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Real-Timely Decrease of Snoring in Patients with Severe Degree of Obstructive Sleep Apnea Syndrome Using SNORAP

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Abstract: The decrease and/or removal of snoring complaint, a significant social and familial health problem, is an important medical issue that needs to be solved interdisciplinary for sleep medicine. Surgical techniques and technological studies related to this topic have been mentioned in a few articles. SNORAP, developed by Yağanoğlu et al (2017), is a wearable device that operates just by the application of vibration to the patient. SNORAP is a device designed to improve the sleep health of snoring patients especially with Sleep Disordered Breathing (SDB). In this study, the detection of snoring sound at patients with severe degree obstructive sleep apnea syndrome (OSAS), and the effect of SNORAP device on snoring sound in these patient group were investigated. SNORAP consists of Raspberry Pi, Grove, microphone, vibration motor and screen. It uses the SNORAP audio fingerprint (AF) method to detect the snoring sound. AF is a short digital summary of the quick index and audio object that can be used to introduce the short and unlabeled part of the audio signal to correspondences at audio database, and similar elements. First of all, SNORAP performs sampling by receiving audio data with a microphone. Secondly, spectrograms are obtained from the audio data. Thirdly, peak points are found, and the summarization of fingerprint is created. Finally, SNORAP detects whether this is a snoring sound or other sounds, through database. SNORAP was applied to 2 voluntary patients (male, mean age: 49, body mass index average: 27.5) diagnosed with severe OSAS in company with polysomnography (PSG). The experimental protocol was performed in the form of a night sleep test to the volunteers, by using and without using SNORAP, with a week interval, in a sleep and electrophysiology laboratory under the supervision of the responsible physicians and technicians. The resulting data were analyzed by a sleep medicine physician, in accordance with the 2007 American Academy of Sleep Medicine (ASSM) criteria. PSG, known as a night sleep test, has sensors that measure body systems for all purpose. This study was conducted especially on the basis of snoring sensor of PSG. Patients who diagnosed as severe OSAS, accepted to sleep laboratory two times for a night-sleep test, first with SNORAP, later without SNORAP. The snoring parameters of the first volunteer patient whose number of snoring 716/night and average amplitude of snoring 50 µV before using SNORAP was high, decreased after using SNORAP (number of snoring: 98/night, average amplitude of snoring: 3,52 µV). The snoring parameters of the second volunteer patient whose number of snoring 1738/night and average amplitude of snoring: 62,5 µV before using SNORAP was high, decreased after using SNORAP (number of snoring: 81/night, average amplitude of snoring: 1,40 µV).

Keywords: Snoring, SNORAP, Severe Degree Obstructive Sleep Apnea Syndrome, Audio Fingerprint, Wearable Processing.

1. Introduction

Technological developments in health care services aim at increasing life quality by providing people with better treatment and doing supporting works for the emergence of healthy communities for the future. In this direction, disciplinary studies have increased with the contribution of the discipline of medicine as well as of engineering and diagnosis and treatment of diseases have been

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provided in short-term. One of the important fields of study on health is the studies on sleep physiology and sleep disorders. These studies are done at sleep labs having information about people's sleep physiology by getting electrophysiological signal records from body systems. These labs include practitioners specialized on sleeping medicine, sleeping technicians and other allied health personnel. Sleep physiology and disorders is a multidisciplinary field of study relating to lots of medical fields impressing all body systems, notably brain. It is too difficult and demanding to diagnose that kind of interpenetrated activities. As sleeping and electrophysiology labs help sleep disorders to be diagnosed and treated, they allow for developing new diagnosis and treatment tools for the disorders at the same time. While these labs really provide that one understands a lot of physiologic mechanisms' relations with each other in body, they strengthen scientific curiosity of the researches on both medicine and engineering fields. SNORAP has been developed as a part of that curiosity.

Sleep is a physiologic process being necessary for people to function daily. This process is completed every night, regularly and constantly. Human brain, a part of biological rhythm, has a more true mechanism by catching dark and day moments. Sleep is a mixture of physiological and behavioral processes.

