REAL TIME AUTOMATIC EEG REPORT MAKING BASED ON QUANTITATIVE INTERPRETATION OF AWAKE EEG

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ABSTRACT

A new method for making automatic electroencephalogram (EEG) report based on the automatic quantitative interpretation of awake EEG was developed. We first analysed a relationship between EEG reports and quantitative EEG interpretation done by a qualified electroencephalographer (EEGer) for 22 subjects. Based on the analysed relationship and usual process of report making by the EEGer, we defined all terminology necessary for EEG report and established rules for EEG report making. By the combined use of the proposed EEG report making and the method for automatic quantitative EEG interpretation presented at '90 KACC, we were able to make the automatic EEG reports which were equivalent to the EEG reports written by the EEGer. As all the procedures were programmed in a personal computer equipped with an AD (analogue-to-digital) converter, the automatic EEG reports were obtained in almost real time in usual actual EEG recording situation with only a few seconds time lag for the analysis in the computer. The proposed report making method and the quantitative EEG interpretation method will be effectively applicable to the clinical use as an assistant tool for physicians.

1. INTRODUCTION

As regards automatic EEG interpretation, spike detection in epileptic patients has drawn special attention (Godman and Gloor 1976; Frost 1985; Godman 1985) and has been applied successfully to hospital use. Automatic analyses of sleep stages by using EEG data have also been implemented, and a high accuracy in the recognition was achieved (Inoue et al. 1982). Automatic diagnosis of awake EEGs has been investigated by Kowada et al. (1971) and Yamamoto et al. (1975). However, most previous studies of awake EEGs were restricted to a certain aspect of EEG characteristics such as the dominant rhythm or slow waves. In contract with the previous analyses of awake EEG which were focussed only on certain aspects of EEG, authors (Nakamura, Shibasaki, Imajoh et al. 1990; Nakamura, Shibasaki, Imajoh et al. 1992) had proposed a new computer-assisted system for the automatic integrative interpretation of awake EEG. First, all the items necessary for EEG interpretation were determined in accordance with the procedure that a qualified EEGer goes through for the visual inspection of the background EEG activity, and then each item was defined quantitatively. For the automatic interpretation, specific EEG parameters were determined for each item so that they could fit the graded judgement of the item by a qualified EEGer as closely as possible. These specific EEG parameters were actually calculated from periodograms obtained from the time series of EEG records. The automatic EEG interpretation system thus established was applied to the EEG data, and the results were compared with those obtained through the visual interpretation by the EEGer. The automatic quantitative EEG interpretation was found to be in good agreement with the visual interpretation by the EEGer in most EEG records. However the style for expressing the results of the quantitative EEG interpretation was different from that of EEG reports which was usually written by EEGers, and therefore was not easily understandable to other medical doctors.

In this paper, we proposed a method for automatic making of EEG report which had the same form as written by EEGers. By combined use of the developed method for the EEG report making and the automatic quantitative EEG interpretation method (Nakamura, Shibasaki, Imajoh et al. 1990), we could make the automatic EEG reports which were equivalent to the EEG reports written by the EEGer.

2. METHOD

2.1 Subjects and visual inspection of EEGs

EEG of 22 subjects were arbitrarily selected from consecutive EEG records of Saga Medical School for development of the automatic report making system. All EEGs were recorded in a quiet, dimly lit room where the subjects were placed in a supine position in a bed with the eyes closed. Exploring cup electrodes were fixed to the scalp at 16 portions of International 10-20 System, and all electrodes were referenced to the ipsilateral ear electrode. The 16-channel EEGs were recorded by an electroencephalograph with a time constant of 0.3 sec and a high frequency cut-off at 120 Hz (-3dB) at a paper speed of 3 cm/sec and a sensitivity of 0.5 cm/50 μV. Ten artifact-free consecutive strips of EEG, each 5 sec long, were selected from the entire record of the above montage for each subject and were subjected to visual inspection by a qualified EEGer (one of the authors, H. S.) as well as to the source of automatic report making. The 50 sec long EEG record of each subject was visually inspected and interpreted quantitatively by the qualified EEGer according to the criteria which were categorized into 16 items as shown in Table 1. Every item of EEG was graded into 4 scores : normal (0), mildly abnormal (1), moderately abnormal (2) and markedly abnormal (3). At the same time, the EEG reports were written by the EEGer for each subject. In the usual EEG reports written by the EEGer, a term for grading of the whole EEG appeared first, and terms for expressing abnormalities of each item succeeded afterwards.

