

Regular and non regular snore features as markers of SAHS

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Abstract— Sleep Apnea-Hypopnea Syndrome (SAHS) diagnosis is still done with an overnight multi-channel polysomnography. Several efforts are being made to study profoundly the snore mechanism and discover how it can provide an opportunity to diagnose the disease. This work introduces the concept of regular snores, defined as the ones produced in consecutive respiratory cycles, since they are produced in a regular way, without interruptions. We applied 2 thresholds ($TH_{adaptive}$ and TH_{median}) to the time interval between successive snores of 34 subjects in order to select regular snores from the whole all-night snore sequence. Afterwards, we studied the effectiveness that parameters, such as time interval between successive snores and the mean intensity of snores, have on distinguishing between different levels of SAHS severity (AHI (Apnea-Hypopnea Index) $<5h^{-1}$, $AHI <10 h^{-1}$, $AHI <15h^{-1}$, $AHI <30h^{-1}$). Results showed that $TH_{adaptive}$ outperformed TH_{median} on selecting regular snores. Moreover, the outcome achieved with non-regular snores intensity features suggests that these carry key information on SAHS severity.

I. INTRODUCTION

SNORING frequently accompanies SAHS (Sleep Apnea-Hypopnea Syndrome) and is universally recognized as one of its earliest symptom [1;2]. Hence, the most recent research in this field is focused on understanding this breathing disorder and proving that it can provide us the earliest opportunity to diagnose/screen this disease.

Several techniques such as sound intensity calculations, power spectrum analysis, feature extraction in time and frequency domains and attempts to model snore sounds are the latest efforts giving evidence that snoring carries information on SAHS [3-5]. Even though these latest works added auspicious information there seems to be a lack of emphasis on how the anatomical structure of the upper airways has effect on the time production of snores. Very few studies address the potential that sequential properties of snoring have on screening of SAHS[6].

In this work we introduce the concept of *regular snores*, as the ones produced in consecutive respiratory cycles, since they are produced in a regular way, without

interruptions. For that we study the time interval between successive snores.

Not all time intervals between snores can be considered because they can either be: apnea episodes or periods of time where the subject is simply breathing (inspiration and exhalation events). For that reason, we applied 2 different thresholds to the time interval between successive snores in order to select the regular snores from 34 subjects. Our purpose is to study the characteristics of regular and non-regular snores and to uncover if their features enable to distinguish between different levels of SAHS severity subjects: AHI (Apnea-Hypopnea Index) $<5h^{-1}$, $AHI <10h^{-1}$, $AHI <15h^{-1}$ and $AHI <30h^{-1}$. These four different levels are proposed by physicians and clinical experts as criteria for SAHS definition [1;7;8].

II. MATERIALS AND METHODS

A. Signal acquisition

Snoring sound signals were acquired while full-night polysomnography was being performed on the sleep disorders laboratory of the *Hospital Universitari Germans Trias i Pujol* in Badalona, Spain. Snoring sound was recorded with a unidirectional electric condenser microphone placed over the trachea at the level of the cricoid cartilage using an elastic band. The sound signal was amplified and filtered using second order Butterworth pass-band filter between 70 and 2000Hz and digitized with a sampling frequency of 5000Hz and a 12-bit analog/digital converter [5].

B. Database

The respiratory sound signal database consisted of 34 subjects (8 females and 26 males with age range of 37-72 years and Apnea-Hypopnea Index range of 3.7-109.9 h^{-1}) described in Table I.

TABLE I
CHARACTERISTICS OF THE SUBJECTS DATABASE

	AHI	NSnores	Age	BMI	Number
m	37.6	2190	50	28.5	34
sd	30.1	937	10	3.9	(8 F; 26 M)

AHI = Apnea-Hypopnea Index, NSnores= total number of snores, BMI = Body Mass Index, F = female, M= male, m = mean value, sd=standard deviation

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C. Snore identification and Threshold application

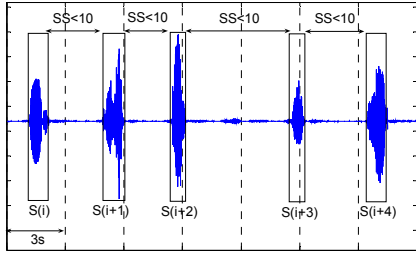


Fig. 1 Example of an excerpt of a snoring sound signal extracted from a subject from our database

Snoring episodes were identified by a proficiently trained and validated automatic detector and analyzer [5;9](Fig1).

