AUTOMATIC SCORING SYSTEM OF EEG AND QUANTITATIVE EVALUATION OF ITS VISUAL INTERPRETATION

Masatoshi **NAKAMURA***, Hiroshi **SHIBASAKI**** and Shigeto **NISHIDA***

* Department of Electrical Engineering, Saga University,
Honjomachi, Saga 840, Japan
** National Institute of Neuroscience, National Center of Neurology and Psychiatry,
Ogawahigashimachi, Kodaira 187, Japan

Abstract: A new system for automatic scoring of 'organization' of the EEG dominant rhythm was constructed and applied to 18 normal subjects and 15 patients. Organization parameters which best represented the 'organization' as judged by 5 neurologists' visual inspection were calculated and the automatic organization scoring was obtained by a linear regression of those organization parameters. Furthermore, values of the regression coefficients were used to study the characteristics of EEG interpretation by each neurologist, and this scoring technique can also be applied to the training of EEG interpretation.

1. Introduction

Observation of the dominant rhythm is of essential importance in interpreting the background activity of EEG. The term 'organization' was defined by the International Federation of Societies for Electroencephalography and Clinical Neurophysiology as a measure of the degree of the background activity (Chatrian et al. 1974). When electroencephalographers (EEGers) inspect the dominant rhythm, they usually pay attention to its wave form, amplitude, frequency, continuity, responsiveness to stimulation, location and distribution, and symmetry of each of these parameters, and then they make the final interpretation by taking all these parameters into account (American Electroencephalographic Society 1986). Therefore, the quantitative evaluation of 'organization' of the dominant rhythm is essential for automatic interpretation of the EEG background activity.

The authors previously proposed a method for quantitative analysis of 'organization' by using the optimal intensity-fitting function based on EEGs of normal subjects (Nakamura et al. 1985). In the present study, the previous method was revised and applied to EEGs of patients with various cerebral diseases. Especially, the calculation of the EEG parameter was simplified, and the combination of the EEG parameters used for the automatic organization scoring was revised, so that the scoring can be made more accurately in real time. Furthermore, this method was useful also for the quantitative evaluation of how each interpreter read the EEG record, and may be applicable even to the training of EEG interpretation.

2. Visual inspection of 'organization'

The subjects of this study were 18 healthy males aged 20-23 and 15 patients aged 20-55. Recording of EEG took place in a quiet, dimly lit room with the subjects placed in a reclining position and with the eyes gently closed. Cup electrodes were placed at O1 and O2 of the international 10-20 system, and referred to the ipsilateral ear electrode. The artifact-free EEG record of each subject, which consisted of 10 segments of 5 sec each, was digitized at a sampling rate of 50 Hz.

Five qualified neurologists visually inspected each segment of the EEG records and scored its 'organization' by using a 4-point scale: normal, 4; slightly abnormal, 3; moderately abnormal, 2; and markedly abnormal, 1. The record was blinded as to the name and diagnosis of the subject, and even as to whether the subject belonged to the normal or patient group. The organization score of each EEG record was obtained by averaging scores of 5 segments interpreted by each neurologist. Then the standard score of each record was obtained by averaging the organization scores of 5 neurologists ('standard organization score').

The standard organization score of each individual record (O1-A1) of normal subjects ranged from 1.88 to 3.92 (3.03 in average with 0.53 standard deviation). Corresponding figures for patients were 1.20 to 3.00 (2.19 in average with 0.61 standard deviation). The mean standard organization score and its standard deviation for all 33 subjects, normal and patients inclusive, were 2.65 and 0.70, respectively (Table I).

3. Automatic scoring of 'organization'

A procedure of the automatic scoring of 'organization' consists of 4 steps: calculation of EEG parameter, parameter extraction, construction of organization scoring function, and organization scoring.

3.1 Calculation of EEG parameter

The power spectra of each EEG record were calculated using the Fast Fourier Transform (FFT) method (Cooley and Tukey 1965). The power spectrum was obtained by averaging periodograms of 10

Table I The mean standard organization scores of all O1-A1 records, the mean EEG parameters for 4 different frequency bands for normal subjects, patients and overall subjects, and correlation coefficients between the organization score and the parameters.