2.2 Determination of terminology for EEG report

We analysed a relationship between EEG reports and quantitative EEG interpretation done by the qualified EEGer for 22 subjects. Based on the analysed relationship and the process of report making by the EEGer, we first defined all terminologies necessary for EEG report divided into three categories, namely, terminology for expressing the integrative grade of EEG, abnormality of each item, and scalp site of abnormality as shown in Table 2,3 and 4, respectively. In the process of defining the terminology, we selected all terms for expressing quantitative EEG interpretation which appeared in the EEG reports written by the EEGer for 22 subjects and added several supplementary terms, in a manner so that a unique term to each specific expression for the quantitative EEG interpretation was obtained. Fifteen terms for expressing the scalp sites of abnormality were arranged from wider to focal distributions.

2.3 Rules for EEG report making

By analysing a relationship between EEG reports and quantitative EEG interpretation done by the qualified EEGers, we established rules for automatic making of EEG reports based on grading scores of each item for quantitative EEG interpretation.

1) The integrative grade of EEG, as shown in Table 2, was determined by taking into account the grading scores of each item for the quantitative EEG interpretation. The appropriate term for the integrative grading of EEG was selected from the terminologies described in Table 2 by summing up the corresponding weights for each item for quantitative EEG interpretation. The weights, as shown in Table 3, for each item were determined by the qualified EEGer, and the threshold values for each terminology in Table 2 were determined so as to attain the conformity between the results of automatic interpretation and those by the qualified EEGer for 22 subjects. In case of lack of dominant rhythm in the quantitative EEG interpretation, the weights of all grading scores of dominant rhythm except for asymmetry were assigned 10 (worst weight).
2) All corresponding terms for abnormality of each item for the quantitative EEG interpretation were selected from the terminologies for abnormality (Table 3) and were arranged in order of sequential numbers.
3) In order to draw a special attention, symbol (*) was attached in front of the sequential number if the grading score was higher than 2.
4) To express asymmetry of items (organization, frequency and amplitude of dominant rhythm, amplitude of beta rhythm), terms of 'on the left ' or 'on the right' were adopted to modify the terms for abnormality of each item.
5) To express the scalp site of abnormality for duration of theta, delta and non-dominant alpha rhythm, a term was extracted from the terminologies for expressing the scalp sites of abnormality (Table 4), based on the grading score of duration of each rhythm at 16 scalp sites.

3. RESULTS

3.1 Evaluation of automatic EEG report making

Automatic EEG report making was evaluated based on the EEG data for 22 subjects and additional 3 subjects. The data of additional 3 subjects were not included in the data used for developing the present system. Evaluation was performed in two stages. For the first evaluation, automatic EEG reports were made based on scores of each item for quantitative EEG interpretation given by the EEGer. Almost all automatic EEG reports were proved to be equivalent to respective EEG reports written by the EEGer. Only the expression for paroxysmal abnormalities did not appear in the automatic EEG report, because the automatic EEG interpretation was restricted to the awake background EEG. This evaluation of conformity proved validity of the defined terminology and rules for the automatic EEG report making. In the second stage of evaluation, automatic EEG reports were made based on grading scores by the automatic quantitative EEG interpretation. These automatic EEG reports also proved to be equivalent to the respective EEG reports written by the EEGer, because the difference between the grading scores of each item obtained by automatic interpretation and visual inspection had been small (Nakamura, Shibasaki, Imajoh et al. 1992).

3.2 Samples of EEG report

Out of 25 EEG reports subjected to the second stage of evaluation, namely based on automatic quantitative EEG interpretation, two samples of EEG interpretation are shown in Table 5 and 6. Subject A was a 64-year-

Table 1 Items and criteria (threshold values) for grading each item used for the present visual interpretation of EEG.

Item		Normal	Abnormal		
			Mild	Moderate	Marked
		Score 0	Score 1	Score 2	Score 3
DOMINANT	Existence	Yes			No
	Organization	0	1	2	3
	Asymmetry [%]	<0.3	0.3≦ <0.6	0.6≦ <1.0	1.0≦
	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≦
	Extension[μV]	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≦
THETA	Duration [%]	0	<5	5≦ <50	50≦
	Electrodes	Active electrodes			
DELTA	Duration [%]	0	---	<50	50≦
	Electrodes	Active electrodes			
ALPHA*	Duration [%]	<10	10≦ <30	30≦ <75	75≦
	Electrodes	Active electrodes			

*:Non-dominant alpha rhythm

Table 2 Terminology for expressing the grade of EEG abnormality

Total weight	Terminology
22≦	Markedly abnormal record
11≦ <22	Moderately abnormal record
10≦ <11	Mildly abnormal record
<10	Normal record

