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Clinical Application of Automatic EEG Interpretation: Automatic Detection of Artifacts and Vigilance Level

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Abstract

The automatic detection of artifacts and vigilance level as for pre-processing of the automatic EEG interpretation are discussed. The equations for detecting artifacts and vigilance level were determined such that they would conform to the procedures that an EEGer (one of the authors, H.S.) usually adopts for visual inspection of the actual EEG record. The automatic EEG interpretation was found to be improved by the newly developed pre-processing method even with artifact contamination or in drowsy condition of the subjects.

1. Introduction

The automatic integrative interpretation of awake background EEG, consisting of quantitative EEG interpretation and EEG report making has been developed by the authors and was presented in '90 KACC (Nakamura et al.1990) and '92 KACC (Nakamura et al. 1992a). The automatic EEG interpretation has been in good agreement with the EEGer's visual inspection for the EEG data which were selected carefully by the EEGer as for the development of the method. In applying the automatic EEG ineterpretation method to clinical use, we have encountered two problems: artifacts contamination in the EEG records and change of the subject's vigilance level during the EEG recording. The EEG records are often contaminated with artifacts such as eye blinks, EMG artifacts, electrode artifacts etc. If the EEG records were interpreted without any attention to the artifacts, some misinterpretation of the EEG records will occur. Moreover, as EEG records during drowsy condition are different from those of wakefulness, the detection of vigilance level is an important task for EEGer in interpreting awake EEGs.

This paper considered the automatic detection of artifacts and vigilance level in the pre-processing of the automatic EEG interpretation. The equations for detecting artifacts and vigilance level were determined such that they would conform to the procedures that the EEGer (H.S.) usually adopts for visual inspection of the actual EEG record. The automatic EEG interpretation was found to be improved by the newly developed pre-processing method even with artifact contamination or drowsy condition of the subjects. The developed automatic EEG interpretation with the pre-processing method will be effectively applicable to the clinical use.

2. Method

2.1 Subjects and Data Acquisition

EEGs of 32 subjects were selected from consecutive EEG records of Saga Medical School for development of the automatic EEG interpretation system and were classified into two groups A and B. EEGs of 22 subjects in group A were carefully selected by the EEGer (H.S.) so that they were awake artifact-free data, and were adopted to the development of quantitative EEG interpretation (Nakamura et al.1992b; Nakamura et al.1990). Other EEGs of 10 subjects in group B were arbitrary selected without any attention to artifact contamination nor vigilance level of the data, and were adopted to the development of the pre-processing of the EEG interpretation.

All EEGs were recorded in a quiet, dimly lit room where the subject was placed in a supine position in a bed with the eyes closed. Exploring cup electrodes were fixed to the scalp at 16 portions F_{P1}, F_3, C_3, P_3, O_1, F_{p2}, F_4, C_4, P_4, O_2, F_7, T_3, T_5, F_8, T_4 and T_6 of the international 10-20 system, and all electrodes were referenced to the ipsilateral ear electrode (A_1 orA_2). 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 at a paper speed 3cm/sec and a sensitivity of 0.5cm/50 μV.

Ten consecutive strips of EEG, each 5 sec long, were extracted from the entire records for each subject at a sampling interval of 20 msec. The time series of the EEG were input to the automatic EEG interpretation system of the personal computer NEC PC-9801 BA. Figure 1 shows a flow chart of the automatic EEG interpretation system which consists of data acquisition, pre-processing and EEG interpretation. The digital data of the EEG time series were then transformed into the Fourier components by the FFT method (Cooley and Tukey 1965), and the periodagram of each segment was obtained for each of the 16 channels as the squares of the Fourier components for each recording frequency of 0.2 Hz. The Nyquist frequency of the Fourier components was 25 Hz because of the sampling interval being 20 msec. The pre-processing of the automatic EEG interpretation consisted of automatic detection of artifacts and vigilance level.

2.2 Blink Artifacts Detection

Blink artifacts in the EEG data were visually detected by the EEGer (H.S.). Features of the blink artifacts were summarized as follows:

1. Frequency components of the blink artifacts overlap with the delta band of 0.5-4 Hz (existence property).
2. Waveforms of the blink artifacts show the maximum positive peaks symmetrically in the frontal region of the scalp (symmetry property).
3. Amplitudes of the positive peaks decrease to the central region gradually (extension property).

