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Article / Makale

An Alternative New Signal in the Respiratory Scoring Process in Patients with Obstructive Sleep Apnea: Photoplethysmography Signal

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Abstract

Objective: The diagnosis of obstructive sleep apnea is made by the examination of biological signals taken from the patient by means of Polysomnography device by the specialist. The examination consists of two steps including sleep staging and respiratory scoring. The respiratory scoring process is performed with the airflow signal taken by means of a nasal sensor, chin electromyography, signals taken from the abdomen and thorax arches. The method of obtaining signals gives discomfort to the patient. An expert technician is required to connect the electrodes to the patient. Moreover, the system is not suitable for use at home. Considering all these disadvantages, practical systems capable of performing respiratory scoring process are necessary.

Materials and Methods: In this study, the relationship of photoplethysmography signal with an easy measurement that could be used for the respiratory scoring process with abnormal respiratory events was examined. Photoplethysmography signal can be measured at any place on the skin by the noninvasive method. The distinctiveness level of characteristic features of photoplethysmography signal for normal and abnormal respiratory events was statistically analyzed by means of Eta correlation coefficient in this study.

Results: R>0.2 for 6 of 10 features extracted. In addition, p<0.01 for all features and all features are significant for the normal-abnormal respiratory events.

Conclusion: As a result of this study, it is considered that PPG signal could be used as an alternative to the existing.

Keywords: Obstructive sleep apnea, polysomnography, sleep staging, photoplethysmography

Özet

Amaç: Obstrüktif uyku apnesinin tanısı, polisomnografi cihazı kullanılarak, hastadan alınan biyolojik işaretlerin uzman tarafından incelenmesi ile yapılır. Muayene, uyku evrelemesi ve solunum skorlaması olmak üzere iki aşamadan oluşur. Solunum skorlama işlemi, burun sensöründen alınan hava akışı sinyali, çene elektromiyografisi, karın ve göğüs kemerlerinden alınan sinyallerle gerçekleştirilir. Sinyal elde etme yöntemi hastaya rahatsızlık verir. Elektrotları hastaya bağlamak için uzman bir teknisyene ihtiyaç vardır. Bunlara ilave olarak sistem evde kullanım için uygun değildir. Tüm bu dezavantajları göz önüne alındığında, solunum skorlama işlemini gerçekleştirebilecek pratik sistemler gerekli olduğu görülür.

Materyal ve Yöntem: Bu çalışmada, anormal solunum olaylarıyla solunum skorlama işlemi için kullanılabilecek kolay bir ölçüm yöntemi olan fotopletismografi sinyali ilişkisi incelenmiştir. Fototopletismografi sinyali, noninvaziv yöntemle cilt üzerinde herhangi bir yerde ölçülebilir. Bu çalışmada, normal ve anormal solunum olayları için fotopletismografi sinyalinin karakteristik özelliklerinin ayırt edicilik düzeyi Eta korelasyon katsayısı ile istatistiksel olarak analiz edildi.

Bulgular: Çıkartılan 10 özellikten 6'sında R> 0.2 olarak bulunmuştur. Ek olarak, tüm özellikler için p <0.01 bulunmuştur, yani kullanılan tüm özellikler normal-anormal solunum olayları için önemlidir.

Sonuç: Bu çalışma sonucunda, PPG sinyalinin mevcut sistemlere alternatif olarak kullanılabileceği düşünülmektedir.

Anahtar Kelimeler: Obstrüktif uyku apnesi, polisomnografi, uyku evrelemesi, fototopletismografi

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Introduction:

Obstructive Sleep Apnea (OSA) is a syndrome which is frequently seen with a decrease in the oxygen saturation and which is characterized by the decrease in airflow or respiratory arrest due to the upper respiratory tract obstructions recurring during sleep[1,2]. OSA diagnosis is made by the interpretation of biological signals taken from the patient via Polysomnography (PSG) device in accordance with the guideline regarding the determination of sleep events and the standard methods of measurement of abnormal respiratory events that occur during sleep which was published by American Academia of Sleep Medicine (AASM) association[3,4]. PSG is an expensive and time-consuming method requiring special teams but is a "gold standard" method in diagnosis which is useful for the determination of various diseases associated with sleep by being recorded in the laboratory environment[5].

