Proceedings of the 17th World Congress
The International Federation of Automatic Control
Seoul, Korea, July 6-11, 2008

Automatic EEG Arousals Detection for Obstructive Sleep Apnea Syndrome

Takenao Sugi * **Fusae Kawana** ** **Masatoshi Nakamura** ***

* *Department of Electrical and Electronic Engineering, Saga University, Saga 840-8502, Japan (e-mail: sugi@cntl.ee.saga-u.ac.jp).*
** *Department of Clinical Physiology, Toranomon Hospital, Tokyo, Japan*
*** *Department of Advanced Systems Control, Saga University, Saga 840-8502, Japan*

Abstract: EEG arousals are seen in EEG records as awakening response of human brain. Obstructive sleep apnea (OSA) is one of serious sleep disorders. Sevier OSA brings about EEG arousals and sleep of patients with OSAS is frequently interrupted. Number of respiratory-related arousals during the whole night PSG recordings is directly concerned with the quality of patients' sleep. Therefore, to detect EEG arousals in PSG record is significant task for clinical diagnosis. In this paper, the method for automatic detection of EEG arousals was proposed. In order to detected respiratory-related arousals effectively, threshold values were determined according to the pathological events as sleep apnea and EMG. If the resumption of ventilation (end of apnea) was detected, lower thresholds were adopted for detecting EEG arousals including relatively doubtful arousals. On the other hand, threshold maintains high when the pathological events were not detected. Proposed method was applied to the data of eight patients with OSAS, and accuracy of EEG arousals detection was verified by comparing the visual inspection. Effectiveness of the proposed method in clinical diagnosis was investigated.

1. INTRODUCTION

Disorders of sleep apnea syndrome (SAS) have several episodes as obstructive sleep apnea syndrome (OSAS), central sleep apnea syndrome (CSAS) and their mixtures (mixed apnea), and obstructive sleep apnea (OSA) is most major episode in SAS (Chokroverty [1999]). OSAS, which is a symptom of upper airway closure in patients during sleep, is one of serious disorders. OSA causes interruption of sleep period frequently during night, so the patients can not take a good sleep and always feel daytime sleepiness. Such interruption of sleep period by OSA can be seen as awakening responses in the electroencephalographic (EEG) records, and the response are called EEG arousals. Usually in the hospital and/or clinics, polysomnographic (PSG) test is done for clinical diagnosis on sleep disorders. To grasp the relationship between sleep apnea and appearance of arousal responses is most important in the diagnosis on SAS. To interpret the EEG arousals from the long lasting PSG record is laborious and time consuming task for medical doctors and medical technologists. Therefore, the computer assisted system for detecting EEG arousals will be the powerful aid in the clinical scene from the view point of efficiency and burden.

Studies on automatic analysis for sleep EEG such as automatic sleep staging have been done by many researchers in the past. Concerning the automatic detection of EEG arousals, many studies have already been proposed (Pillar et al. [2002], Pitson et al. [2006]). However, actual clinical PSG include various noise components and characteristics EEG and other physiological data have different for each subject. Hence, the satisfactory method usable in the clinical diagnosis aid has not existed yet.

In this paper, the method for automatic detection of EEG arousals for OSAS is proposed. EEG arousals appear in the EEG record by the several reasons such as OSAS, CSAS, periodic limb movement (PLM) and so on, and the rate of patients with OSAS is major as compared with other diseases. Thus, the proposed automatic detection method aimed at the detection of respiratory-related arousals, especially for OSA. The method was developed by using the PSG data recorded from patients with OSAS. Parameters were constructed based on the characteristics and definitions of EEG arousals (ASDA [1992]), and were obtained from the periodograms by the FFT method. In order to detect EEG arousals with airway reopening, respiratory state was taken into account for determining the threshold values of EEG arousals detection. In addition to the respiratory state information, chin-electromyogram (EMG) and tibialis-EMG were also considered in the automatic detection. Proposed method was applied to the data of eight patients with OSAS recorded at Toranomon hospital. Usefulness and accuracy of the proposed method were investigated.