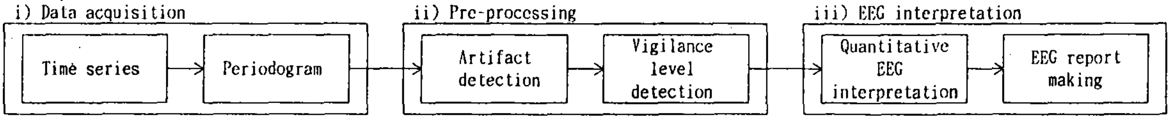


Figure 1 Automatic EEG interpretation system: data acquisition, pre-processing and EEG interpretation

Those features were expressed in the equations in Fig.2(B). Equations (1)-(2) represent the existence property, (3)-(4) correspond to the symmetry property and (5)-(8) the extension property. If the all three properties 1-3, equations (1)-(8) are fulfilled , the positive peak in the EEG record is regarded to be the blink artifact, automatically.

2.3 Vigilance Level Detection

Features of drowsy EEG record were summerized as:

1. Organization (the most important measure of the dominant rhythm: 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 and psychiatric diseases, and other illnesses that might be associated with dysfunction of the brain (Chatrian et al.1974)) of the dominant rhythm (a dominant EEG activity that consisted of waves with an approximately constant period and with the maximum amplitude at the occipital or parieto-occipital regions of the head) would be deteriorated.
2. Slow wave components would be increased in comparison with the waking record.

The equations for detecting vigilance level were determined so that they would confirm to the procedure that the EEGer usually adopts for visual inspection of the actual record, and all threshold values in the equations were determined (Nakamura et al. 1993, see equations in Fig.3).

2.4 Visual Inspection of EEG

As visual inspection of EEG was explained in detail Nakamura et al 1990, brief explanation of the visual inspection will be reviewed in this section. Ten consecutive strips of EEG, each 5 sec long, were subjected to visual inspection by the EEGer (H.S.). The 50 sec long EEG record of each subject was usually inspected and interpreted quantitatively, and then categorized into 16 items (see B1 of Fig.4 and Fig.5). 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 EEG report, the term for final integrated grading of the whole EEG appeared first and the terms for expressing abnormalities of each item succeeded afterwards (see C1 of Fig.4 and Fig.5).

2.5 Automatic Quantitative EEG Interpretation and EEG Report Making

Automatic quantitative EEG interpretation was proposed by the authors (Nakamura et al. 1990; Nakamura et al. 1992b) and the automatic report making was also developed in KACC'92 (Nakamura et al.1992a; Nakamura et al. 1993), and those methods will be described briefly.

For the automatic quantitative EEG interpretation, specific EEG parameters were determined for each item so that they could fit the graded judgment of the item by the EEGer as closely as possible (Nakamura et al, 1992b). These specific EEG parameters were actually calculated from periodograms obtained from time series of EEG records. By using the estimates of the EEG parameters and the threshold values for grading, we obtain an automatic quantitative EEG interpretation. For the automatic report making, the terminology necessary for EEG report and the rules for EEG report making were established by analysing the relationship between EEG reports and quantitative EEG interpretation done by EEGer (Nakamura et al, 1992b). The automatic EEG report can be obtained by using the defined terminology and the EEG report making rule based on the result of the automatic quantitative EEG interpretation.