A standard PSG device records the oral-nasal airflow, blood oxygen saturation, thoracic-abdominal respiratory movements and body position along with Electroencephalogram (EEG), Electromyogram (EMG), Electrooculogram (EOG) and Electrocardiogram. Records can only be taken with a full night sleep of the patient in the sleep laboratory. The patient is connected to PSG device by the sleep technician, and records are taken all night long. After records are taken, they are analyzed by the specialist according to the guideline published by AASM, and the diagnosis is made[3]. Diagnosis is made in two steps. Firstly, the patient's time elapsed during sleep is determined by analyzing the records taken. Then, abnormal respiratory events occurring during sleep (apnea, hypopnea, mixed apnea, central apnea) are determined.

Sleep staging and respiratory scoring processes are indispensable for the diagnosis of OSA[3]. Each step is an important part of the diagnosis. Patient's moments throughout the night are determined by the sleep staging process. Abnormal respiratory events that occur during these periods while sleeping are determined by the respiratory scoring process. The number of the detected abnormal respiratory events is determined. Then, this number is compared with the time elapsed during sleep which is determined by sleep staging. This calculated value is called Apnea Hypopnea Index (AHI). Treatment is started by determining the level of OSA according to this value obtained[3].

OSA diagnosis process is quite troublesome. The operations performed and the elapsed time are also quite troublesome and complicated. Minimum four different signals are used for the respiratory scoring process. These are airflow signal taken by means of a nasal sensor, chin EMG, signals taken from the abdomen and thorax arches. The excessiveness of these electrodes causes the patient to be late for falling asleep and to move away from the natural sleep environment. The fact that the patient sleeps in an unusual environment will reduce the reliability of the results to be obtained. Methods which are more practical and less disturbing for the patient are needed because of these negative aspects of the respiratory scoring method.

In this study, the relationship between Photoplethysmography (PPG) signal which is considered to be used as an alternative to the signals used in the respiratory scoring process and abnormal respiratory arrests will be analyzed.

PPG is a noninvasive and electrooptic method providing information about the volume of blood flowing in a test region of the body which is close to the skin. PPG signal has recently begun to be studied in the literature, and it has a high information ratio. Studies on the association between PPG and apnea cases in the literature have increased recently. However, the number of available publications is quite low. The relationship between the sleep apnea status and PPG signal was investigated in some studies performed on children between the years of 2006 – 2014. According to the results obtained at the end of the study, it was reported that PPG signal could be used in the diagnosis of OSAS[6]. In other studies performed, it was demonstrated that the patient's status of apnea during sleep could be determined by the PPG signal[7]. In another study performed for the arousal determination of PPG, it was emphasized that PPG might help to determine arousals with the help of a simple system[8]. The amplitude of general PPG signal was used in these studies. In other words, a single PPG signal feature was used. The use of a single feature of the signal in any system design will reduce the reliability of the system. In this article, the signal will be discussed from different perspectives by extracting 10 features from the PPG signal. The respiratory scoring process can be performed by extracting quite simple rules in respiratory scoring processes with different features. The visual quality of the extracted features will provide visual verification opportunity for the doctor. In this study, 10 characteristic features which can be determined visually from the PPG signal will be extracted. Whether there is a

relation between the features extracted and the abnormal respiratory events, and the degree of relationship if available will be analyzed with the help of the correlation coefficient.

Methods

Study design and population

The database used in this study was formed in the Chest Diseases Sleep Laboratory in Sakarya Hendek State Hospital. The Ethics Committee report and data usage permission were received to perform the study.