For a quality wakefulness within day, we need a quality sleep throughout the night. A person sleeps in one third of his life. Balance of that important sleep physiology for life shouldn't be deteriorated. Sleep-related breathing disorders have been tried to be understood curiously in terms of research, diagnosis and treatment (Table 1) (Medicine, 2005). Obstructive sleep apnea syndrome (OSAS) from this group of sleep disorders is of special interest by researchers because of its systemic impacts on human body (Table 2).

Table 1. Sleep-Related Breathing Disorders

Sleep-Related Breathing Disorders
Primer Snoring, Simple Snoring
Central Sleep Apnea Syndromes
Obstructive Sleep Apnea Syndromes
Sleep-related hypoventilation/hypoxemia syndromes

Table 2. OSAS Classification

Apnea Hipopnea Index	OSAS Degree
5<	Normal
5-15	Mild
16-30	Moderate
>30	Severe

OSAS is an important sleep disorder that deteriorates sleep physiology because of repeated upper airway obstructions throughout the night (respiratory standstill for at least 10s or over it; apnea or decrement; "hypopnea") and that damages all body and organ systems like brain and heart. The most frequent symptom of OSAS is snoring. Along with snoring, apnea observed by bed partner or family is its another important complaint. Day sleepiness originating from apnea attacks leading to a person's sleep interruption throughout the night forbids his intraday activity of the patients with OSAS mentally and physically. Because this disorder exercises influence over all systems, weight creep, increase of weights, waking up with apnea, waking up because of his own snoring sound, sweating on breast and back of the neck overnight, nocturia, enuresis, sexual impotence, depression, anxiety, forgetfulness, attention deficit, difficulty in concentration, problems on learning, headache and dryness of the mouth on the morning, bruxism, insalivation, insomnia, sleep walking and reflux symptoms should bring OSAS to mind (Guilleminault et al., 2006; Karacan and Karatas, 1995). Gold standard method in diagnosis is polysomnography (PSG) known as a sleep test for a single night. Non-diagnostic and untreated disorders are important reason for morbidity and mortality: "Loss in cognitive functions, decrement in life quality, increment in traffic and work accidents associated with day sleepiness, hypertension, arrhythmia, coronary artery disease, impaired glucose tolerance, increment in health expenses and increment in mortality" (Young and Peppard, 2000).

Snoring is a medical and social complaint affecting both sleeping and general health of mothers, fathers and children. It considerably affects married life and interaction between partners. Snoring occurs based on tissue vibrations in upper airway while breathing in sleep. That vibration of upper airway is generally formed in velum, tongue

base or posterior pharyngeal wall (Ayappa and Rapoport, 2003; Urschitz et al., 2004).

SDB called simple snoring or primer snoring is a situation that regularly continues but doesn't lead to extreme day sleepiness and interruption of sleep. Only if who snores is woken up by his bed partner, it would lead to interruption of sleep and insufficient sleep. In the cases of snoring man, the risk of progress of OSAS is high in 10 years. Predisposing factors for snoring can be listed as the gender of man, obesity, alcohol, use of sedative medicine, smoking and nasal obstruction (Gavriely and Jensen, 1993; Urschitz et al., 2004). Hoffstein et al. said that there is no standard method of measurement for snoring and ear of the person witnessing snoring measures it in fact. Volume of snoring can show difference between patients and in the same patient between nights, be constant or discrete. According to acoustic analyses, it can be 200 Hz on the level of palate and 1000 Hz in tongue base (Gavriely and Jensen, 1993; Hoffstein et al., 1994).

Snoring acoustic analyze studies and some important scientific studies presenting the relation of snoring with SDB should be mentioned here: It was argued by Cohen and Lieberman that analysis and classification of snoring signals occurring during inhalation and exhalation can be considered as an objective criterion to be able to be used by practitioner in treatment to apply to patient(Cohen and Lieberman, 1986). Sound records gotten through sticking a miniature microphone on chins as 1 cm below from lips of the patients while getting PSG records have been analyzed on time and frequency domains by Fiz et al.(Fiz et al., 1996) on seventeen patients (seven out of them have never smoked and are with simple snoring diagnosis and ten out of them are with OSAS diagnosis).