2. METHOD

2.1 Data acquisition

Whole night PSG recording was done at the Department of Clinical Physiology, Toranomon Hospital. Eight men patients, aged from 46 to 58, were diagnosed as OSAS as principal symptom. As PSG information for each subject, four channels of EEG (C3-A2, C4-A1, O1-A2, O2-A1), chin-EMG, horizontal and vertical electrooculogram (EOG), electrocardiogram (EKG), tibialis-EMG, pressure changes of airflow in nostril by cannula, temperature changes of airflow at nostril and mouth by thermistor, blood-oxygen saturation, thoracic and abdominal motion, and body position were simultaneously recorded as PSG data. From the whole PSG data, four channels of EEG were used for detecting EEG arousals, pressure changes and temperature changes of airflow were utilized for detecting respiratory state on sleep apnea, and two EMG (chin-EMG and tibialis-EMG) were also employed as supplemental information. Data except EEG were used as for determining the threshold values of EEG arousals detection. Recording conditions concerning the sampling frequency, time constant of low-cut filter and high-cut frequency were set at 100 Hz, 0.3s, 30 Hz for EEG, 200 Hz, 0.003 s, 70 Hz for EMG and 12.5 Hz, 1 s, 3 Hz for airflow changes (pressure and temperature). The above recorded data were stored into the computer and automatic detection was executed. One-fourth of total data were used in order to develop the method as determining the parameters, threshold values and so on. Verification of the method was examined by all data of eight patients.

2.2 EEG arousals in PSG records

Definition concerning EEG arousals was instituted by American Sleep Disorders Association (ASDA) report (ASDA [1992]). Principal features of EEG arousals in the time series were two; appearance of arousal response longer than 3 seconds and existence of sleep period at least longer than 10 seconds immediately before the arousal responses (see Fig.2 as typical EEG arousals by apnea). Except the above two definitions, more characteristics were defined in the ASDA report. However, two definitions are most fundamental ones, so the proposed method also considered the two key features. In the clinical diagnosis, arousal responses concerned with pathological factors are regarded as significant information, but ones not concerned with any pathological factors have less meaning. Therefore, to distinguish the respiratory-related arousals, which appear by pathological sleep apnea, and non-respiratory-related arousals (spontaneous arousals) are important in the diagnosis. In the visual inspection of EEG arousals, existence of pathological factors such as sleep apnea, periodic limb movement (PLM) and rapid increase of EMG are taken into account in the interpretation. I case of the inspection for OSA, inspector carefully examines around the time occurring the resumption of ventilation (end of apnea period). Proposed method was constructed in accordance with the features of the arousal response in EEG record and the manner of the visual inspection of PSG for patients with OSAS.

2.3 Whole flow of automatic detection of EEG arousals

The method for automatic EEG arousals detectionconsists of four procedures; data acquisition, parameters calculation, detection of pathological events and detection of EEG arousals. At first, in the data acquisition part, PSG data was stored into computer and were segmented. Periodograms of segmented time series were then obtained by the FFT method. Next, in the parameter calculation part, characteristic parameters for detecting EEG arousals and pathological events such as sleep apnea and increase of EMG amplitude were calculated from the periodograms information. All the characteristic parameters were normalized their values for reducing the variability of parameters among different subjects. Then, in the part on detection of pathological events, resumption of ventilation (end of apnea interval), increase of chin-EMG and increase of tibialis-EMG were detected from the data except for EEG time series. Threshold values for detecting EEG arousals were then determined according to the state of detected pathological events. Finally, in the part on detection of EEG arousals, appearance of arousal response in EEG record was judged by the parameters and selected threshold values. Detected EEG arousals were classified into the respiratory-related arousals and non-respiratory-related arousals.

