\} \times 100$ [%]. The notation S_T represents the total area of the periodogram for one segment, and S' represents the area of each frequency band in which the waves exceeded the threshold value of the existence. The quantity 'asymmetry' was the relative ratio in percentage of the measurement on the right to that on the left.

Dominant Rhythm Dominant rhythm was defined as a dominant EEG activity that consists of waves with an approximately constant period and shows maximum at the posterior regions of the head, and it was expressed by

$$\bar{S}_d/S_T \geq 0.2, \qquad (1-1)$$

$$\bar{S}_d/\tilde{S}_d \geq 1.0, \qquad (1-2)$$

$$8\sqrt{\bar{S}_d} \geq 10.0[\mu V]. \qquad (1-3)$$

The explanation of the symbols used above are as follows. The area covered by ±1 around the peak frequency in the interval 4-13 Hz of the periodograms at O and P was measured and the larger one out of those two areas was designated as $\bar{S}_d$. The maximum area of all the periodograms except O and P was measured, between the some interval as the dominant band of $\bar{S}_d$, and designated as $\tilde{S}_d$. The notation S_T was the total area of the individual periodogram. Dominancy, the maximum amount over the posterior regions of the head and the threshold value for the existence of the dominant rhythm were expressed by using the equations (1-1), (1-2) and (1-3), respectively. The dominant rhythm was evaluated on the left and right hemispheres separately. If the above three criteria were fulfilled, the dominant rhythm was judged to exist, and the features of the dominant rhythm were evaluated by using the EEG parameters : the peak frequency (f_d), the amplitude ($8\sqrt{\bar{S}_d}$) and the organization (y).

The 'organization' is the most important measure of the dominant rhythm and is defined by the International Federation of Societies for Electroencephalography and Clinical Neurophysiology as "the degree to which physiologic EEG rhythms conform to certain ideal characteristics displayed by a proportion of subjects in the same age group, free from personal and family history of neurologic

Table 2 EEG parameters for the automatic EEG interpretation.

Item		EEG Parameters
DOMINANT	Existence	$\bar{S}_d/\bar{S}_T \geq 0.2$, $\bar{S}_d/\tilde{S}_d \geq 1.0$, $8\bar{S}_d^{1/2} \geq 10.0$
	Frequency [Hz]	f_d
	Asymmetry [Hz]	$\mid f_d(X_2) - f_d(X_1) \mid$
	Amplitude[μV]	$8\bar{S}_d^{1/2}$
	Asymmetry [%]	$\{\bar{S}_d(X_2)^{1/2} - \bar{S}_d(X_1)^{1/2}\}/\mathrm{Max}\{\bar{S}_d(X_2)^{1/2}, \bar{S}_d(X_1)^{1/2}\} \times 100$
	Organization	$0.49 + 0.58\sigma\alpha - 0.13S\alpha + 4.82 \times 10^{-5}(S\alpha)^2 - 0.41S\alpha/S_T + 3.12S\delta/S_T$
	Asymmetry [%]	$\mid \mathrm{Orga}(X_2) - \mathrm{Orga}(X_1) \mid$
	Extension [%]	$\{\Sigma(S_d/S_T)/10\} \times 100 \geq 45.0$ (low) , 55.0 (high)
BETA	Amplitude[μV]	$8S\beta'^{1/2} \geq 10.0$
	Asymmetry [%]	$\{S\beta'(X_2) - S\beta'(X_1)\}/\mathrm{Max}\{S\beta'(X_2), S\beta'(X_1)\} \times 100$
ALPHA	Duration [%]	Residual of dominant rhythm $\Sigma\{(S\alpha'/S_T) \times 10 \mid 8S\alpha'^{1/2} \geq 15\}$
	Electrodes	Active electrodes
THETA	Duration [%]	$\Sigma\{(S\theta/S_T) \times 10 \mid 8S\theta^{1/2} \geq 20\}$
	Electrodes	Active electrodes
DELTA	Duration [%]	$\Sigma\{(S\delta/S_T) \times 10 \mid 8S\delta^{1/2} \geq 30\}$
	Electrodes	Active electrodes

and psychiatric diseases, and other illnesses that might be associated with dysfunction of the brain" (Chartrian et al. 1974). We adopted the organization scoring function as

$$y_d = 0.49 + 0.58\sigma_\alpha - 0.13S_\alpha + 4.82 \times 10^{-5}(S_\alpha)^2 - 0.41S_\alpha/S_T + 3.12S_\delta/S_T. \qquad (2)$$