Sola-Soler et al. (Sola-Soler et al., 2007) have recommended a new method to identify electrophysiological characteristics of snoring in the patients with sleep apnea in their studies. It was set forth by Beck et al. (Beck et al., 1995) and Fiz et al. (Fiz et al., 1996) that analysis of snoring voices can be taken advantage of in determining such SDB as OSAS and upper respiratory airways.

Ng et al. (Ng et al., 2009) have applied wavelet bicoherence analysis from multiple spectrum wavelet analysis techniques to snoring voices. Remarkable differences have been found between the patients with OSAS and simple snoring in terms of the parameters of peak frequency and total peak frequency obtained from the analysis.

Snoring voices are generally reviewed by electrode microphones, a dielectric part of matters attached on patient's chest wall or neck region or capacitor microphones hanged in a distance of 15-20 cm meter from patient's lip-length in studies by PSG and other sleep analysis devices. Snoring voices are kept on computer by transforming into a digital signal by analog/digital converter. Such reviews as generic and regular sound level analysis, time and frequency domain analysis, power spectrum analysis, linear prediction coding analysis and multidimensional voice parameter analysis have been made for measurement and analysis of the signals kept on computer.

Just as snoring isn't sufficient by itself while diagnosing OSAS, there may be OSAS without occurrence of distinct snoring. However, every degree of OSAS can be together with the complaint of snoring. In the cases of those with mild- and moderate degree OSAS with the complaints of snoring (Table 3), SNORAP is a device that has contributed to treatment of sleep disordered breathing in terms of decrement in the number and severity of snoring and apnea-hypopnea and whose prototype has been created by ourselves (Yağanoğlu et al., 2017). In this study, the impact of SNORAP on the number and severity of snoring voices has been tried to be understood in 2 volunteer cases with severe degree OSAS.

Table 3. Patient groups SNORAP contributed in treatment

Simple Snoring Patients
Mild Degree OSAS Diagnosed Patients with Snoring Complaints
Moderate Degree OSAS Patients with Snoring Complaints
In normal patient groups (increased snoring and apnea)

2. Material and Method

2 man volunteers have been included in the planned study in accordance with Declaration of Helsinki. Experimental procedure belonging to the device tried on volunteers having respiration disorder in sleep (Table 4) is as the following: Firstly, night PSG records have been gotten from volunteers with the only aim of diagnosis. Then, PSG records have been gotten with the application of SNORAP (Figure 1 example record). At first night, severe degree OSAS has been diagnosed on volunteers by the practitioner receiving education on medicine of sleep, MD specialist of physiology. At second night, SNORAP application has been performed under the surveillance of sleep technicians at the same time with PSG. Number and severity of snoring belonging to those records of two nights have been compared.

Table 4. Characteristics of volunteers with sleep disordered breathing. BMI: Body Mass Index, AHI: Apne Hipopne Index, AI: Apne Index, TST: Total Sleep Time, SE: Sleep Efficiency)

	First Volunteer Patient	Second Volunteer Patient
Age	32	68
BMI (Kg/m^2)	25,8	31,5
AHİ	%78	%54,4
AI	%58,9	%51,4
TST (min)	260	261
SE	%63	%81

2.1. Psg recording

In PSG, measurements are made of the electroencephalogram (EEG), electro-oculogram (EOG), and electromyogram (EMG) for muscle tone, respiratory airflow, respiratory effort, arterial oxygen saturation, snoring intensity, electrocardiogram, and EMG of the anterior tibialis muscles (Figure 1).