2.4 Parameters calculation

In the proposed method, EEG, pressure and temperature of airflow changes, chin-EMG and tibialis-EMG were used for the detection of EEG arousals and the determination threshold values. Sampling interval and events to be detected were different for respective time series information, thus the segmentation of time series were adequately settled independently for them. Figure 1 shows the data segmentation of PSG record for EEG arousals detection. Duration of arousal response in EEG record was at least longer than 3 seconds in the definition, so the automatic detection was executed 1.28 seconds interval for continuous PSG data. For EEG and EMG data, they were segmented at 2.56 sec long. Frequency resolution was about 0.4 Hz due to the data length (2.56 s) and those values were appropriate for analyzing background EEG activities. For respiratory data (pressure and temperature of airflow changes), 10.24 seconds was adopted as segmentation length, because the definition of the duration of obstructive apnea was ten seconds at least. Frequency resolution for respiratory data was about 0.1 Hz and the value was enough for analyzing respiratory state changes. Characteristic parameters described in the next paragraph were calculated from the segmented data shown in Fig.1. Time series except for EEG were used for detecting pathological events such OSA and others. Detected events were then utilized for determining the threshold values of EEG arousals detection. In this study, the main purpose was to detect arousal response concerned with OSA. Respiratory-related arousals due to OSA occur as phenomena with

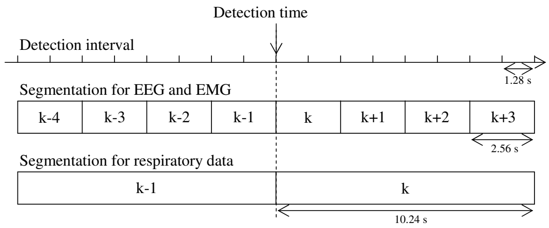

Fig. 1. Segmentation of PSG time series. PSG data was separated to segments with 2.56 sec long and 10.24 sec long according to the characteristic of waveform.

airway reopening in EEG time series. Therefore, two respiratory-related information; pressure and temperature of airflow changes; were used for detecting the resumption of ventilation from apnea. In addition to the respiratory information, chin-EMG and tibialis-EMG were also used as supplemental pathological information. All the parameters for detecting pathological events were summarized as amplitudes and their variability. In this study, mean amplitude of one segmented data k was obtained from the summation of periodograms, and was defined as $A(k) = 6\sqrt{S(k)}$. $S(k)$ shows summation of periodograms for established frequency range, and $A(k)$ represents mean amplitude of the segment k. Expression of $6\sqrt{S(k)}$ as amplitude was theoretically and empirically determined in the past study (Nishida et al. [1986]). First of all, parameters on respiratory state changes were explained. For airflow pressure, amplitudes for the forward section and backward section of detection time in Fig.1 were obtained as

$$A_{PF}^{FW}(k) = 6\sqrt{S_{PF}(k)} \tag{1}$$

$$A_{PF}^{BW}(k) = 6\sqrt{S_{PF}(k-1)} \tag{2}$$

where, $S_{PF}(k)$ represented the sum of periodograms of all frequency range. Then, ratio of amplitudes between forward section and backward section was defined as

$$R_{PF}^{A}(k) = \frac{A_{PF}^{FW}(k)}{A_{PF}^{BW}(k)} \tag{3}$$

The above three parameters were adopted as for detecting the resumption of ventilation. For airflow temperature, similar parameters in airflow pressure were obtained as $A_{TF}^{FW}(k)$, $A_{TF}^{BW}(k)$ and $R_{TF}^{A}(k)$. Meaning of those parameters obtained from airflow temperature were; $A_{TF}^{FW}(k)$ as amplitude for forward section, $A_{TF}^{BW}(k)$ for backward section and $R_{TF}^{A}(k)$ as their ratio. EEG arousals are the phenomenon that can be seen in EEG time series, so all the parameters for detecting EEG arousals were calculated from four channels of EEG; C3-A2, C4-A1, O1-A2 and O2-A1. In case of EEG, summation of periodograms was obtained for individual frequency bands as; $S_L(i,k)$ for less than 2 Hz, $S_T(i,k)$ for 0.5 - 25 Hz (sum of background activity from δ to β band), $S_\alpha(i,k)$ for 8 - 13 Hz, $S_\beta(i,k)$ for 13 - 25 Hz and $S_H(i,k)$ for 25 - 50 Hz. Where, i corresponds to four EEG channels from C3-A2 to O2-A1. Amplitude of each frequency band was defined as mean amplitude of four channels as