	Standard organization scores		EEG parameters															
			S [μV^2]				S/S_T [1]				σ [Hz]				m [Hz]			
			δ	θ	α	β	δ	θ	α	β	δ	θ	α	β	δ	θ	α	β
Normal subjects (n=18)	Mean	3.03	16.30	7.23	51.18	9.04	0.22	0.09	0.57	0.13	1.05	1.19	0.88	3.03	1.83	6.21	10.27	18.30
	s.d.	0.53	9.00	5.69	41.44	3.94	0.06	0.02	0.11	0.05	0.06	0.03	0.16	0.15	0.26	0.17	0.43	0.38
	Correlation		0.50	0.53	0.79	0.40	-0.76	-0.58	0.88	-0.79	-0.09	-0.22	-0.76	0.03	0.18	0.21	-0.44	-0.29
Patients (n=15)	Mean	2.19	12.75	22.73	15.29	9.34	0.27	0.31	0.25	0.17	1.11	1.07	1.26	3.54	1.60	6.62	9.69	19.19
	s.d.	0.61	7.82	29.97	15.25	9.38	0.13	0.14	0.10	0.11	0.07	0.11	0.17	0.41	0.11	0.35	0.45	1.21
	Correlation		0.06	0.52	0.62	0.54	-0.87	0.34	0.42	0.20	0.56	-0.54	-0.40	-0.22	0.26	0.68	-0.19	-0.26
Total (n=33)	Mean	2.65	14.69	14.27	34.87	9.18	0.24	0.19	0.42	0.15	1.08	1.14	1.05	3.26	1.73	6.40	10.00	18.70
	s.d.	0.70	8.67	22.04	36.90	6.96	0.10	0.15	0.19	0.09	0.07	0.10	0.25	0.39	0.23	0.34	0.53	0.97
	Correlation		0.35	0.13	0.75	0.37	-0.77	-0.36	0.79	-0.23	-0.02	0.10	-0.75	-0.47	0.42	-0.04	0.12	-0.44

$S\alpha$, $S\alpha/S_T$, $S\delta/S_T$ and σ_α had high correlation coefficients; the former 2 parameters positive and the latter 2 negative.

segments, each segment lasting 5 sec and consisting of 256 samples. The Nyquist frequency was 25 Hz and the resolving frequency was 0.2 Hz. Features of the power spectrum were expressed as EEG parameters for each of the 4 bands; delta ($0<f<4$ Hz), theta ($4\leq f<8$ Hz), alpha ($8\leq f\leq 13$) and beta ($13<f<25$). The EEG parameters consist of the quantity of the power spectrum within the respective band S, the ratio of quantity in a specific band to the total quantity S/S_T, the frequency deviation σ and the mean frequency m.

The mean values of EEG parameters and the standard deviations for each frequency bands of O1-A1 records in normal subjects and patients are shown in Table I.

3.2 Parameter extraction

To investigate the relationship between the organization score obtained by the neurologists' visual inspection and the EEG parameters, the correlation coefficient was calculated between the standard organization scores and the respective EEG parameters. The correlation was considered significantly high if the absolute value of the correlation coefficient was close to unity. EEG parameters with the high correlation were extracted as the 'organization parameters' which would characterize the standard organization score.

The correlation coefficients between the standard organization scores and the EEG parameters are shown in Table I, and those correlations are graphically represented in Fig. 1. High correlation was found for the following 4 parameters: the ratio of quantity in the alpha band to the total quantity $S\alpha/S_T$, the ratio of quantity in the delta band to the total quantity $S\delta/S_T$, the frequency deviation in the alpha band σ_α and the quantity in the alpha band S_α (Table I, Fig. 1). The correlation coefficients for $S\alpha/S_T$ and $S\alpha$ were positive while those for $S\delta/S_T$ and σ_α were negative. As seen from Fig. 1, the optimal polynomials of the respective parameters using a measure of AIC (Akaike 1974) were proved to be linear functions for S_α/S_T, σ_α, S_δ/S_T and others. Only the parameter $S\alpha$ was optimally fitted by the second order polynomial function.

3.3 Construction of organization scoring function

For this analysis, all subjects were arbitrarily and sequentially numbered and divided into 2 groups. The data of odd numbered subjects were used for constructing an organization scoring function as the training data, and others were used for making an organization scoring as the test data.

The automatic organization scoring function was expressed by a linear regression of the normalized organization parameters z_1, z_2, ..., z_k as

$$\hat{y}=a_0+a_1z_1+a_2z_2+\cdots+a_kz_k \quad (1)$$

where a_0, a_1, ...,a_k were the regression coefficients. The parameters z_1, z_2, ..., z_k were normalized by the standard deviation of each organization parameter based on the training data. The regression coefficients were obtained by solving the normal equation from the least squares method based on the training data of the normalized organization parameters and the 'standard organization scores' by 5 neurologists. As the parameters z_1, z_2, ..., z_k were normalized, the absolute values of the regression coefficients showed an extent of contribution of each parameter to the automatic organization scoring.