3. Results

3.1 Automatic Detection of Blink Artifacts

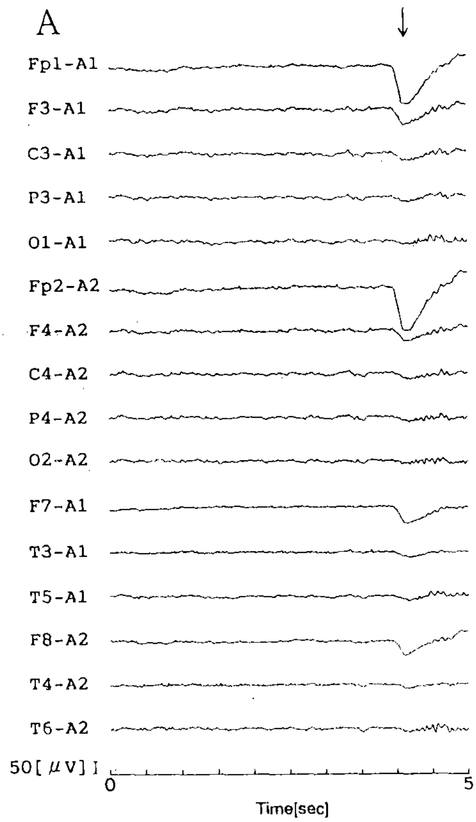
The artifacts detection method was adopted for the EEG data of all groups. Figure 2 shows the EEG data (OD15-1) contaminated with blink artifacts and its automatic detection. The time series of 5 sec long each were taking into the pre-processing system and the estimates for the blink artifacts conditions (1)-(8) were calculated. If all conditions were fulfilled for the positive peak, the final decision was then concluded that the EEG time series included the blink artifacts. The current decision making for the positive peak proved to be correct by comparing the decision done by the visual inspection of the EEGer (H.S.).

Table 1 shows the automatic detection and visual inspection of the blink artifacts for all data. Seventy eight segments out of 330 were determined by the visual inspection of the EEGer to be contaminated with the blink artifacts and 74 segments of the 78 segments (95%) were correctly detected by the automatic blink artifacts detection.

Table 1 Blink artifacts detection for EEG records of all subjects (33×10 segments)

EEGer	Automatic detection		
Detected No.	Detected No.	Undetected No.	Overdetected No.
78	74 (94.9%)	4 (5.1%)	19

A



B

Conditions for blink artifacts	Estimate	Decision
Existence of delta components		
(1) $6(S\delta(\mathrm{Fp1}))^{\frac{1}{2}} \geq 25[\mu V]$	135.25	○
(2) $6(S\delta(\mathrm{Fp2}))^{\frac{1}{2}} \geq 25[\mu V]$	156.04	○
Symmetry of the waveform		
(3) $6(S\delta(\mathrm{Fp1+Fp2}))^{\frac{1}{2}} \geq 50[\mu V]$	291.09	○
(4) $\frac{6(S\delta(\mathrm{Fp1-Fp2}))^{\frac{1}{2}}}{6(S\delta(\mathrm{Fp1+Fp2}))^{\frac{1}{2}}} \times 100 \leq 55[\%]$	8.12	○
Extension to central region		
(5) $\frac{6(S\delta(\mathrm{F3}))^{\frac{1}{2}}}{6(S\delta(\mathrm{Fp1}))^{\frac{1}{2}}} \times 100 \leq 85[\%]$	43.62	○
(6) $\frac{6(S\delta(\mathrm{F4}))^{\frac{1}{2}}}{6(S\delta(\mathrm{Fp2}))^{\frac{1}{2}}} \times 100 \leq 85[\%]$	26.55	○
(7) $\frac{6(S\delta(\mathrm{C3}))^{\frac{1}{2}}}{6(S\delta(\mathrm{Fp1}))^{\frac{1}{2}}} \times 100 \leq 78[\%]$	23.12	○
(8) $\frac{6(S\delta(\mathrm{C4}))^{\frac{1}{2}}}{6(S\delta(\mathrm{Fp2}))^{\frac{1}{2}}} \times 100 \leq 78[\%]$	14.46	○
Automatic detection		○
EEGer's visual detection		○