Table 3 Terminology for expressing abnormality of each item

No	Item	S	Terminology	Weight
			Dominant rhythm	
1	Existence	3	lack of dominant rhythm	10.0
2	Organization	3	markedly disorganized background activity	7.0
		2	disorganized background activity	4.5
		1	poorly organized background activity	2.0
3	Asymmetry	3	marked asymmetry of dominant rhythm organization, poor on (L or R)	5.0
		2	asymmetry of dominant rhythm organization, poor on (L or R)	3.5
		1	slight asymmetry of dominant rhythm organization, poor on (L or R)	2.0
4	Frequency	3	markedly slow dominant rhythm (Hz)	8.0
		2	slow dominant rhythm (Hz)	5.0
		1	slow α rhythm	2.0
5	Asymmetry	3	marked asymmetry of dominant rhythm frequency, slower on (L or R)	5.0
		2	asymmetry of dominant rhythm frequency, slower on (L or R)	3.5
		1	slight asymmetry of dominant rhythm frequency, slower on (L or R)	2.0
6	Amplitude	2	excessively high amplitude dominant rhythm	3.0
		1	high amplitude dominant rhythm	2.0
7	Asymmetry	3	suppression of dominant rhythm on (L or R)	5.0
		2	depression of dominant rhythm on (L or R)	3.5
		1	mild depression of dominant rhythm on (L or R)	2.0
8	Extension	3	excessive anterior extension of α rhythm	2.0
		2	anteriorly extension of α rhythm	1.5
		1	mild anteriorly extension of α rhythm	1.0
			Beta rhythm	
9	Amplitude	2	excessively high amplitude rhythmic fast activity	3.0
		1	high amplitude rhythmic fast activity	2.0
10	Asymmetry	3	suppression of rhythmic fast activity on (L or R)	5.0
		2	depression of rhythmic fast activity on (L or R)	3.5
		1	mild depression of rhythmic fast activity on (L or R)	2.0
			Theta rhythm	
11	Duration	3	continuous, rhythmic and/or irregular θ waves	8.0
		2	intermittent, rhythmic and/or irregular θ waves	5.0
		1	occasional θ waves	2.0
12	Electrodes			
			Delta rhythm	
13	Duration	3	continuous, rhythmic and/or irregular δ waves	8.0
		2	intermittent, rhythmic and/or irregular δ waves	5.0
		1	occasional δ waves	2.0
14	Electrodes			
			Non-dominant alpha rhythm	
15	Duration	3	continuous rhythm of α frequency waves	4.0
		2	intermittent rhythm of α frequency waves	3.0
		1	occasional waves of α frequency	2.0
16	Electrodes			

Table 4 Terminology for expressing the scalp sites of abnormalities

Region	Electrodes	Terminology
R 1	12≦ (total)	diffusely
R 2	6≦ (left), ≦11	more on the left hemisphere
R 3	6≦ (right), ≦11	more on the right hemisphere
R 4	6≦ (F_P, F>C, T_3, T_4), symmetry	bianteriorly
R 5	6≦ (F_P, F>C, T_3, T_4)	anteriorly
R 6	6≦ (O, P>T, C)	posteriorly
R 7	5≦ (C, F)	on the fronto-central region
R 8	4≦ (F_{P1}, F_3, F_7>C_3, T_3)	on the left anterior quadrant
R 9	4≦ (F_{P2}, F_4, F_8>C_4, T_4)	on the right anterior quadrant
R10	3≦ (O_1, P_3, T_5>C_3, T_3)	on the left posterior quadrant
R11	3≦ (O_2, P_4, T_6>C_4, T_4)	on the right posterior quadrant
R12	2≦ (C, P)	on the centro-parietal region
R13	2≦ (F_{P1}, F_3, F_7)	on the left frontal region
R14	2≦ (F_{P2}, F_4, F_8)	on the right frontal region
R15	2≦ (F)	on the frontal region