The optimal function of the automatic organization scoring was selected based on the test data. Substituting the normalized organization parameters z_1, z_2, ..., z_k of each test data into the linear regression (1), we obtained an automatic organization score for respective subject. The scoring error was calculated by subtracting the automatic organization score from the 'standard

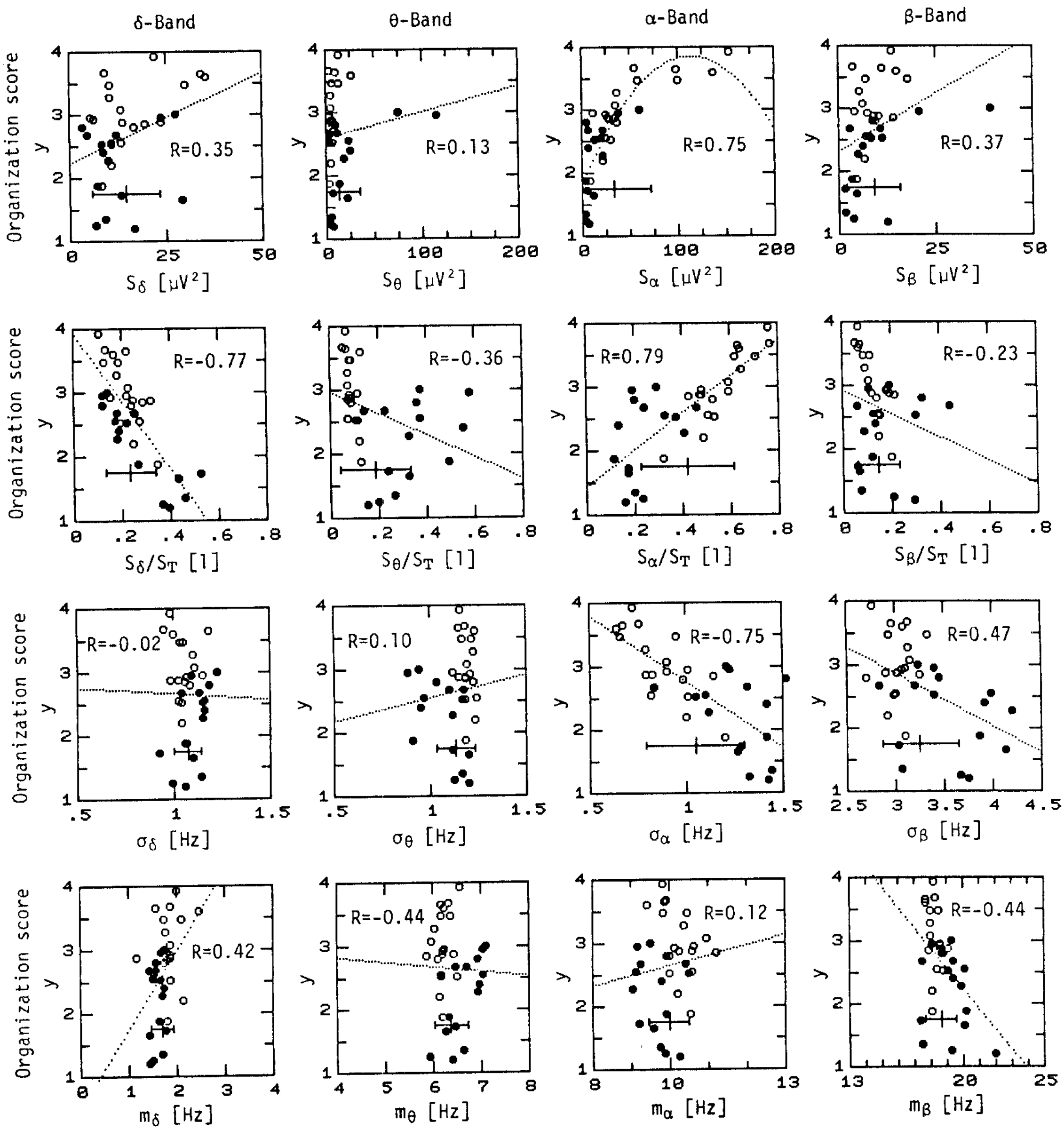

Fig. 1 Correlations between the standard organization scores (y) and the EEG parameters for 4 frequency bands : the quantity of the power spectrum S, the ratio of quantity in a specific band to total quantity S/S_T, the frequency deviation σ and the mean frequency m (○ normal subject, ● patient). The optimal polynomials of the respective EEG parameters are linear functions for all parameters except S_α for which it is the second order function. Each solid line represents the standard deviation around the mean value of the EEG parameter. The value of the R represents the correlation coefficient.