$$A_j(k) = \frac{1}{4}\sum_i 6\sqrt{S_j(i,k)} \tag{4}$$

$$i = C_3, C_4, O_1, O_2$$

$$j = L, T, \alpha, \beta, H$$

In addition to the parameters on amplitude, duration of α and β band, and central-frequency of EEG activity were calculated in the following equations as

$$D_\alpha(k) = \frac{1}{4}\sum_i (\frac{S_\alpha(i,k)}{S_\alpha(i,k)} \tag{5}$$

$$D_\beta(k) = \frac{1}{4}\sum_i (\frac{S_\beta(i,k)}{S_\beta(i,k)} \tag{6}$$

$$F_T(k) = \frac{1}{4}\sum_i \frac{\sum_h P(i,h\Delta f)\dot{h}\Delta f}{\sum_h P(i,h\Delta f)} \tag{7}$$

$$i = C_3, C_4, O_1, O_2$$

The above fundamental parameters on amplitude, duration and central-frequency of EEG were calculated for each segment. Then, characteristic parameters used as for detecting EEG arousals were constructed. Amplitude of background EEG activity (0.5 - 25 Hz) for forward section $A_T^{FW}(k)$ and backward section $A_T^{BW}(k)$ were obtained as follows

$$A_T^{FW}(k) = \frac{1}{2}(A_T(k) + A_T(k+1)) \tag{8}$$

$$A_T^{BW}(k) = \frac{1}{4}\sum_{n=k-4}^{k-1} A_T(n) \tag{9}$$

Amplitudes for another frequency bands for both forward section and backward section were calculated as same procedure. Actually, following parameters were obtained; $A_\alpha^{FW}(k)$ and $A_\beta^{FW}(k)$ for forward section, and $A_L^{BW}(k)$ and $A_H^{BW}(k)$ for backward section. In addition to them, three parameters $R_T^A(k)$, $R_\alpha^A(k)$ and $R_\beta^A(k)$ were adopted for the ratio of EEG amplitude between forward section and backward section. Characteristic parameters on duration for two sections were defined as same as those on amplitude. Totally, three parameters $D_L^{BW}(k)$, $R_\alpha^D(k)$ and $R_\beta^D(k)$ were used for the detection. As same manner, $F_L^{BW}(k)$ and $R_T^F(k)$ were employed as parameters concerning central-frequency of EEG. Properties of EEG and other data are different for the subjects. In particular, amplitude of EEG has large variability for individual subjects. Such kind of property differences among subjects often causes deterioration of accuracy for the automatic detection. In order to avoid such deterioration, normalization procedure was done for all characteristic parameters for reducing the differences among subjects' property. Actually, normalized parameters were obtained as to divide mean value of whole segmented parameters into each parameter. For example, normalized parameter on amplitude of background activity for forward section $\overline{A_T^{BW}}(k)$ was calculated by

$$\overline{A_T^{BW}}(k) = A_T^{BW}(k) / \frac{1}{N}\sum_{n=1}^{N} A_T^{BW}(n) \tag{10}$$

where, N is number of available data in whole record in a subject. Other characteristic parameters for EEG and except for EEG were converted to the normalized ones by completely same way as equation (10).