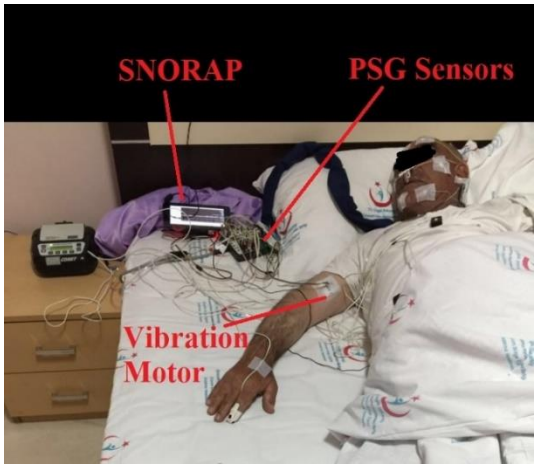

Figure 1. PSG recording and SNORAP

Assessment of respiratory events observed in sleep and sleep stages has been made according to the guide of AASM-2007. Apnea is the shortness of orinasal air flow for at least 10 seconds. Hypopnea is defined as a 3% decrement in oxygen saturation with decreasing by at least 50% in orinasal air flow or arousal track. Arousal is to wake up while sleeping or transition to more superficial sleep stage.

AHI is division of the sum of numbers of apnea and hypopnea seen in sleep by hourly time of sleep. Thanks to this value, degree of disorder is determined. In case this index is bigger than 5, it can be said that there is sleep apnea syndrome but clinically important value is 15 and bigger than it. Amplitude and frequency of snoring is monitored by snoring sensor channel belonging to PSG (Figure 2).

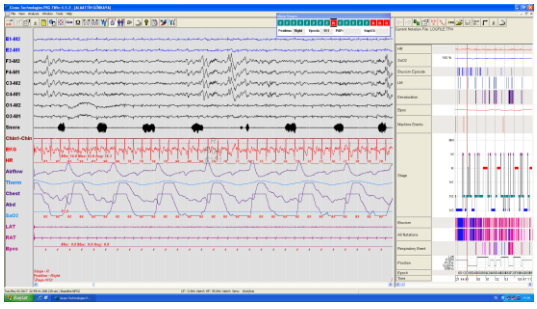

Figure 2. Snoring trace in 9th channel on PSG screen is seen

2.2. Snorap

SNORAP is composed of Raspberry Pi, Grove Pi, Vibration Motor, Microphone, Hearth Rate Sensor and Screen parts as seen in Figure 3. Raspberry pi is a full equipment minicomputer composed of a single credit card-size board. Grove is plugged on Raspberry Pi without needing any other connection. Vibration motor works as connected to Grove module. If SNORAP determines any snoring voice, vibration would work. Magnitude of the vibration can be adjusted with respect to person. Microphone is connected to Raspberry Pi thanks to USB sound card. After microphone receives sound, it is transmitted to Raspberry Pi environment by sampling. After sound is received from microphone, it is determined by Audio Fingerprint method whether that sound is a snoring or not. Heart Rate Sensor measures heart rate. This sensor is connected to user by finger clip and if value is smaller or larger than determined reference values (40-120/min), it sends frequent vibrations to keep user away from heart problems. Screen provides whether user snores real-timely or not and that we easily see heart rate (Yağanoğlu et al., 2017).