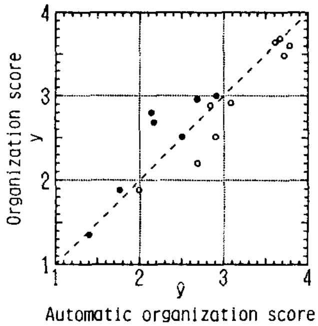

Fig. 2 The relationship between the standard organization scores (y) and the automatic organization scores calculated by the linear regression for the test data of odd numbered subjects ($\hat{y}$) :

$$\hat{y}=2.55-0.23(S_\delta/S_T)^*+0.16(S_\alpha/S_T)^* +0.47(S_\alpha)^*-0.30(S_\alpha{}^2)^*-0.16(\sigma_\alpha)^*.$$

The open dots indicate normal subjects and the closed ones patients.

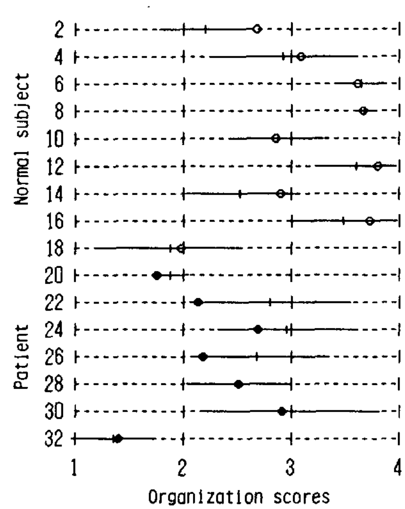

Fig. 3 The organization scores for individual subjects. The dots represent the automatic organization scores (○ normal subject, ● patient). Each solid line represents the standard deviation of the organization scores of each EEG record interpreted by 5 neurologists and the standard organization score which is an average of the 5 scores (vertical line at the center of each solid line).

organization score' by 5 neurologists. As the number of parameters in the linear regression increased, a residual of the linear regression became smaller. However, a scoring error by the linear regression for the test data did not always decrease in proportion to the number of the 'organization parameters' used for the organization scoring function. The optimal combination of the normalized organization parameters in the linear regression was determined to minimize the mean squares of the scoring errors based on the total test data.

Among a large number of possible combinations of the normalized organization parameters, the automatic organization scoring using the linear regression of S_δ/S_T, S_α, $(S_\alpha)^2$, S_α/S_T, σ_α was proved to be optimal in terms of minimum scoring error. The optimal organization scoring function was determined as:

$$\hat{y}=2.55-0.23(S_\delta/S_T)^*+0.16(S_\alpha/S_T)^*+0.47(S_\alpha)^* -0.30(S_\alpha{}^2)^*-0.16(\sigma_\alpha)^* \quad (2)$$

where asterisk represents the normalized value of each parameter.

3.4 Organization scoring

Figures 2 and 3 shows the relationship between the standard organization scores by neurologists' visual inspection (y) and the automatic organization scores by the optimal scoring function (2) based on the test data ($\hat{y}$). The automatic organization scores ($\hat{y}$) showed a good agreement with the standard organization scores (y) (Fig. 2). All automatic organization scores of the test data (open dots for normal subjects and closed dots for patients) were distributed within the range of the standard deviation of neurologists' scores which were shown as solid lines (Fig. 3). The scoring error by the automatic organization scores (ε=0.28) was smaller than the standard deviation of the 5 neurologist's scores (η=0.46).

4. Evaluation of visual EEG interpretation

To study the characteristics of EEG interpretation by each neurologist, the automatic scoring function (1) was computed based on the organization scores by each individual neurologist. The regression coefficients obtained from the organization scores of each neurologist were compared with those of the standard scores. The absolute values of the regression coefficients for each organization parameter showed the extent of the importance that each neurologist put in interpreting the 'organization' of the dominant rhythm and therefore reflected the characteristics of the interpreter.