2.5 Detection of pathological events

In order to determine the threshold values for detecting EEG arousals, events related to the pathological factor, which brings on the arousal responses in EEG record, were automatically detected. Main purpose of this study is to detect respiratory-related arousals for patients with OSAS, accordingly the resumption of ventilation from apnea was mainly detected. Rapid increase of EMG was supplementally detected for determining threshold values. Obstructive apneas are characterized by the total cessation of airflow at the nose and mouth, lasting at least 10 seconds. During the cessation of airflow, waveforms of airflow pressure and airflow temperature are almost flat, and after the resumption of ventilation from the apnea, rhythmic breathing can be seen in the waveform. Parameters for detecting resumption of ventilation were employed by taking account of such characteristics of respiratory information on patients with OSAS. Parameters and their threshold values for detecting the resumption of ventilation were described as (a-1) and (a-2) in Table 1. Table 1 (a-1) was the condition for airflow pressure and (a-2) was that for airflow temperature. Three items; increase of amplitude, amplitude after apnea and existence of apnea; were adopted as characteristics for the resumption of ventilation. Threshold values were determined by using the training data, which were randomly selected from all the data used in this study. If either of the conditions (a-1) or (a-2) were satisfied, then the existence of resumption of ventilation was recognized at the time. Threshold values for detecting

Table 1. Parameters and threshold values for detecting events on sleep apnea. In order to detect EEG arousals with airway reopening, resumption of ventilation was detected.

(a-1) Resumption of ventilation (airflow pressure)

Items	Parameters	Thresholds
Increase of amplitude	$\overline{R^A_{PF}(k)}$	≥ 2
Amplitude after apnea	$\overline{A^a_{PF}(k)}$	≥ 1.3
Existence of apnea	$\overline{A^s_{PF}(k)}$	≤ 0.5

(a-2) Resumption of ventilation (airflow temperature)

Items	Parameters	Thresholds
Increase of amplitude	$\overline{R^A_{TF}(k)}$	≥ 6
Amplitude after apnea	$\overline{A^a_{TF}(k)}$	≥ 0.7
Existence of apnea	$\overline{A^s_{TF}(k)}$	≤ 0.5

EEG arousals were determined based on the results of pathological events detection. In the visual inspection of EEG arousals for patients with OSAS, medical doctor and/or medical technologists inspect time series carefully if the resumption of ventilation from the apnea was seen. EEG arousals allied with pathological factors such as obstructive apnea have significant meaning in the clinical diagnosis. In contrast, EEG arousals not allied with pathological factors have clinically less meanings, so such spontaneous arousal responses are sometimes not counted in the visual inspection. In the proposed method, threshold values were determined as four grades by taken into account the results of pathological events detection. Relationship between threshold values and pathological events were shown in Table 2. Threshold sets T1 was the lowest values and T4 was the highest ones. If both the resumption of ventilation and rapid increase of EMG were simultaneously detected at the same detection time, the lowest threshold sets T1 was adopted for EEG arousals detection. In case that only the resumption of ventilation was detected, next smaller threshold sets T2 was employed. Inversely, highest threshold sets T4 was selected only for detecting clear arousal responses when there were no pathological events at the time.

Table 2. Relationship between threshold values and detected events. Threshold level was settled at four grades. Lower thresholds T1 and T2 were adopted when the resumption of ventilation was detected.

(a) Resumption of ventilation	Yes		No	
(b) Rapid increase of EMG	Yes	No	Yes	No
Thresholds	T1	T2	T3	T4

2.6 Detection of EEG arousals

Principal features of EEG arousals in EEG records were two; existence of sleep period at least longer than 10 seconds immediately before the arousal response and appearance of arousal response at least longer than 3 seconds. Judgment items and parameters were constructed by considering the above definitions. As for judging the existence of sleep period, parameters corresponding to the characteristics of sleep EEG were adopted. In general, characteristics of EEG in the state of light sleep were slower frequency and increase of slow components as compared with characteristics for awakening state of EEG. Accordingly, parameters shown in Table 3 a) were employed. The condition was not only for detecting arousal response but also for detecting sleep period, thus

Table 3. Parameters and thresholds for detecting EEG arousals. Threshold values for appearance of EEG arousals were determined according to the detected events.