Let SS be the time interval between successive snores:

$$SS(i) = S_{on}(i) - S_{on}(i-1)$$

$$i = 1, \dots, NSnores$$

where $S_{on}(i)$ is the onset of the detected i th snore $S(i)$ and $NSnores$ is the total number of detected snores.

Previous studies never offered a proper and decisive explanation for the fact that all time intervals between snores should be considered if they have less than 10 seconds [6;10]. The 10 second threshold (TH_{10}) is based on the accepted convention that an air flow cessation that lasts more than 10 seconds is scored as an apnea[7].

Since we are interested in selecting regular snore episodes from all night (6 hours) sequences, we applied two different thresholds to the $SS(i)$ in order to identify consecutive snoring respiratory cycles.

The adaptive threshold, $TH_{adaptive}(i)$, is defined as follows:

$$TH_{adaptive}(i) = \begin{cases} \theta, & i < 10 \\ A + B, & \text{otherwise} \end{cases}$$

$$A = (1 - \delta) \frac{\sum_{i=10}^j SS(i-1) H[TH_{adaptive}(i-1) - SS(i-1)]}{\sum_{i=10}^j H[TH_{adaptive}(i-1) - SS(i-1)] - 1}$$

$$B = \delta \frac{\sum_{i=10}^j SS(i-1) H[TH_{adaptive}(i-1) - SS(i)] + SS(i)}{\sum_{i=10}^j H[TH_{adaptive}(i-1) - SS(i)]}$$

where $\theta=10$ is a constant threshold, $\delta=0.1$ is the significance assigned to i th SS for computing the adaptive threshold $TH_{adaptive}(i)$ at the i th snore and $H[\beta]$ is the Heaviside step function, whose value is 0 for $\beta < 0$ and 1 for $\beta \geq 0$.

The median threshold, TH_{median} , is defined as follows:

$$SS_{10} = \{ SS(i) \mid SS(i) < 10 \}$$

$$TH_{median} = Median(SS_{10}) + Std(SS_{10})$$

Let $R_{SS}(i)$ be the time interval between successive regular snores:

$$R_{SS_{adaptive}}(i) = SS(i) \mid_{SS(i) < TH_{adaptive}(i)}$$

$$R_{SS_{median}}(i) = SS(i) \mid_{SS(i) < TH_{median}}$$

Let A_Snores , R_Snores and NR_Snores be all snores, the selected *regular* snores and *non-regular* snores, respectively:

$$A_Snores = \{S(i)\}$$

$$R_Snores_{adaptive} = \{S(i) \mid R_{SS_{adaptive}}(i)\}$$

$$NR_Snores_{adaptive} = \{S(i) \mid S(i) \notin R_{SS_{adaptive}}\}$$

For instance, in Fig.1, $S(i+3)$ would belong to the group of $NR_Snores_{adaptive}$.

D. Parameters and Features of Snores

The parameters studied were: $R_{SS}(i)$, the time interval between successive *regular* snores, and $IMean(i)(dB SPL)$, the mean snore intensity of $S(i)$. The features computed from each parameter are shown in Table II.

TABLE II
FEATURES DERIVED FROM EACH PARAMETER

Name	Description
M	Mean value
Std	Standard Deviation
CV	Coefficient of Variation
$p25$	25 th percentile
$p50$	50 th percentile
$p75$	75 th percentile
$Mode$	Mode
sIQ	Semi-Interquartile Range
$Kurt$	Kurtosis of the probability distribution
$Skew$	Skewness of the probability distribution
Max	Maximum value
RMS	Root mean square

III. RESULTS

We applied $TH_{adaptive}$, TH_{median} and TH_{10} to the $SS(i)$ of all 34 subjects. In the case of $TH_{adaptive}$ the M , $p75$, $Skew$ and RMS features were significantly different in subjects with $AHI < 30h^{-1}$ and in subjects with $AHI \geq 30h^{-1}$, with statistical significance $p < 0.001$ in the Mann-Whitney U test (Table IIIa). Moreover, the results were also favourable for the Std and sIQ features when distinguishing between groups of subjects with AHI above and under $5h^{-1}$ and $10h^{-1}$ ($p < 0.05$).