The database consists of 33 channels obtained by taking the records of 5 individuals all night long with SOMNOscreen Plus branded PSG device. However, the study was performed just with the PPG signals. PPG data were taken with the help of electrodes placed on the abdominal region. The sampling frequency for PPG signal was 128 Hz. While receiving data, the laboratory environment where the patient could sleep was ensured, and the patients slept for about 7-8 hours.

All signals were examined by specialists, and 1234 respiratory labels were determined by performing sleep staging and respiratory scoring processes. Statistical information related to the patients is summarized in Table 1. 512 PPG records between 10 and 30 seconds were taken from 2 patients during normal breathing while sleeping. This group was used as a control group. 740 PPG records were taken from 3 patients for Apnea during respiratory arrests while sleeping. The minimum duration of the signals received for both groups was 10 seconds.

The data collected were processed by being subjected to a series of operations according to the flow diagram in Figure 1, and the analysis results were obtained.

Figure 1: Signal processing flow diagram

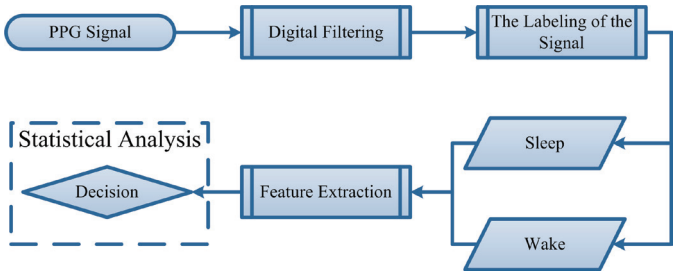


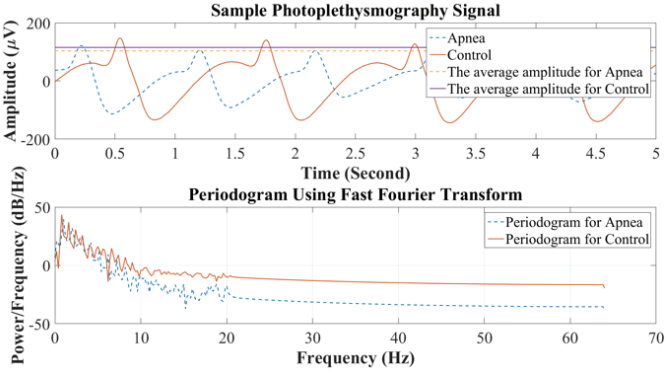
Table 1: Statistical information related to subjects

	Control		Apnea		
	1	2	1	2	3
Gender	F	F	F	M	M
Age (Year)	62	63	42	59	54
Weight (kg)	90	110	86	93	105
Height (cm)	160	160	155	180	174
BMI (kg/m^2)	35,2	43,0	35,8	28,7	34,7
AHI	1,4	3,2	56,1	39,6	57,5
Recording time (Mean ± Std)	10,0105±13,8081		26,8610±12,7007		
n	270	242 (%19,6)	223	251 (%20,3)	248 (20,1)
Total	512		722		
	1234				

Data reported as n (%)
BMI Body Mass Index, AHI Apne Hipopne Index,
Mean ± Std Mean ± Standard Deviation, F Female, M Male

The digital filter was designed and applied in order to wipe off the artifacts and noises formed on the PPG signal. Firstly, the filter passing Chebyshev Type II band between 0.1 – 20 Hz was applied, and then Moving Average Filter was applied to the signal. In Figure 2, PPG sample signals obtained as a result of filtering are shown in the time domain. In the figure, the averages of the maximum amplitudes of the signals are shown in line. The difference between the averages is quite significant. In addition, the difference between the amplitudes of the frequency components of the signals is shown in the Periodogram graph. The amplitude of the signal of the control group marked with red seems to be more dominant