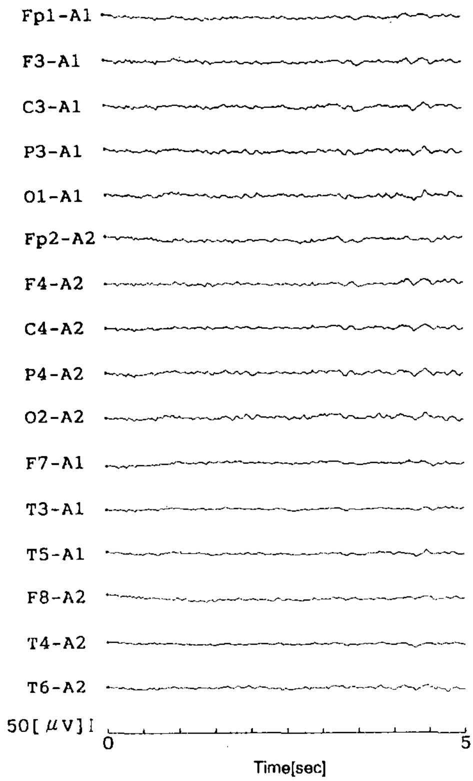
Figure 2 Blink artifact detection for EEG record (OD15). A, the EEG time series of 5 sec long contaminated with blink artifact(arrow). B, the conditions for the blink artifacts detection. The conditions consist of three properties; existence of the delta components, symmetry of the waveforms and extension to central region. In the equations of (1)-(8), $6\sqrt{S\delta}$ represents the amplitude of a delta wave(Nakamura et al. 1986), $S\delta$ is the summation of the squared Fourier components in the frequency band (0.5-4Hz) and the symbol with in the parentheses after $S\delta$ represents the portion of the electrodes on the scalp.

3.2 Automatic Detection of Vigilance Level

The method for vigilance level detection was adopted for the all EEG data. Figure 3 shows two segments of the EEG (OD19-4) and a table for the result of automatic vigilance level detection. The vigilance level were determined based on 10 segments (50 sec long) of the EEG record of each subject. The table in Figure 3 showed that the all conditions of drowsiness were fulfilled and the final decision of the vigilance level was drowsy record. The above automatic decision making procedure agreed with the decision of the visual inspection done by the EEGer (H.S.). All results of the automatic vigilance level detection for 32 subjects completely coincided with the visual inspection for total judgement of each subject. The segmental judges (318) out of 320 also coincided with ones done by the EEGer.

3.3 Automatic EEG Interpretation (Artifact Free Record)

The automatic EEG interpretation with the preprocessing of artifacts detection and vigilance level determination were adopted to the EEG data of all subjects. Figure 4 shows the EEG time series (EEG-11) of 2 segments out of 10 segments and its interpretation. B shows the quantitative interpretation for 16 items and C shows the corresponding EEG report of sentence style. Both B and C include the visual inspection and the automatic interpretation. Later part of the automatic EEG report shows 'artifacts free record' and 'waking record'. These remarks represent that the EEG records of this subject were judged to be artifact free data by the automatic artifacts detection, and to be waking record through the method of vigilance level determination. Those decisions were the same as ones done by the EEGers (H.S.). In the table B of the quantitative EEG interpretation, all scores of each item of the automatic interpretation coincided with ones by the EEGer, except for the duration of the theta rythm. The difference of the score 2 and 1 of the theta rhythm duration was small enough for the final integrative judgement of the EEG. The automatic EEG report was made based on the scores in the table B. The final integrative judgement shows 'marked abnormal record' which coincides with one in the EEGer's report of C1. The explanations of the judgments after the final integrative judgement (1), (2), (3) in the automatic EEG report proved to be

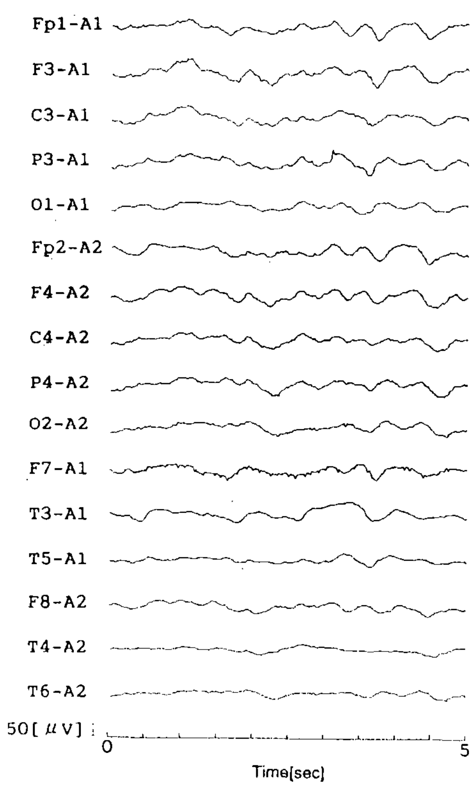


(Subject: OD19)