a) Existence of sleep period

Items	Param.	Thresholds
Amplitude during sleep	$\overline{A^s_L(k)}$	≥ 1.0
	$\overline{A^s_T(k)}$	≤ 0.9
	$\overline{A^s_H(k)}$	≤ 0.7
Duration during sleep	$\overline{D^s_L(k)}$	≥ 0.7
Frequency during sleep	$\overline{F^s_L(k)}$	≤ 0.7

b) Appearance of arousal response

Items	Param.	Thresholds T1	T2	T3	T4
Increase of amplitude	$\overline{R^A_\alpha(k)}$	≥ 1.1	≥ 1.2	≥ 1.3	≥ 1.5
	$\overline{R^A_\beta(k)}$	≥ 1.1	≥ 1.2	≥ 1.3	≥ 1.4
	$\overline{R^A_T(k)}$	≥ 1.2	≥ 1.3	≥ 1.4	≥ 1.6
Increase of duration	$\overline{R^D_\alpha(k)}$	≥ 1.2	≥ 1.3	≥ 1.5	≥ 1.6
	$\overline{R^D_\beta(k)}$	≥ 1.1	≥ 1.2	≥ 1.3	≥ 1.4
Increase of frequency	$\overline{R^F_T(k)}$	≥ 1.4	≥ 1.5	≥ 1.7	≥ 2.0

the threshold sets were fixed as one. If all the conditions were satisfied, the interval lasting 10 seconds before the detection time was regarded as sleep period. Arousal response in EEG record has features on awakening EEG. It is a rapid increase of central-frequency on EEG and consists of alpha or beta frequency activity in general. Such features of arousal response were taken into account in the method and the conditions for detecting arousal response were shown in Table 3 b). Threshold sets were depended upon the results of pathological events detection described in the previous paragraph. The data that satisfied both two conditions concerning the existence of sleep period and appearance of arousal response shown in Table 3 was finally judged as EEG arousal. Detected arousals were then classified into two groups. If EEG arousals were detected with the threshold sets T1 or T2, they were treated as respiratory-related arousal. Other detected EEG arousals by employing threshold sets T3 or T4 were counted as non-respiratory-related arousals.

3. RESULT

3.1 Detection of respiratory-related arousals

Examples for the results of automatic EEG arousals detection with different threshold sets; T1 - T4 were displayed at Fig.2. Fig.2 (a) and (b) show the detected EEG arousals by the threshold sets T1 and T2 respectively. Those were detected as respiratory-related arousals. Resumption of ventilation and apnea interval were seen in the time series of airflow pressure and airflow temperature and the arousal response occurred simultaneously for the resumption of ventilation. Proposed method correctly detected those arousal responses and agreed with the result by the visual inspection. Fig.2 (c) and (d) represent the results by the threshold sets T3 and T4. Apnea intervals could not be seen in the time series. Arousal responses in EEG record were correctly detected and were treated as non-respiratory-related arousals. All the detected EEG arousals were classified from the view points of selected threshold sets and respiratory-related arousals or not, and the total number was shown in Table 4. Total number of respiratory-related arousals and non-respiratory-related arousals were independently displayed for each subject. From those results, proposed method can be indicated the degree of appearance for pathological respiratory-related arousals.

3.2 Accuracy of EEG arousals detection

Accuracy of automatic EEG arousals detection was also evaluated by comparing the results of visual inspection. The result was seen in Table 5. Agreement means coincidence rate between visual inspection and automatic detection. Disagreement 1 was defined as rate of undetected number by automatic detection per detected number by visual inspection. As same mannar, disagreement 2 was defined as rate of over-detected number by automatic detection per detected number by visual inspection. Results were displayed as percentage, and numerals in brackets mean detected (undetected, overdetected) number by automatic detection to the left side and detected number by visual inspection to the right. 84 % of accuracy was obtained in total. Lowest accuracy was 64 % for subject 5 and highest one was 95 % for subject 7.