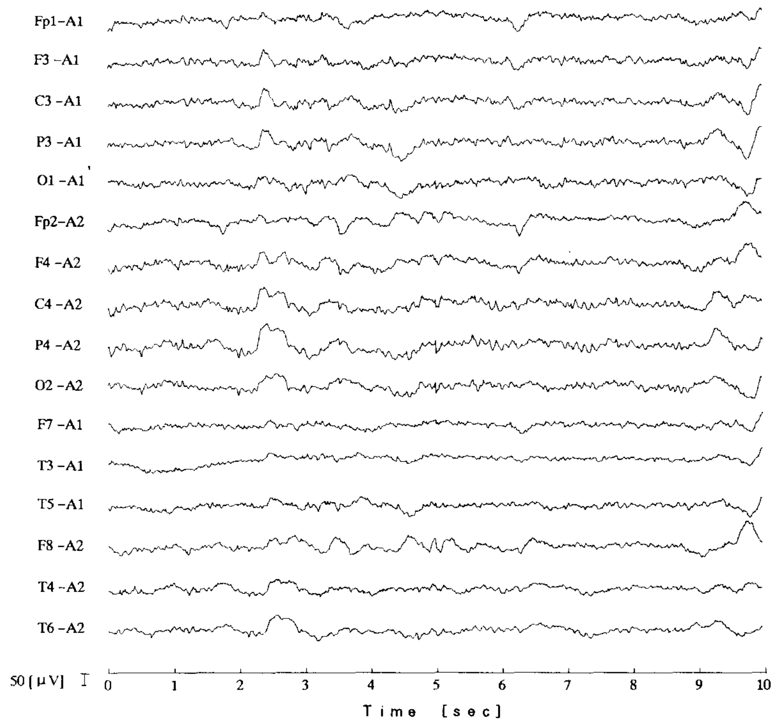

Fig. 1 Awake EEG time series (Subject A)

Table 5 Quantitative EEG interpretation for each item and EEG report. comparing the EEGer's report and automatic report (Subject A)

No	Item	EEGer		Automatic	
		Value	Score	Value	Score
	Dominant rhythm				
1	Existence	no	3	no	3
2	Organization	---	---	---	---
3	Asymmetry[%]	---	---	---	---
4	Frequency[Hz]	---	---	---	---
5	Asymmetry[Hz]	---	---	---	---
6	Amplitude[μV]	---	---	---	---
7	Asymmetry[%]	---	---	---	---
8	Extension[μV]	---	---	---	---
	Beta rhythm				
9	Amplitude[μV]	10	0	14.6	0
10	Asymmetry[%]	0	0	42.9	0
	Theta rhythm				
11	Duration[%]	35	2	15.1	2
12	Electrodes	F_P, F, C P, O, T		Fp_{12}, F_{3478}, T_{456} C_{34}, P_{34}, O_{12}	
	Delta rhythm				
13	Duration[%]	55	3	88.2	3
14	Electrodes	a F_{P2}, F_4, F_8 b paroxysmal burst		Fp_{12}, F_{3478}, T_{3456} C_{34}, P_{34}, O_{12}	
	Non-dominant alpha rhythm				
15	Duration[%]	20	1	7.6	0
16	Electrodes	C_4, P_4		---	

EEGer's report
Markedly abnormal record because of (1) lack of dominant rhythm, (2) continuous θ waves diffusely, (3) continuous localized irregular δ waves on the right frontal region, (4) paroxysmal bursts of high amplitude δ waves diffusely, and (5) occasional waves of α frequency waves on the right centro-parietal region.

Automatic report
Markedly abnormal record because of •(1) lack of dominant rhythm, •(2) intermittent, rhythmic and/or irregular θ waves diffusely, and •(3) continuous, rhythmic and/or irregular δ waves diffusely.

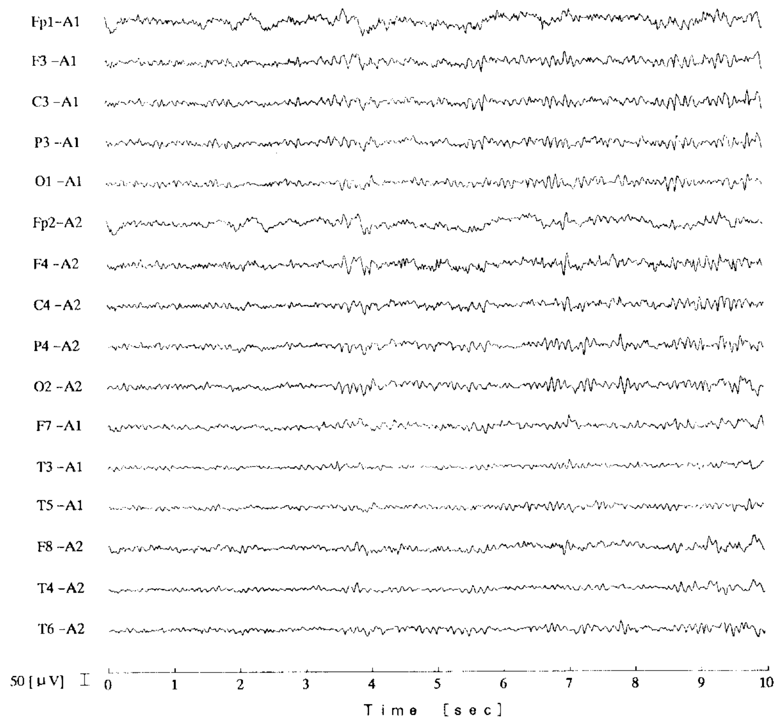

Fig. 2 Awake EEG time series (Subject B)