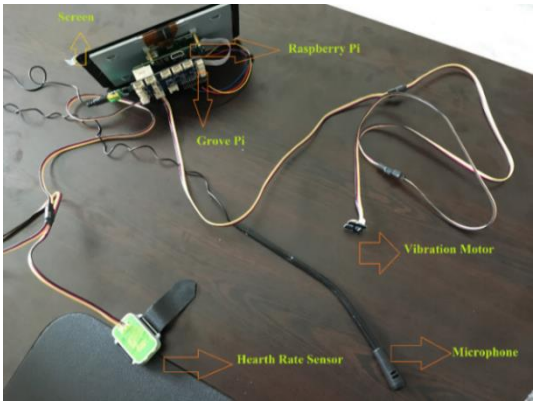

Figure 3. Prototype of SNORAP

As speech recognition method in SNORAP, Audio Fingerprint (AF) has been used. AF is brief summary of a voice file. Sound track is a brief digital summary of rapid index and sound object to be able to be used to identify short and untagged part of sound signal to corresponding ones or similar elements in sound database. As audio fingerprint, combinations created by taking advantage of differences of time and frequency between peak points in spectrogram have been used. Firstly, sound data received has been sampled. According to Nyquist-Shannon Sampling Theorem, 44100 samplings are made per second. Because received samples are a kind of signal, spectrogram of the sound has been created. Thus, Fast Fourier Transform is used from sound samples in little time windows. Amplitude peak points of sound signal have been found from its spectrogram and time corresponding to the value of amplitude, the biggest one of the adjacencies around that peak point, is frequency pair. By using frequency values and time differences of peak points found, fingerprint is created. When we find peak points, there can be similar peak points, therefore a summary to distinguish sounds by considering with time difference between Spectrograms' peak points and peak-frequency combinations has been created (Yağanoğlu et al., 2017).

One of the factors to determine availability of a recognition system is that an unknown part of sound can be effectively compared to known millions of sound parts. Comparison method depends on fingerprint model. General approach here is ˇto create an index structure to decrease the number of distance calculations when an inquiry is given. The fingerprint model we have created is coincided with new sound data. As a result of search in the database, a certain level of matching has been obtained with some sound parts. To express the amount of matching with sound parts, distance calculation methods are used. Sound part whose distance is the shortest is the biggest candidate. Our system distinguished sound coming whether it is snoring or another sound and if it is snoring sound, it would send signals to user.

3. Results

3.1. Number of snoring

According to review on snore sensor trace in first PSG records belonging to the first volunteer with severe degree OSAS, number of snoring throughout sleep has been found as 716/night. In second PSG records after using SNORAP, number of snoring has been found as 98/night. According to review on snore sensor trace in first PSG records belonging to the second volunteer with severe degree OSAS, number of snoring throughout sleep has been found as 1738/night. In second PSG records after using SNORAP, number of snoring has been found as 81/night (Table 5 and Table 6).

3.2. Snoring amplitude

According to review on snore sensor trace in first PSG records belonging to the first volunteer with severe degree OSAS, average amplitude of snoring throughout sleep has been found as 50μV. In second PSG records after using SNORAP, average amplitude of snoring has been found as 3,52 μV. According to review on snore sensor trace in first PSG records belonging to the second volunteer with severe degree OSAS, average amplitude of snoring throughout sleep has been found as 62,5 μV and average amplitude of snoring has been found as 1,40 μV in second PSG records after using SNORAP (Table 5 and Table 6).

Table 5. Comparison of Patient1

	Before SNORAP (Volunteer Patient 1)	Using SNORAP (Volunteer Patient 1)
Number of Snoring	716	98
Snoring Amplitude	50μV	3,52 μV

Table 6. Comparison of Patient1

	Before SNORAP (Volunteer Patient 2)	Using SNORAP (Volunteer Patient 2)
Number of Snoring	1738	81
Snoring Amplitude	62.5 μV	1.40 μV

4. Discussion and Conclusions

Snoring is a social problem leading to embarrassment in society and even affects married life. Volume of snoring can vary between patients and in the same patient between nights and be continuous or discrete. Simple snoring is a situation that doesn't lead to continuous interruption of sleep. However, if he is woken up by his bed partner, it would lead to interruption of sleep and insufficient sleep. In the cases of man with snoring, the risk of progress of OSAS in ten years has risen (Lindberg et al., 1999). It has been foreseen that hypertension in severe degree snoring ones is found as multiplication of the normal value by 1,4, myocardia infarcts is found as multiplication of the normal value by 1,34 and decrement is found as multiplication of the normal value by 1,67 independently from age, gender, body mass index, diabetes, level of education, smoking and alcohol in the multiple variable analysis (Dunai et al., 2008). Solving problems of the patients with snoring and the complaint of snoring leading to very important social and medical problems has excited our study group and SNORAP is a device that has been prepared by ourselves to solve these problems and our innovative efforts are still continuing on.