This regression equation of the scoring had been previously derived by the authors (Nakamura et al. 1989). The extension of the dominant rhythm to anterior regions of the head was measured as the average ratio of the area of the periodogram within the dominant band as follows :

$$\{\sum_{1}^{10}(S_d/S_T)/10\} \times 100 \geq 45(\text{low}), \; 55(\text{high}). \qquad (3)$$

Beta Rhythm Beta rhythm is any EEG rhythm over 13 Hz. As a waveform of alpha rhythm is sharp in negative (upper) and blunt in positive (down), higher harmonics of the rhythm appear in the Fourier analysis. Consequently, the second harmonic of the dominant rhythm may occur in the beta band. Therefore the modified area of the periodogram in beta band (S'_β) was calculated by summing up the periodogram within the beta band while ignoring the area of ± 1 Hz around twice the peak frequency of the dominant rhythm ($2f_d$).

The threshold value of the existence of the beta rhythm was given as

$$8\sqrt{S'_\beta} \geq 10. \qquad (4)$$

The features of the beta rhythm were evaluated using the EEG parameters, namely the amplitude and the asymmetry of the modified areas in percentage.

Alpha, Theta and Delta Rhythm Alpha rhythm excluding the dominant rhythm was expressed by any rhythm in the alpha band (8 - 13 Hz) other than the dominant rhythm. The threshold value for the existence of the alpha rhythm was given by

$$8\sqrt{S'_\alpha} \geq 15. \qquad (5)$$

The threshold values for the existence of theta rhythm and delta rhythm were selected as follows :

$$8\sqrt{S_\theta} \geq 20, \qquad (6-1)$$

$$8\sqrt{S_\delta} \geq 30. \qquad (6-2)$$

The features of the above three rhythms were evaluated by their durations, and the active electrodes for respective rhythms were marked.

All EEG parameters for the automatic EEG interpretation were summarized in Table 2.

3.3 Automatic interpretation

EEGs of 14 subjects were analyzed by automatic interpretation. The EEG records were changed into numerous values by using the image scanner, and the periodograms of the EEG were calculated by the FFT method. The EEG parameters were computed according to the formulas (Table 2) and the scores of each parameter

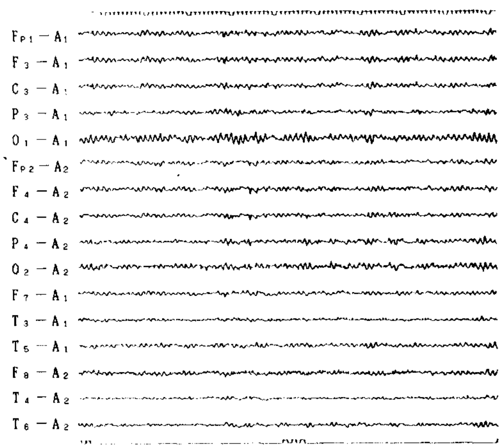

Figure 1 Two segments of 16 channel EEG record from a subject (subject 5)

were obtained for the automatic EEG interpretation.

4. RESULTS AND DISCUSSION

Two segments (10 sec) out of 10 segment-16 channel EEG record from a subject are illustrated in Figure 1. Table 3 shows intermediate estimates of the EEG parameters for each segment of the subject. The estimates for the automatic EEG interpretation were determined as the average of the intermediate estimates, and thescores of the automatic EEG interpretation were obtained based on the threshold values of the degrees (Table 1). The estimates and the scores of the automatic EEG interpretation of the subject were listed in the right two columns of Table 4, and the corresponding results inspected by the EEGer were shown in the left two columns. We found a good conformity between the results obtained by EEGer and the automatic ones. The EEGs of 14 subjects were interpreted by following the same way, and the results were summarized in Table 5. The scores of the automatic EEG interpretation in general showed a good agreement with the scores obtained by the EEGer.