Table 6 Quantitative EEG interpretation for each item and EEG report. comparing the EEGer's report and automatic report (Subject B)

No	Item	EEGer Value	EEGer Score	Automatic Value	Automatic Score
	Dominant rhythm				
1	Existence	○	0	○	0
2	Organization	Mode ab.	2	1.3	1
3	Asymmetry[%]	0.0	0	0.0	0
4	Frequency[Hz]	10.8	0	10.3	0
5	Asymmetry[Hz]	0.0	0	0.1	0
6	Amplitude[μV]	95.0	0	57.6	0
7	Asymmetry[%]	0.0	0	1.8	0
8	Extension[μV]	till C	0	45.1	1
	Beta rhythm				
9	Amplitude[μV]	<35.0	0	18.8	0
10	Asymmetry[%]	0.0	0	3.0	0
	Theta rhythm				
11	Duration[%]	20.0	2	14.8	2
12	Electrodes	Diffuse , more on R		Fp F C P O T	
	Delta rhythm				
13	Duration[%]	40.0	2	30.5	2
14	Electrodes	Fp F C P O T more on R		Fp F C P O T	
	Non-dominant alpha rhythm				
15	Duration[%]	0.0	0	23.4	1
16	Electrodes	———		Fp F C P O T	

EEGer's report

Moderately abnormal record
because of
(1) disorganized background activity,
(2) intermittent irregular slow waves (θ and δ) deffusely, more on the right,
(3) paroxysmal bursts of high amplitude rhythmic δ waves bilaterally, more anteriorly.

Automatic report

Moderately abnormal record
because of
(1) poorly organized background activity,
(2) mild anteriorly extension of α rhythm,
*(3) intermittent, rhythmic and/or irregular θ waves diffusely,
*(4) intermittent, rhythmic and/or irregular δ waves diffusely, and
(5) occasional waves of α frequency diffusely.

old man who was included among 22 subjects. and subject B was a 48-year-old woman who was one of the additional 3 subjects. Figs. 1 and 2 illustrate the initial 10 sec long segment of the 50 sec EEG record of subject A and B, respectively. Tables 5 and 6 show quantitative EEG interpretation for each item and EEG report, comparing the EEGer's report and automatic report. A slight difference of expression between the EEGer's report and the automatic report was found. However, total meaning of the automatic EEG reports was equivalent to that of the EEGer's report except for paroxysmal abnormalities.

4. DISCUSSION

i) As all the procedures are programmed in a personal computer NEC PC-9801 RA equipped with an AD (analogue-to-digital) converter, the automatic EEG report can be obtained in almost real time with several seconds time lag for computing time in actual EEG recording.

ii) In automatic quantitative EEG interpretation, only blink artifacts could be detected automatically. Therefore, other artifacts such as EMG artifacts, electrode artifacts etc, should be avoided in the EEG recording in order to get the correct results from the proposed automatic EEG interpretation system.

iii) As the automatic EEG interpretation system dealt with awake background EEG, drowsy situation of the subject during the course of EEG recording should be strongly avoided, because the records of EEG during sleep are quite different from those of wakefulness.

iv) The criteria for grading each item in the quantitative EEG interpretation was determined for subjects, aged 25-65. We can extend this system to young subjects (15-20, 20-25) and old subjects (68-80, over 80), by modifying the threshold values of each item.

v) The automatic EEG report was written in English. Following the present procedure, we can develop a method for EEG report making even in Japanese, in Korean and other languages.

If we solve the above mentioned problems, the system for combined use of the EEG report making method and automatic quantitative EEG interpretation method can be used clinically as an assistant tool for medical doctors.

5. CONCLUSION

A method for making automatic EEG report based on quantitative interpretation of awake EEG was developed. We defined all terminologies necessary for EEG report and established rules for EEG report making by analysing a relationship between EEG reports and quantitative EEG interpretations done by the qualified EEGer for 22 subjects. By combined use of the proposed method for EEG report making and the automatic quantitative EEG interpretation method, we were able to make the automatic EEG reports which were equivalent to the EEG reports written by the EEGer. As the automatic EEG report can be obtained in almost real time in actual EEG recording situation, this system will be effectively applicable to clinical hospitals as an assistant tool for physicians.

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