		Segment 1	2	3	4	5	6	7	8	9	10
I	i) $\sigma_a = (\sum_{n=1}^{10}(6(S\alpha(n))^{1/2} - \bar{x})^2/10)^{1/2}$ $\sigma_a \geq 4.0[\mu V]$	○									
I	ii) $6(S\alpha(n))^{1/2}/6(S\alpha(n-1))^{1/2} \leq 1.0$ (w→d) $6(S\alpha(n))^{1/2}/6(S\alpha(n-1))^{1/2} \leq 0.8$ $6(S\alpha(n))^{1/2}/6(S\alpha(n-1))^{1/2} \leq 1.55$ (d→w)	○	○	○	○	○	○	○	○	○	○
I	iii) $y = 0.49 + 0.58\sigma_\alpha - 0.013 S\alpha + 4.82\times10^{-3}(S\alpha)^2 - 0.41 S\alpha/S_T + 3.12 S_D/S_T$ $y \geq 1.6$ or Lack of dominant rhythm	○	○	○	○	○	○	○	○	○	○
II	iv) $\sigma_f = (\sum_{n=1}^{10}(f_a(n) - \bar{f})^2/10)^{1/2}$ $\sigma_f \geq 0.70[Hz]$	○									
II	v) θ: $6(S\theta)^{1/2} \leq 19[\mu V]$	○	○	○	○	○	○	○	○	○	○
II	v) δ: $11 \leq 6(S\delta)^{1/2} \leq 29[\mu V]$	○	○	○	○	○	○	○	○	○	○
II	vi) $y = 0.49 + 0.58\sigma_\alpha - 0.013 S\alpha + 4.82\times10^{-3}(S\alpha)^2 - 0.41 S\alpha/S_T + 3.12 S_D/S_T$ $y \geq 1.6$ or Lack of dominant rhythm	○	○	○	○	○	○	○	○	○	○
Auto	Segmental judgement	d	d	d	d	d	d	d	d	d	d
Auto	Total judgement	Drowsy									
EEGer	Segmental judgement	d	d	d	d	d	d	d	d	d	d
EEGer	Total judgement	Drowsy									

Figure 3 Vigilance level detection for EEG record (OD19). A, two segments of the EEG time series out of 10 segments (50 sec long). B,the conditions of drowsyness and their decisions for the EEG record. The conditions consists of two parts. (I). Decision of the mixture of waking segments and drowsy segments in the total 10 segments or not. (II). Decision of the waking record or the drowsy record. In the equations, $6\sqrt{S}$ represents the amplitude , and the subscript of S represents the respective rhythm.

A



(Subject: EEG11) B 1 B 2

No.	Items	EEGer Estimate	EEGer Score	Automatic Estimate	Automatic 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	7.4	0
10	Asymmetry[%]	0	0	68.0	0
	Theta rhythm				
11	Duration [%]	10	2	1.6	1
12	Electrodes	diffuse.		F_{p1}, F_3, P_3, F_{p2}, F_4, P_4	
	Delta rhythm				
13	Duration [%]	90	3	69.5	3
14	Electrodes	diffuse.		$F_{p12}, F_{3478}, C_{34}$, P_{34}, O_{12}, T_{356}	
	Non-dominant alpha rhythm				
15	Duration [%]	0	0	0.0	0
16	Electrodes	– – –		– – –	

C 1 EEGer's report

Markedly abnormal record

because of

(1)lack of dominant rhythm.
(2)continuous, irregular and occasionally rhythmic δ waves diffusely. and
(3)occasional triphasic waves.