Figure 2: Sample PPG Signal



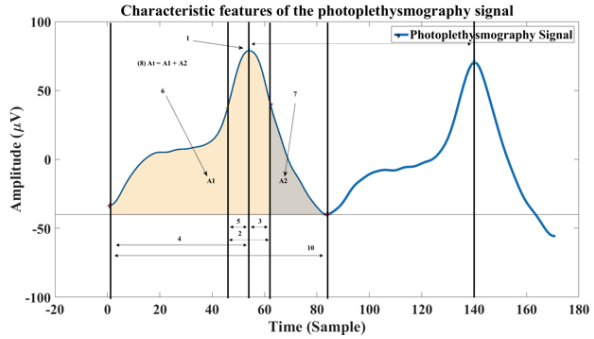
After the digital filtering process, labels given by the specialist were associated with the signals. Then, characteristic features were extracted from the PPG signal and analyzed statistically.

Photoplethysmography signal and features

In studies carried out in the literature, many different features were extracted from the PPG signal. Some of these features are the features that were calculated based on the shape of the signal[9]. The features changing depending on the shape of the signal are called characteristic features. In this study, 10 characteristic features of the PPG signal were extracted, and they were numbered and shown in Figure 3.

Feature 1 is the systolic peak value which is one of the characteristic features of the PPG signal. Dicrotic notch is another characteristic feature of the PPG signal. However, it may not be available in all signals. This may cause an error in systems operating in real time. Therefore, the amplitude value at the moment the systolic peak value was reduced by half was used instead of this feature in the study. This value is the value that separates A1 and A2 regions from each other in Figure 3. Figure 2 represents the value in seconds of the bandwidth of two halves systolic peak amplitude. Figure 3 is the value in seconds of the time elapsed from systolic peak amplitude to the point where the systolic peak amplitude was reduced by half. Feature 4 represents the time elapsed from the beginning of a PPG signal to the beginning of systolic peak amplitude. Feature 5 represents the time elapsed from the half of the maximum amplitude to the formation of the systolic peak amplitude. Feature 6 and 7 represent the and areas. Feature 8 is equal to the sum of the and areas. Feature 9 represents the time elapsed between two systolic peaks. Feature 10 represents the time elapsed between the start and end of a PPG signal. All durations were calculated in seconds.

Figure 3: Characteristic features of the photoplethysmography signal



Statistical analysis

Correlation coefficients are the criteria providing information about the force and direction of the relationship between variables. The correlation coefficient formula to be used varies according to the type of the variables compared. In this study, calculation of the correlation coefficient was made between qualitative (abnormal respiratory events 1: available 2: none) and continuous digital (measurements of a biological signal) variables. Results were obtained in the study by using Eta correlation coefficient calculation suitable for these variables[10]

The t-test is the method which is most commonly used in hypothesis tests. The averages of the two groups are compared by the T-test, and the decision is made about whether the difference is random or statistically significant[11]. It is necessary to provide the required parametric hypotheses to perform this test. When it is said that the parametric test hypotheses are provided for a group, this means that the group's normal distribution variance is homogeneous. "Homogeneity test of variances" and "Significance test of the difference between the two averages" are applied since the parametric test hypotheses are provided. The "Mann-Whitney U Test" is used in the case that parametric test hypotheses are not provided[12]. The data used in the study were tested with the "Mann-Whitney U Test" which is the most powerful test that can be used in providing parametric test hypotheses, and analyzes were performed using MATLAB 2015b[13].

According to the p value calculated, it is decided whether there is a significant difference between the two groups. There is a significant difference between two groups if $p < 0.05$, and it can be said that the feature, the p value of which is calculated, is distinguishing for both groups. There is not a significant difference between two groups if $p > 0.05$, and it can be said that the feature, the p value of which is calculated, is not distinguishing for both groups.

The purpose of using this test in the study is to decide whether the relation between Apnea and Control groups of the features extracted from the PPG signal is random or statistically significant.