By detailed observation of the results, we found slight discrepancies for some items. The cause of the differences was found to be twofold; an artifact of eye blinks and an activation of the reference electrodes. Such disagreements will be reduced by an appropriate preprocessing of EEG data for blinks, and by using a non-cephalic referential EEG record with an EKG elimination method (Nakamura and Shibasaki 1987) to skirt the problem of the earlobe activation.

The algorithm for the present automatic EEG interpretation was programmed in C language and implemented by using a personal computer NEC PC-9801 Vm21 with a DSP board for the FFT computation. The total computing time for the automatic EEG interpretation for one subject was about 16 minutes : the data input time was 10 minutes, the main calculation time 1.5 minutes, and the print-out time 4.5 minutes. We can reduce the calculation time remarkably by programming the total algorithm in a DSP board.

Table 3 Intermediate estimates of the EEG parameters for the automatic EEG interpretation in a subject.

Item				Subject 5									
				Intermediate Estimates of 5sec EEG Record Each									
				Segment 1		Segment 2		Segment 3		Segment 4		Segment 5	
DOMINANT	Existence			○	○	○	○	○	×	○	○	○	○
	Max Electrode			01	02	01	02	01	---	01	02	01	02
	Frequency [Hz]			8.9	8.9	8.7	8.7	8.5	---	8.7	8.9	8.7	8.7
	Asymmetry [Hz]				0.0		0.0		---		-0.2		0.0
	Amplitude[μV]			42.3	44.3	56.7	29.1	61.8	---	48.3	29.4	49.8	47.9
	Asymmetry [%]				-4.4		48.7		---		39.1		3.7
	Organization			1.3	0.9	0.7	1.4	0.9	---	0.7	1.5	0.8	1.1
	Asymmetry [%]				0.4		-0.7		---		-0.7		-0.3
	Exten. [%]	Fp1	Fp2	49.6	39.5	30.0	21.3	40.8	---	39.2	26.1	35.9	28.9
		F3	F4	53.2	47.9	35.3	24.8	42.8	---	41.9	23.0	33.1	26.3
		C3	C4	49.8	42.0	23.9	16.1	34.9	---	31.8	18.7	26.5	25.9
		F7	F8	46.9	42.2	30.9	25.9	38.3	---	44.4	19.5	37.0	22.0
		T3	T4	26.0	36.7	21.6	18.4	21.6	---	23.9	13.7	16.9	18.9
		T5	T6	33.4	41.3	49.4	37.9	40.5	---	34.8	23.8	41.1	50.7
BETA	Amplitude[μV]	Fp1	Fp2	13.5	11.1	11.3	10.3	11.8	12.6	12.5	11.8	16.6	11.8
		F3	F4	15.5	13.3	12.9	14.1	13.4	14.2	14.4	13.6	17.4	16.2
		C3	C4	13.2	11.7	11.8	11.9	12.7	11.1	12.4	12.8	16.4	13.9
		P3	P4	12.6	11.9	10.1	11.2	12.0	12.6	12.6	14.5	12.4	17.3
		01	02	16.3	13.5	15.9	17.4	18.1	18.2	17.8	17.6	16.6	20.2
		F7	F8	9.6	13.5	9.5	12.6	8.3	12.6	9.3	11.2	11.9	12.0
		T3	T4	10.7	6.5	---	---	---	---	---	---	10.1	8.5
		T5	T6	10.9	8.5	---	---	9.5	10.0	---	---	9.4	11.9
	Asymmetry[%]	Fp1	Fp2		32.6		16.9		12.3		10.9		49.5
		F3	F4		26.4		19.2		10.9		10.8		13.3
		C3	C4		21.4		1.7		23.6		6.2		28.2
		P3	P4		10.8		18.7		9.3		24.4		48.6
		01	02		31.4		16.4		1.1		2.2		32.5
		F7	F8		49.4		43.1		56.6		31.1		1.7
		T3	T4		63.1		---		---		---		29.2
		T5	T6		39.2		---		9.8		---		37.6
ALPHA	Duration[%]	Fp1	Fp2	9.7	14.2	14.1	---	19.2	34.2	10.6	16.1	10.5	16.6
		F3	F4	11.1	18.5	14.5	13.1	19.5	40.3	10.7	18.6	16.0	20.1
		C3	C4	15.2	20.5	17.6	19.5	22.3	39.0	18.1	28.1	16.8	22.9
		F7	F8	---	17.1	---	---	14.5	39.2	---	17.4	15.8	17.3
		T3	T4	---	---	---	---	---	37.7	---	---	27.0	---
		T5	T6	---	24.0	14.9	---	13.0	31.2	18.0	24.7	---	---
THETA	Duration[%]	Fp1	Fp2	---	---	---	---	---	---	20.8	---	17.2	16.0
		F3	F4	---	11.7	15.0	18.7	12.7	19.3	18.3	24.9	15.5	16.9
		C3	C4	---	---	---	---	17.3	---	---	---	15.2	15.9
		P3	P4	---	---	---	16.0	---	---	---	13.2	---	11.4
		01	02	---	---	9.6	17.3	8.5	19.7	16.5	15.3	14.1	14.4
		F7	F8	---	---	---	---	---	---	---	---	---	---
		T3	T4	---	---	---	---	---	---	---	---	---	---
		T5	T6	---	---	---	---	---	---	18.7	---	---	---
DELTA	Duration[%]	Fp1	Fp2	---	29.1	32.4	42.1	---	40.6	---	---	---	---
		F3	F4	---	---	---	---	---	27.8	---	---	---	23.4
		C3	C4	---	---	---	---	---	---	---	---	---	---
		P3	P4	---	---	---	---	---	---	---	---	---	---
		01	02	23.8	---	---	---	22.3	29.4	15.5	---	---	21.1
		F7	F8	---	---	---	---	---	---	---	---	---	---
		T3	T4	---	---	---	---	---	---	---	---	---	---
		T5	T6	---	---	---	---	---	---	---	---	---	---