C 2 Automatic EEG report

Markedly abnormal waking record

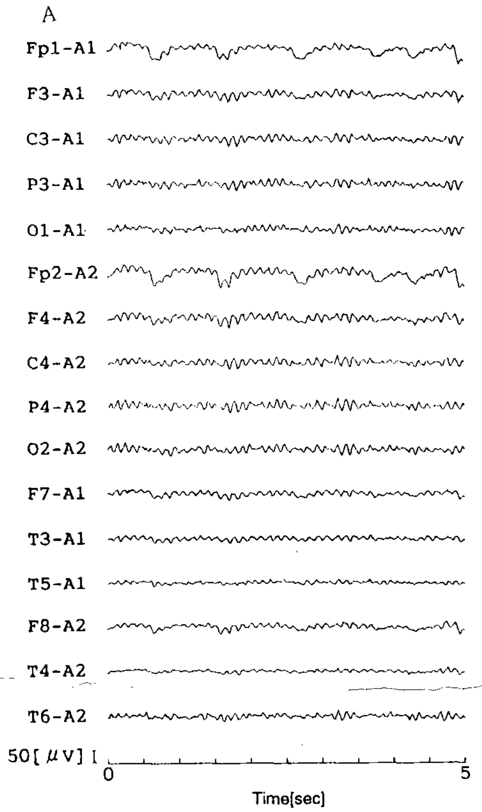
because of

(1)lack of dominant rhythm.
(2)occasional θ waves anteriorly, and
(3)continuous, rhythmic δ waves diffusely, more on the left frontal region.

[Artifact detection]
Artifact free record

[Vigilance level]
Waking record

Figure 4 EEG record (EEG11) and its EEG interpretation. A, time series of 5 sec long out of 50 sec record. B, the quantitative interpretation for 16 items. C, the corresponding EEG report of sentence style.



(Subject: OD16) B 1 B 2

	Items	EEGer Estimate	EEGer Score	Automatic Estimate	Automatic Score
	Dominant rhythm				
1	Existence	Yes	0	Yes	0
2	Organization	Mild. ab.	1	0.9	1
3	Asymmetry[1]	0	0	0.2	0
4	Frequency[Hz]	9.5	0	9.2	0
5	Asymmetry[Hz]	0	0	0.1	0
6	Amplitude[μV]	40	0	31.7	0
7	Asymmetry[%]	0	0	20.0	0
8	Extension[μV]	Fp. AT	2	8.3	0
	Beta rhythm				
9	Amplitude[μV]	5	0	10.3	0
10	Asymmetry[%]	0	0	20.2	0
	Theta rhythm				
11	Duration [%]	4	1	3.6	1
12	Electrodes	indefinite		$F_{p1,2}, F_{3,4}, C_3, P_4, O_2$	
	Delta rhythm				
13	Duration [%]	0	0	0.0	0
14	Electrodes	---		---	
	Non-dominant alpha rhythm				
15	Duration [%]	0	0	21.1	1
16	Electrodes	---		$F_4, C_{3,4}, P_{3,4}, O_{1,2}, T_{3,4}$	

C 1 EEGer's report

Mildly abnormal record

because of

(1)poorly organized background activity.
(2)too anteriorly extended α rhythm.
(3)occasional θ waves diffusely.

C 2 Automatic EEG report

Mildly abnormal waking record

because of

(1)poorly organized background activity.
(2)occasional θ waves bianteriorly, and
(3)occasional waves of α frequency posteriorly.

[Artifact detection]
Blink artifacts were present in the following segments(1, 2, 3, 4, 5, 6, 7, 8, 9, 10), and were taken into account in the interpretation.

[Vigilance level]
Waking record

Figure 5 EEG record (OD16) and its EEG interpretation. The format of the figure is the same as that of Figure 4.

equivalent to ones in EEGer's report, except for the findings of 'triphsic waves'.

3.4 Automatic EEG Interpretation (Blink Artifacts Contaminated Record)

Figure 5 shows another EEG record (OD16) and its interpretation. Findings of the artifacts and the vigilance level in the automatic EEG report indicated 'blink artifacts were present' and 'waking record'. These findings agreed with ones done by the EEGer. Both the automatic scores in the quantitative EEG interpretation and the automatic EEG report were almost equivalent to those done by the EEGer. Small difference existed in the extension of the dominant (EEGer) and the non-domonant alpha rhythm (automatic). However, the above differences were small enough in the final integrative decision of the EEG interpretation. Importance of the blink artifact detection in the interpretation of the EEG record will be discussed in the next Discussion chapter.