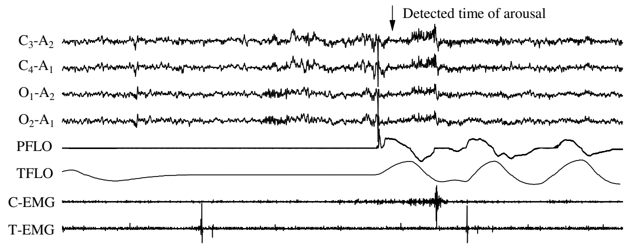

Fig. 2. Results of automatic EEG arousals detection. Four EEG (C3-A2, C4-A1, O1-A2, O2-A1), airflow pressure (PFLO), airflow temperature (TFLO), chin-EMG (C-EMG) and tibialis-EMG (T-EMG) were shown. Detected time of EEG arousals was incicated arrow.

Table 4. Result of automatic detection of EEG arousals. Detected number with respective thresholds were shown. The proposed method can distinguish the detected arousals as respiratory-related arousals and other non-respiratory-related arousals.

Subject no.	Respiratory-related			Non-respiratory			Total
	T1	T2	Sub-total	T3	T4	Sub-total	
Sub.1	12	211	233	12	72	84	331
Sub.2	1	23	24	22	80	102	138
Sub.3	14	17	31	156	30	186	241
Sub.4	14	168	182	9	36	45	221
Sub.5	9	63	72	20	57	77	165
Sub.6	8	217	225	14	63	87	332
Sub.7	18	374	392	16	92	108	492
Sub.8	47	130	177	14	30	44	246

Table 5. Accuracy of automatic detection of EEG arousals. Results were compared with visual inspection.

Sub. no.	Agreement	Disagreement 1	Disagreement 2
Sub.1	87%(331/382)	13%(51/382)	10%(39/382)
Sub.2	68%(138/202)	32%(64/202)	14%(28/202)
Sub.3	72%(241/334)	28%(93/334)	13%(43/334)
Sub.4	84%(221/262)	16%(41/262)	15%(38/262)
Sub.5	64%(165/257)	36%(92/257)	40%(103/257)
Sub.6	90%(332/368)	10%(36/368)	37%(135/368)
Sub.7	95%(492/517)	5%(25/517)	15%(77/517)
Sub.8	91%(246/270)	9%(24/270)	32%(86/270)
Total	84%(2166/2592)	16%(426/2592)	21%(549/2592)

4. DISCUSSION

4.1 Classification of respiratory-related arousals

Proposed method can be classified the detected EEG arousals into respiratory- related arousals and non-respiratory-related arousals. Results about the detection for rapid increase of EMG were not explained in this paper, but the results can also be shown supplementally as one of information. From the view point of pathological importance, arousal responses appeared in

EEG records are classified into three groups; respiratory-related arousals, movement-related arousals and spontaneous arousals. Respiratory-related arousals give significant information in clinical diagnosis of sleep apnea/hypopnea such as OSAS and CSAS. Movement-related arousals have importance in the diagnosis of PLM and RLS. Spontaneous arousals are a kind of physiological phenomenon, so they have clinically less meaning. Proposed can grasp the relationship between sleep apnea and arousal response during whole night PSG recording quantitatively. Various meaningful statistics will be calculated from the automatic detection result and will be indicated efficiently to medical doctors, medical technologists, patients with OSAS and so on.

4.2 Comparison with visual inspection

Accuracy for Subject 2, Subject 3 and Subject 5 were 68 %, 72 % and 64 % respectively, and were not so high. Main reason was contamination of various artifacts in EEG records. Electrode artifact and body movement artifact were frequently and continuously contaminated with EEG data of three subjects. Amplitudes of those artifacts were often quite large as compared with that of EEG, so the disagreement with the visual inspection occurred. EMG artifacts also contaminated with EEG record so often. Central-frequency of EEG was increased by EMG artifacts contamination. Proposed method was sometimes miss-detected such phenomenon as EEG arousals. The proposed method did not taken into account those artifacts contamination, but the results for the data without or less artifacts contamination were good enough. In the visual inspection, the results of PSG interpretation such arousal index, apnea and hypopnea indices, and sleep stage scoring do not have complete agreement among inspectors due to the difference of their experience and knowledge (Collop [2002]). Considering the above facts, 84 % of coincidence for visual inspection is acceptable as enough accuracy.