Item				Subject 5									
				Intermediate Estimates of 5sec EEG Record Each									
				Segment 6		Segment 7		Segment 8		Segment 9		Segment 10	
DOMINANT	Existence			○	×	○	○	○	×	○	○	×	×
	Max Electrode			01	---	01	02	01	---	01	02	---	---
	Frequency [Hz]			8.5	---	8.5	8.7	8.3	---	8.5	8.9	---	---
	Asymmetry [Hz]				---		-0.2		---		-0.4		---
	Amplitude[μV]			46.4	---	55.1	30.3	38.5	---	66.4	36.5	---	---
	Asymmetry [%]				---		45.0		---		45.1		---
	Organization			1.0	---	0.8	1.5	1.4	---	0.4	1.3	---	---
	Asymmetry [%]				---		-0.7		---		-0.9		---
	Exten. [%]	Fp1	Fp2	26.8	---	44.5	28.6	31.9	---	43.4	21.5	---	---
		F3	F4	25.2	---	42.1	28.5	33.2	---	44.2	24.6	---	---
		C3	C4	24.2	---	31.4	20.6	31.5	---	33.4	22.2	---	---
		F7	F8	24.2	---	38.6	26.8	32.7	---	47.5	24.0	---	---
		T3	T4	9.0	---	10.9	21.2	14.7	---	18.4	23.1	---	---
		T5	T6	41.3	---	41.5	23.1	31.9	---	60.4	32.0	---	---
BETA	Amplitude[μV]	Fp1	Fp2	12.9	11.8	10.7	10.3	13.2	11.1	12.7	10.2	10.7	11.1
		F3	F4	14.5	14.4	12.9	12.1	15.0	14.4	14.9	11.7	10.4	12.3
		C3	C4	13.0	12.4	11.6	11.1	12.1	11.5	12.6	10.7	10.0	10.0
		P3	P4	11.7	12.3	10.9	11.2	10.8	12.9	11.0	10.3	---	---
		01	02	14.7	14.6	16.5	15.6	13.4	16.0	15.5	14.0	11.6	11.2
		F7	F8	9.7	11.5	9.0	11.1	9.3	11.4	9.9	10.7	---	---
		T3	T4	---	---	---	---	---	---	---	---	---	---
		T5	T6	---	---	---	---	---	---	---	---	---	---
	Asymmetry[%]	Fp1	Fp2		16.3		7.3		29.2		35.4		7.0
		F3	F4		1.3		12.0		7.8		38.3		28.5
		C3	C4		9.0		8.4		9.6		27.9		0.0
		P3	P4		9.5		5.2		29.9		12.3		---
		01	02		1.4		10.6		29.8		18.4		6.7
		F7	F8		28.8		34.2		33.4		14.3		---
		T3	T4		---		---		---		---		---
		T5	T6		---		---		---		---		---
ALPHA	Duration[%]	Fp1	Fp2	16.1	30.8	17.8	15.2	17.5	12.7	10.4	18.8	16.8	9.1
		F3	F4	18.9	32.7	16.8	19.8	16.6	44.9	12.6	22.9	70.5	63.5
		C3	C4	26.1	34.6	22.7	21.3	20.4	45.1	20.1	28.1	65.6	62.4
		F7	F8	15.1	27.9	---	20.3	15.9	43.2	---	17.0	72.5	54.5
		T3	T4	---	23.9	---	---	---	44.2	---	---	58.8	41.4
		T5	T6	13.6	30.1	11.2	---	17.0	36.3	---	---	61.1	56.5
THETA	Duration[%]	Fp1	Fp2	20.6	15.9	18.7	---	11.6	---	13.3	16.1	---	---
		F3	F4	20.8	20.4	19.3	18.3	11.0	---	15.0	16.9	---	9.1
		C3	C4	19.0	21.4	---	---	---	---	16.3	17.1	---	---
		P3	P4	21.1	---	---	30.0	---	22.0	---	23.2	---	---
		01	02	19.3	17.6	19.3	23.8	19.4	22.8	8.7	25.4	19.9	---
		F7	F8	---	18.6	---	---	---	---	---	17.9	---	---
		T3	T4	---	---	---	---	---	---	---	---	---	---
		T5	T6	---	---	21.8	---	---	---	---	---	---	---
DELTA	Duration[%]	Fp1	Fp2	30.4	45.9	---	---	33.6	41.0	26.9	36.0	---	26.1
		F3	F4	28.7	39.0	---	---	32.5	35.4	---	27.1	---	---
		C3	C4	---	36.1	---	---	31.0	34.1	---	---	---	---
		P3	P4	---	---	---	---	---	---	---	---	---	---
		01	02	---	40.3	15.1	---	24.2	32.8	---	---	---	---
		F7	F8	---	44.1	---	---	---	---	---	---	---	---
		T3	T4	---	---	---	---	---	---	---	---	---	---
		T5	T6	---	53.2	---	---	---	---	---	---	---	---