4. Discussion

4.1 Artifacts Detection

In spite of an effort of eliminating artifacts contamination in the EEG recording, we often inevitably encounter the contamination of blink artifacts, EMG artifacts electrode artifacts, body movement artifacts etc. Out of many kinds of artifacts , the blink artifacts often occur and cause trouble in the EEG interpretation, if we do not care the blink artifacts contamination. This study mainly concentrated on development of the blink artifacts detection method. The method for blink artifact detection was tested for the 32 data and showed satisfactory accuracy in the automatic detection as shown in Table 1.

We had implemented an automatic EEG interpretation without the blink artifacts detection for the same data of Fig.5 (OD16). The score of the delta rhythm in the above automatie EEG interpretation was 3 instead of 0, and the final integrative decision of the EEG became 'moderately abnormal' instead of 'mildly abnormal'. This misinterpretation was caused by the blink artifacts which were treated as the delta rhythm. The importance of the blink artifacts detection for the EEG interpretation was proved by the comparison between the EEG interpretation with artifact detection and one without artifact detection.

The detection method for artifacts other than blink artifacts was constructed as the similar procedure of the blink artifact detection: equations for detecting EMG artifacts, electrode artifacts were determined so that they would conform to the procedures that the EEGer usually adopts EEG record. Those equations for the detection were applied to the all EEG data and gave satisfactory accuracy in the detection of each artifact. However, those detection did not change final integrative decision of the EEG interpretation. The results show that the adopted EEG record did not contaminated with large artifacts other than blink artifacts.

4.2 Vigilance Level

Automatic detection of sleeping stage(Rechtschaffen and Kales, 1968) through sleep EEG interpretation have been actively investigated (Smith et al. 1978). However, as drowsyness of the EEG record for the awake EEG interpretation is too slight in the sleeping stage, the detection of the sleeping stage does not work in the detection of the vigilance level in this study. There are few researches of the vigilance level detection except for a report (Kawana et al.,1993) which aimed at detection of the vigilance level of car drivers. In detecting the vigilance level of car drivers, they used not only EEG record but also EOG and sweat measurement in parallel. The uniqueness of the proposed method for the vigilance level was that the decision making of the vigilance level was done based on the EEG record only, because the main objective of this study is the improvement of the automatic interpretation of awake EEG.

We had applied the automatic EEG ineterpretation without the vigilance level detection for the EEG data of drowsy record in Fig. 3 (OD19). The automatic EEG interpretation gave mis-decision of 'markedly abnormal record' to the EEG data (OD19) which were normal light sleep records. The mis-interpretation was caused by the EEG interpretation without consideration of the vigilance level of the EEG record. The automatic detection of the vigilance level gave the correct decission of 'drowsy record' for the EEG record. The importance of the vigilance level detection as for the pre-processing of the awake EEG interpretation was proved by the above mentioned results.

4.3 Clinical Application

The automatic EEG interpretation system consisted of data acquistion, pre-processing of artifact detection and vigilance level detection, and the EEG interpretation. The EEG interpretation was remarkably improved by introducing the pre-processsing procedure. The automatic EEG interpretation system was adopted to the EEG data of 32 subjects and gave satisfactory results. However, more detailed interpretation , such as waveform of triphasic one in (EEG11), paroxysmal burst, are not taken into account at this stage. The integrative interpretation of awake EEG is so complex and deep one, and the automatic EEG interpretation system developed in this stage has rooms for improvement from now on. However, the automatic EEG interpretation system of the current version can be used clinically as assistant tool for medical doctors.

5. Conclusion

As for pre-processing procedure for the automatic integrative interpretation of awake background EEG, the automatic detection of artifacts and vigilance level of the EEG record were developed. All equations for the detection were derived so that they would conform to the procedure that the EEGer adopts for visual EEG inspection. The automatic EEG interpretation system was improved by accompanying the proposed pre-processing procedure, and gave satisfactory interpretation results for the EEG data even with artifacts or in the drowsy condition of the subjects. The automatic EEG interpretation would be applicable in the clinical use as an assistant tool for EEGers and physicians.

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