4.3 Feature of the method

In this study, normalization of parameters was executed in order to avoid the deterioration of accuracy due to the property differences among subjects. Mean amplitude of EEG for the data of subject 1 was about 100 μ V, and that for subject 4 was almost 30 μ V. However, the accuracy of the EEG arousal detection for subject 1 and subject 4 was 87 % and 84 %, respectively. Effectiveness of the normalization procedure could be recognized from the above fact. Difference of accuracy among subjects was concerned with other factors such as artifacts contamination. Two essential features on EEG arousals; existence of sleep period and appearance of arousal response were adopted in the proposed detection method. Parameters corresponded to the above features were then constructed from the periodograms of EEG time series. Main feature of EEG arousals was the rapid change of all frequency components before and after the appearance of arousal response in EEG records. Therefore, all the parameters for detecting EEG arousals were not only calculated directly from the time series, but were also obtained from the periodograms information. Segmentation of the data length was also determined by considering the feature of EEG arousals in EEG records. Four grades of threshold sets were used for detecting arousal responses and were determined according to the detected pathological events; resumption of ventilation and rapid increase of EMG. In the clinical diagnosis for patients with OSAS, to grasp the relationship between apnea and arousal response is a most significant item. Hence, the lowest threshold sets were adopted for detecting much more arousal responses even if they were small amplitude or relatively doubtful.

4.4 Usage in clinical diagnosis

Threshold sets for detecting EEG arousals were changeable in accordance with the existence of pathological events as the resumption of ventilation. Small and relatively doubtful arousal responses were treated as meaningful information under the condition that the resumption of ventilation from apnea was seen. Inversely, the clear arousal response with high amplitude was only detected if there were no pathological events around the detection time. Therefore, the proposed method can be effectively detected EEG arousals that are important in the clinical diagnosis. Of course, the screening use with the fixed lower threshold sets will be possible. Proposed method will be usable as a powerful tool for the assistance of visual inspection, and will bring the reduction of inspection time and the load.

5. CONCLUSION

The feature of the method was to select the adequate threshold sets according to the existence of pathological events related to obstructive apnea. Therefore, the proposed method can be denoted the effective information about the interpretation of EEG arousals for patients with OSAS. Proposed method will be usable in the clinical diagnosis as an assistant tool of visual inspection.

REFERENCES

American Sleep Disorders Association and Sleep Research Society: EEG arousals: scoring rules and examples, *Sleep*, vol. 15-2, pp173-184 (1992)

G. Pillar, A. Bar, A. Shlitner, R. Schnall, J. Sheffy and P. Lavie: Autonomic arousal index: an automated detection based on peripheral arterial tonometry, *SLEEP*, Vol. 25, No. 5, pp. 541-547, 2002

D. J. Pitson and J. R. Stradling: Autonomic markers of arousal during sleep in patients undergoing investigation for OSA, their relationship to EEG arousals, respiratory events and subjective sleepness, *Journal of Sleep Research*, Vol. 7-1, pp.53, 2006

N. A. Collop: Scoring variability between polysomnography technologists in different sleep laboratories, *Sleep Medicine*, 3, pp.43-47, 2002

S. Chokroverty (edited): Sleep disorders medicine: basic science, technical considerations and clinical aspects, Butterworth-Heinemann, pp.331-354, 1999

S. Nishida, M. Nakamura and H. Shibasaki: An EEG model expressed by the sinusoidal wave with the Markov process amplitude. *J. J. of Med. Elect. Biol. Eng.*, 24(1):8-14, 1986 (in Japanese).