Results

The relationship level between PPG features and the abnormal respiratory events was calculated in the study. Whether PPG could be used in determining abnormal respiratory events was investi-

gated by the calculated values. For this purpose, the correlation values between abnormal respiratory events and PPG features were calculated. Furthermore, statistical parameters of the groups were also calculated to provide information about the distribution of the groups. All results obtained are shown in Table 2. Since PPG signal features were not normally distributed, features' minimum, maximum, minimum and maximum in the 95% confidence interval, average and standard deviation values are given in the table. Moreover, the p value was calculated using the Mann-Whitney U test in the last column in the same table.

Discussion

p values in Table 2 are $p<0.01$ and significant for all features. According to these results, it could be said that there is a significant difference between abnormal and normal respiratory events.

In Table 2, the relationship between abnormal respiratory events and PPG signal features is shown by calculating with Eta correlation coefficient (R). Correlation is quite weak for $R<0.2$. Places of $R>0.2$ are marked with a dark color in the table. Moreover, features in the table are sorted from left to right and from small to big by the correlation coefficient. When R values are analyzed in the table, feature 7 has the best correlation with the value of 0.689. It can be said that there is a medium-level correlation between feature 7 and abnormal respiratory events for the value of 0.689[10]. It could be said that there is a certain level of relationship in other features despite their decreasing correlation values.

The fact that the minimum and maximum values of the features extracted showed significant differences between the groups can be seen in Table 2. Moreover, it could be seen that minimum and maximum values in the 95% confidence interval varied for each group. For instance, while the 95% confidence interval of the apnea group was [818.335-863.621], the 95% confidence interval of the control group was [1566.578-1652.995] according to feature 7. It was seen that the groups were not intersected when numeric values were analyzed. They are also quite far from each other. In this way, they are separated very clearly in all other features.

The average values given for the features can be considered as the center point of distribution for the groups. When the average values between groups were analyzed, it could be seen that the centers were quite far from each other. For instance, while the

Table 2: Results of statistical analysis

			7	8	6	1	2	3	10	9	4	5
Apnea	Min		166,297	469,279	301,905	104,099	0,122	0,061	0,562	0,561	0,409	0,310
	Max		4413,213	12729,102	8315,889	770,984	0,213	0,103	1,063	1,063	0,868	0,789
	Mean		840,978	2050,274	1209,296	304,589	0,157	0,082	0,798	0,798	0,630	0,548
	Std		309,691	854,419	590,984	106,578	0,012	0,007	0,111	0,111	0,096	0,095
	95% CI	LB	818,335	1987,803	1166,086	296,797	0,156	0,082	0,790	0,790	0,623	0,541
		UB	863,621	2112,746	1252,507	312,382	0,158	0,083	0,806	0,806	0,637	0,555
Control	Min		604,500	1611,252	870,214	71,845	0,137	0,067	0,505	0,495	0,298	0,230
	Max		3646,841	8956,455	6262,670	651,982	0,701	0,352	2,248	2,304	1,485	1,133
	Mean		1609,787	3725,640	2115,854	436,759	0,178	0,090	0,840	0,840	0,663	0,574
	Std		497,654	1038,560	607,765	93,323	0,029	0,015	0,094	0,096	0,071	0,065
	95% CI	LB	1566,578	3635,468	2063,085	428,656	0,175	0,088	0,832	0,832	0,657	0,568
			1652,995	3815,813	2168,623	444,862	0,180	0,091	0,848	0,848	0,670	0,579
R (Eta)			0,689	0,662	0,599	0,541	0,439	0,326	0,195	0,192	0,189	0,152
R^2 (Eta Squared)			0,475	0,438	0,359	0,293	0,193	0,106	0,038	0,037	0,036	0,023
p			0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000

LB Lower Bound, UB Upper Bound, 95% CI 95% Confidence Interval for Mean,
Std Standard Deviation, Min Minimum, Max Maximum

average value of feature 7 was 840.978 for the apnea group, this value was 1609.787 for the control group. The fact that the center points of the same feature between two groups are different is another indicator that the feature is a significant distinguishing feature for these groups. Standard deviation shows the distribution of data around the center (average). When feature 7 is analyzed, the standard deviation value is 309.691 for the apnea group; this value is 497.654 for the control group. When standard deviation values were compared, it could be said that the control group showed more scattering around the average value.