Table 4 Estimates and scores of the EEG interpretation in a subject.

Item		Electrodes	Subject 5 EEGer Value	EEGer Score	Auto Value	Auto Score
DOMINANT	Existence		○ ○	0	○ ○	0
	Max Erectrode				01 02	
	Frequency [Hz]		8.8 8.8	1	8.6 8.8	1
	Asymmetry [Hz]		- 0.0	0	-0.2	0
	Amplitude[μV]		70.0 35.0	0	51.7 36.2	0
	Asymmetry [%]		50.0	1	29.9	0
	Organization		Mild ab.	1	0.9 1.3	1
	Asymmetry [%]		0.0	0	-0.4	1
	Exten.[%]	Fp1 Fp2	till C, MT	0	38.0 27.7	0
		F3 F4			39.0 29.2	
		C3 C4			31.9 24.2	
		F7 F8			37.8 26.7	
		T3 T4			18.1 22.0	
		T5 T6			41.6 34.8	
BETA	Amplitude[μV]	Fp1 Fp2	10.0>	0	12.6 11.2	0 0
		F3 F4			14.1 13.6	0 0
		C3 C4			12.6 11.7	0 0
		P3 P4			11.2 12.3	0 0
		01 02			15.6 15.8	0 0
		F7 F8			9.3 11.6	0 0
		T3 T4			--- ---	0 0
		T5 T6			--- ---	0 0
	Asymmetry[%]	Fp1 Fp2	0.0	0	21.0	0
		F3 F4			7.0	0
		C3 C4			13.8	0
		P3 P4			17.1	0
		01 02			2.5	0
		F7 F8			35.7	0
		T3 T4			---	0
		T5 T6			---	0
ALPHA	Duration[%]	Fp1 Fp2	0.0	0	14.3 16.8	1 1
		F3 F4			20.7 29.4	1 1
		C3 C4			24.5 32.1	1 2
		F7 F8			13.4 25.4	1 1
		T3 T4			8.6 14.7	0 1
		T5 T6			14.9 20.3	1 1
THETA	Duration[%]	Fp1 Fp2	3.0 (Diffuse)	1	10.2 4.8	2 1
		F3 F4			12.8 15.6	2 2
		C3 C4			6.8 5.4	2 2
		P3 P4			2.1 11.6	1 2
		01 02			13.6 15.6	2 2
		F7 F8			--- 3.6	0 1
		T3 T4			--- ---	0 0
		T5 T6			4.1 ---	1 0
DELTA	Duration[%]	Fp1 Fp2	15.0 (T6, 02, P4 Occa T4)	2	12.3 26.1	2 2
		F3 F4			6.1 15.3	2 2
		C3 C4			3.1 7.0	2 2
		P3 P4			--- ---	0 0
		01 02			10.1 12.4	2 2
		F7 F8			--- 4.4	0 2
		T3 T4			--- ---	0 0
		T5 T6			--- 5.3	0 2