Based on the organization scores of all subjects interpreted by each neurologist, the linear regression for each individual neurologist was computed. Among many combinations of the organization parameters, S_δ/S_T, S_α/S_T, S_α and σ_α were found to be the most important factors for organization scoring for all neurologists, although the extent of importance was different among the 5 neurologists.

5. Discussion

In the present analysis, EEG parameters were calculated from the power spectrum of EEG records of 18 normal subjects and 15 patients. Those parameters consisted of the quantity of the power spectrum S, the ratio of quantity in a specific band to the total quantity S/S_T, the frequency deviation

σ and the mean frequency m for delta, theta, alpha and beta bands, respectively. From correlation coefficients between the organization scores visually interpreted by neurologists and each parameter, the organization parameters were extracted from those EEG parameters. The automatic scoring function was defined by a linear regression of the organization parameters, and the regression coefficients were calculated by the use of least squares method based on the training data. The optimal combination of the organization parameters in the linear regression was selected to minimize the scoring error based on the test data. Those parameters were the ratio of quantity in the delta band to the total quantity S_δ/S_T, the ratio of quantity in the alpha band to the total quantity S_α/S_T, the quantity in the alpha band S_α and the frequency deviation in the alpha band σ_α. Values of the regression coefficients expressed the extent of importance of each parameter in the automatic organization scoring. In the previous work, the EEG parameters were calculated by using a rather complicated optimal intensity-fitting function and only the parameters S_α/S_T and σ_α were adopted as the organization parameters (Nakamura et al. 1985). The set of the parameters S_δ/S_T, S_α/S_T, S_α and σ_α selected in the present analysis was proved to be more accurate in the automatic organization scoring. Thus the results gave a quantitative interpretation of the organization which had been defined by the International Federation of Societies for Electroencephalography and Clinical Neurophysiology as "the degree to which physiologic electroencephalographic 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 and psychiatric disease, and other illness that might be associated with dysfunction of the brain" (Chatrian et al. 1974).

The present study was characterized by an automatic organization scoring which was performed off-line by a personal computer equipped with an analogue-to-digital converter. The EEG record was taken into the computer through the analogue-to-digital converter and the organization parameters of the EEG power spectrum were calculated by the FFT method, and then the automatic organization score was obtained by using the previously determined linear regression. As the above computation was simple, the calculation was accomplished within several seconds. This automatic organization scoring, if programmed by using DSP (digital signal processor), can be performed in real time within several milliseconds after the EEG data acquisition. Therefore, if this system is incorporated into the electroencephalograph, it might be of practical use not only for electroencephalographers and neurologists but also for physicians of other specialties who need to know the result of EEG immediately.

The regression coefficients obtained from the organization scores interpreted by each neurologist reflect the characteristics of that particular neurologist in interpreting the 'organization' of the dominant rhythm. Among others, the organization parameters S_δ/S_T, S_α/S_T, S_α and σ_α were found to be the most important factors for the organization scoring of all neurologists, although the extent of the importance varied among the 5 neurologists. This method was used for the quantitative evaluation of how each neurologist read the EEG record. Moreover, the present method can be applied to the training of EEG interpretation. For example, the regression coefficients obtained from organization scores of an EEG trainee can be compared with those of the standard organization score, so that the trainee can learn how to approach the standard scores. Furthermore, this system can be used as a self-training of EEG interpretation, although it is limited to the interpretation of the dominant rhythm.

Acknowledgment

The authors are grateful to Mr. Akio Koga (undergraduate student of Saga University) for his help in the computations used in this study.

References

[1] Akaike, H. A new look at the statistical model identification. IEEE Trans. Automatic Control 1974, AC-19, 6: 716-723

[2] American Electroencephalographic Society. Guideline Eight: Guidelines for writing EEG reports. In: Guidelines in EEG and Evoked Potentials. J. Clin. Neurophysiol., 1986, 3 (Suppl.): 34-37.

[3] Chatrian, G. E., Bergamini, L., Dondey, M., Klass, D. W., Lennox-Buchthal, M. and Petersen, I. A glossary of terms most commonly used by clinical electroencephalographers. Electroenceph. clin. Neurophysiol., 1974, 37:538-548

[4] Cooley, J. W. and Tukey, J. W. An algorithm for the machine calculation of complex Fourier series, Math. Comput., 1965, 19:297-301

[5] Nakamura, M., Nishida, S., Neshige, R. and Shibasaki, H. Quantitative analysis of 'Organization' by feature extraction of the EEG power spectrum. Electroenceph. clin. Neurophysiol., 1985, 60:84-89