According to the results obtained, it was concluded that PPG signal could be used as an alternative to the nasal sensor, chin EMG, the abdomen and thorax arches used in the respiratory scoring process. However, this study has some shortcomings. In this study, all abnormal respiratory events such as obstructive apnea, hypopnea, central apnea and mixed apnea were evaluated as a single group. PPG signal may not be sufficient alone if it is needed to be determined separately in the abnormal respiratory events for the diagnosis. However, only the use of the PPG signal may be sufficient to calculate AHI value which is used in the general OSA diagnosis since total abnormal respiratory events are calculated by being divided by the time elapsed during sleep while calculating AHI [3]. Being able to perform all processes with a single signal will reduce the workload. Furthermore, the discomfort in the patients caused by PSG device will be greatly reduced.

The relationship between respiration and PPG signal has been revealed by many studies in the literature[14–19]. The results obtained in this study are consistent with the results in the literature. It was stated in this study that there was a relationship in general. However, the relationship level was explained clearly. In this article, the relationship level was determined, and PPG characteristic features were determined that would help a specialist to perform visual respiratory scoring.

The breathing rate was determined by PPG in some studies in the literature [14,16,17,20]. These studies were carried out to monitor the overall level of respiration. There are many studies carried out to determine the abnormal respiratory events in OSA patients in addition to these studies[6,7,14,15,19–21]. However, these studies are not appropriate for the practical use for a specialist to perform visual respiratory scoring. With this article, PPG characteristic features were extracted for respiratory scoring, and the level of relationship with abnormal respiratory events was determined clearly.

In a study carried out in 2006, an attempt to determine the respiratory status of patients under anesthesia (apnea-normal) with PPG was made[22]. According to the study results, the sensitivity specificity values were obtained as 0.649 and 0.905, respectively. The same study was repeated in 2008 by developing it[23]. Based on the results obtained in this study, the sensitivity specificity values were obtained as 0.916 and 0.847, respectively. The sensitivity value is desired to be 0.8 and above in the newly developed methods of diagnosis[10,22,23]. The results obtained in the referenced studies are consistent with the results in this article when they are compared. However, the classification process was performed through the signal with significant respiratory labels in both studies. The start and end points of abnormal respiratory events could not be determined exactly. However, it cannot be said that the studies performed on the determination of abnormal respiratory events reached a peak.

Results arouse the expectation that the PPG signal can be used alone in the respiratory scoring process. Easy measurement of the PPG signal allows its transformation to an applicable practical system[9]. It is considered that with the addition of PPG sensor to PSG devices which are currently used, the physician can be supported in visual respiratory scoring and this process can be performed by software by relieving the physician. The workload can be quite reduced by this practical change.

Only the visual features of PPG signal were used in this study. More PPG features can be extracted in a system to be developed to perform the respiratory scoring process. There were many studies in which feature extraction from the PPG signal was performed in the literature[7,8]. The system can be realized with the features having a high correlation by reviewing the relationship between features to be extracted and the abnormal respiratory events. However, the biggest problem in the system to be realized is the accurate determination of the start and end points of abnormal respiratory events. PPG signals of abnormal respiratory events with certain start and end points were used by the specialist in this study. The analysis of the signals with certain start and end points is easy. However, the use of advanced mathematical algorithms may be needed for the accurate determination of the start and end points

of abnormal respiratory events.

As a result of this study, it is considered that PPG signal could be used as an alternative to the existing signals used for respiratory scoring with its feature of distinguishing abnormal respiratory events. The signal can be easily applied to portable systems as it can be achieved practically. A sleep technician will not be required in the first installation phase since there is no need for technical information for measuring the signal. Thus, the respiratory scoring process that can be developed by the PPG signal will be suitable for use at home. The classification processes can also be performed by extracting different features from the PPG signal for the development of this study. It can also be converted to a system operating in real time.

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