The impact of SNORAP, whose use is recommended by ourselves in the cases with mild and moderate degree OSAS with the complaint of snoring, on number and amplitude of snoring has been tried to be understood in two cases with severe degree OSAS in this study. According to results, amplitude and number of snoring of the patients using SNORAP has been found considerably lower compared to previous experiment conditions before using it.

Acoustic analyses for snoring, the most frequent symptom of sleep breathing disorders negatively affecting sleep physiology, are important scientific works for development of diagnosis and treatment. The researchers have noticed the snoring-OSAS correlation and tried to prevent these disorders through acoustic analyses. For example, snoring burst index has been created by analyzing amplitude frequencies of vibration signals on frontal neck during sleep. Emoto et al. (Emoto et al., 2014) have recommended an automatic new method based on PNAR to automatically categorize snoring and breathing voices from sound record and to measure voice signals' forms. Ben-İsrail et al. (Ben-Israel et al., 2010) have developed analysis algorithm for snoring voices all night long that provides prediction of adults' apnea hypopnea index (AHI). SNORAP, which has been designed by Yaganoglu et al. (Yağanoğlu et al., 2017) as a latest and innovative device and whose applications are monitored at lab, determines by Audio Fingerprint method whether voice is a snoring voice or not after receiving voice from microphone. SNORAP, which can isolate snoring voice even in a noisy environment, determines snoring voice at 98,9%.

While the studies done are generally on the level of understanding snoring voice analysis and characteristics of voice signal, SNORAP also sends electrical stimulus in order to decrease amplitude and number of snoring. Just as it positively affects decrement of snoring in patients with mild and moderate degree OSAS, it provides

a recovery in the parameters of AHI, AI, and nocturnal oxygen saturation, increasing sleep quality and is an innovative product. Considering patented devices in the world, SNORAP preserves its originality in terms of its activity, ease of use and recommended disorder indications. It will be put at practitioners' and patients' disposal with the aim of diagnosis/treatment at hospitals and homes as a wearable device in the shortest time.

If you work with a device whose sensitivity to snoring voice is high, your contribution to treating disorders associated with SDB would be proportionately high(Yağanoğlu et al., 2017). SNORAP really sends electrical vibrations to person to change his position while sleeping after determining each one of snoring voices. Thus, it provides decrement in amplitude and number of snoring of the volunteers with severe degree OSAS in this study especially.

Patients with severe degree OSAS breath the air they couldn't throughout the night because of apnea attacks through air-generating devices called continue positive air pressure (CPAP). When they regularly and continuously use, apnea attacks are removed and they are substantially treated. However, amplitude, number of snoring throughout sleep (back-to-sleep position) and even frequency of apnea attacks of the patients with OSAS continue with decreasing in spite of this effective treatment. In this group of patient, the use of SNORAP can be recommended as well as of CPAP. Thus, SNORAP makes an important contribution to success of treatment activity associated with regular use of CPAP by decreasing snoring voice and apnea attacks.

Patients with the complaint of snoring and every degree of OSAS are at cardiac risk. As SNORAP sends tactile stimulus by perceiving signals relating to snoring on one hand, it wakes up by increasing frequency of stimulus out of BPM (number of beat/min) reference values by perceiving heart rhythm changes on the other hand. Heart beats belonging to volunteers included in the study have varied between reference values.

Because snoring and OSAS that will occur in next years will lead to such important problems as "loss in cognitive functions, problems of learning and perceiving, decrement in life quality, traffic and job accidents, hypertension, diabetes, increment in health expenses because of impotence and increment in mortality", studies intended to decrease and remove snoring voice will provide communities with huge benefits both medically and financially. In addition, decreasing snoring voice will help us solve social problems becoming very important today and ending up with sleeplessness, a significant problem in community and family life, and lack of communication between partners.

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