5. CONCLUTION

An automatic EEG interpretation system was developed successfully. We first clarified the items of EEG for the interpretation based on visual inspection done by a qualified EEGer, and defined all items quantitatively. Concerning the automatic EEG interpretation, we made an effort to find out the EEG parameters which faithfully represent the procedure of visual interpretation by the EEGer. The automatic EEG interpretation thus obtained was proved to be almost the same as the visual interpretation made by the qualified EEGer. This system can be used clinically as an assistant tool for neurologists and EEGers, and may be the first step for its clinical application at hospitals.

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Table 5 Scores of the EEG interpretation in 14 subjects.

Item		Subject 1 EEGer	Subject 1 Auto	Subject 2 EEGer	Subject 2 Auto	Subject 3 EEGer	Subject 3 Auto	Subject 4 EEGer	Subject 4 Auto	Subject 5 EEGer	Subject 5 Auto	Subject 6 EEGer	Subject 6 Auto	Subject 7 EEGer	Subject 7 Auto
DOMINANT	Existence	0	0	0	0	0	0	0	0	0	0	0	0	3	3
	Frequency [Hz]	0	0	0	0	0	0	0	1	1	1	0	0	---	---
	Asymmetry [Hz]	0	0	1	3	0	0	0	3	0	0	0	0	---	---
	Amplitude[μV]	0	0	0	0	0	0	0	0	0	0	0	0	---	---
	Asymmetry [%]	0	0	3	3	0	0	0	3	1	0	0	0	---	---
	Organization	0	0	1	1	1	1	2	2	1	1	2	1	---	---
	Asymmetry [%]	0	0	3	3	0	0	0	3	0	1	0	0	---	---
	Extension [%]	1	0	0	0	0	0	0	0	0	0	2	0	---	---
BE	Amplitude[μV]	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Asymmetry [%]	0	0	3	0	0	0, 1	0	0	0	0	0	0	0	0 ,2
ALPHA	Duration [%]	0	0, 1	0	0, 1	0	0, 1, 2	1	0, 1	0	0, 1, 2	0	0, 1, 2	0	0
	Electrodes	---	Diffu	---	Diffu (ex. T_3 T_4)	---	Diffu (ex. F_7 T_3)	F_p F	F_{34} C_{34}	---	Diffu	Biante -rior	Diffu	---	---
THETA	Duration [%]	1	0, 1, 2	2	0, 1, 2	0	0	2	0, 1, 2	1	0, 1, 2	2	0, 1, 2	2	0, 1
	Electrodes	F_{348}	P C F_{34}	Diffu (ex. T_3 T_4)	F_{p1} O_1 F_{347} C P T_{35}	---	---	Diffu	F_p C_4 F_{34}	Diffu	Diffu (ex. F_7 T_{356})	Diffu	Diffu (ex. F_7 T_{346})	Diffu	F_p P F[illegible]
DELTA	Duration [%]	0	0, 2	3	0, 2, 3	0	0, 2	2	0, 2, 3	2	0, 2	2	0, 2	3	3
	Electrodes	---	F_p C_3 P F_{348}	Diffu (ex. O_2 T_{46})	Diffu (ex. T_4)	---	Diffu (ex. F_4 T_{46})	F_p F AT	C_4 P_4 T_4 O_2 F_p F	$T_6O_2P_4$ (Occa. T_4)	Diffu (ex. F_7 T_{345}P)	Poster -ior	F_p P O F_{37} C_3	Diffu	Diffu

Item		Subject 8 EEGer	Subject 8 Auto	Subject 9 EEGer	Subject 9 Auto	Subject 10 EEGer	Subject 10 Auto	Subject 11 EEGer	Subject 11 Auto	Subject 12 EEGer	Subject 12 Auto	Subject 13 EEGer	Subject 13 Auto	Subject 14 EEGer	Subject 14 Auto
DOMINANT	Existence	0	0	0	0	3	3	0	3	0	0	0	3	3	3
	Frequency [Hz]	0	0	2	2	---	---	0	---	0	0	0	---	---	---
	Asymmetry [Hz]	0	0	0	0	---	---	0	---	0	3	lack R	---	---	---
	Amplitude[μV]	0	0	0	0	---	---	0	---	0	0	0	---	---	---
	Asymmetry [%]	0	0	0	0	---	---	0	---	0	3	lack R	---	---	---
	Organization	1	0	2	1	---	---	2	---	0	1	3	---	---	---
	Asymmetry [%]	0	0	0	0	---	---	0	---	0	3	3	---	---	---
	Extension [%]	0	0	1	0	---	---	0	---	0	0	till P	---	---	---
BE	Amplitude[μV]	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Asymmetry [%]	0	0	0	0	0	0	0	0	0	0	2	0	3	2
ALPHA	Duration [%]	0	0, 1, 2	0	0	1	0	1	0	1	0, 1, 2	1	0, 1	1	0
	Electrodes	F_p F AT	Diffu (ex. T_4)	---	T_5	C_4 P_4	Diffu	F F_p	---	Anteri -or	Diffu	Left hemisp -here	F_pF_{347} C_3 P_3 O_1 T_{35}	Anteri -or more R	F_p C_4 F_{48}
THETA	Duration [%]	2	0, 1, 2	2	0, 1, 2	2	0, 1, 2	2	0	0	0, 1	2	0, 2	3	0, 1, 2
	Electrodes	F_p F	F_p C O F_{34} P_3	F C AT	O P C_3 $T_{56}F_{p2}$	Diffu	Diffu (ex. T_3)	F_pF(C)	---	---	T_{34}	Diffu	F_pF_{347} C_3 P_3 O_1 T_5	Anteri -or more R	F_pF_{348} P_4 O_1 T_{46} C
DELTA	Duration [%]	0	0, 2	2	0, 2	3	3	0	0, 2, 3	0	0, 2	3	0, 2, 3	3	0, 2, 3
	Electrodes	---	F_p P_3 O T_6 F_{478}	F_p~O Biante -rior	F_p P_3 F_{378} O	F_{p2} F_{48}	Diffu	---	F_p C_3 F_{78}	---	T P_3 F_{478}	Fp_1 C_3 F_{37}	Diffu (ex. T_{46})	F_p F_{47}	Diffu

Diffu means diffused, Diffu(ex. X) diffused except X, and (Occa Y) occasional at Y.

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APPENDIX

The EEG model of sinusoidal waves with Markov process amplitudes (Nishida et al. 1986) represents features of EEG exactly both in time domain and frequency domain. The mean amplitude of the EEG model is $2\sqrt{S}$, where S represents the total area of the periodogram for one rhythm. The quantity 'amplitude' is a voltage of the EEG waves measured peak-to-peak (2 times), which exceeds the threshold value of the existence (2 times), and then defined as 4 times of the mean amplitude of the EEG model($4\times 2\sqrt{S}$).