For the $R_{SS}(i)$ selected after applying TH_{median} , the features did not perform such good results (Table IIIb). The p-values obtained for all features while differentiating between subjects with AHI of 5, 10 and $15 h^{-1}$ did not have statistical significance ($p > 0.05$). The only significant differences ($p < 0.05$) were obtained for seven features when comparing the groups of subjects with AHI above and under $30h^{-1}$.

With TH_{10} there were no statistically significant differences observed for any feature.

To observe in what extent the $TH_{adaptive}$ offered better results, we computed the histograms of the $R_{SS_{adaptive}}$ for all 34 subjects. The average of the histogram envelopes were calculated and drawn for two groups with different levels of severity: $AHI < 15h^{-1}$ (Fig.2a) and $AHI < 30h^{-1}$ (Fig.2b).

TABLE III

a) Features for $R_SS_{adaptive}(i)$

		M	Std	CV	p25	p50	p75	Mode	sIQ	Kurt	Skew	RMS
p_5		0.2525	0.0402	0.3799	0.3520	0.3799	0.0696	0.3799	0.0296	0.2307	0.4091	0.1127
p_10		0.2157	0.0080	0.4660	0.3056	0.4162	0.0521	0.4921	0.0299	0.1129	0.2321	0.0708
p_15		0.0632	0.1030	0.1199	0.1491	0.2225	0.0485	0.7177	0.2518	0.1112	0.0403	0.0223
p_30		0.0096	0.0733	0.0378	0.0179	0.0316	0.0096	0.8253	0.1501	0.0289	0.0077	0.0043
G AHI<30	m	1.853	0.919	0.772	1.406	1.825	2.271	0.844	0.432	19.545	1.062	2.146
	s	0.861	0.311	0.699	1.086	1.049	1.089	1.188	0.397	21.394	2.488	0.696
G AHI>=30	m	0.918	0.701	1.416	0.651	0.810	1.042	0.585	0.196	55.814	4.777	1.240
	s	0.898	0.301	0.812	0.943	1.040	1.060	0.972	0.126	70.144	4.475	0.826

b) Features for $R_SS_{median}(i)$

		M	Std	CV	p25	p50	p75	Mode	sIQ	Kurt	Skew	RMS
p_30		0.0240	0.2902	0.0146	0.0162	0.0450	0.0854	0.8385	0.0346	0.0240	0.0179	0.0413
G AHI<30	m	2.564	0.904	0.361	2.155	2.712	3.106	1.145	0.476	5.633	-1.067	2.736
	s	0.405	0.307	0.140	0.615	0.414	0.459	1.297	0.318	3.156	0.712	0.390
G AHI>=30	m	2.083	0.991	0.533	1.443	2.192	2.762	0.905	0.659	3.361	-0.390	2.331
	s	0.727	0.316	0.224	0.872	0.869	0.816	1.223	0.298	1.913	0.616	0.713

c) Features for I_{mean} of $NR_Snores_{adaptive}(i)$

		M	Std	CV	p25	p50	p75	Mode	sIQ	Kurt	Skew	Max	RMS
p_5		0.0100	0.0892	0.5371	0.0017	0.0100	0.0149	0.3520	0.0789	0.0789	0.0179	0.0696	0.0149
p_10		0.0521	0.0336	0.2002	0.0265	0.0469	0.0376	0.4921	0.0299	0.0235	0.0420	0.0469	0.0640
p_15		0.0530	0.0064	0.0146	0.0530	0.0632	0.0367	0.8143	0.0044	0.0044	0.0632	0.0302	0.0579
p_30		0.0532	0.0026	0.0038	0.0578	0.0532	0.0378	0.7598	0.0007	0.0020	0.0792	0.0240	0.0532
G AHI<30	m	50.753	8.147	0.159	44.584	50.481	56.466	43.531	5.941	3.099	0.319	74.637	51.415
	s	7.175	1.967	0.024	6.813	8.744	9.092	9.374	2.056	1.292	0.729	6.406	7.341
G AHI>=30	m	54.937	10.278	0.186	46.299	55.255	63.205	44.367	8.453	2.249	0.038	78.761	55.906
	s	4.443	1.980	0.027	3.161	5.370	6.431	10.462	2.202	0.773	0.417	5.769	4.660

p_X: Statistical Significance in Mann-Whitney U Test. Subjects with AHI under X from subjects with AHI above X.
 G AHI < 30: group of subjects with AHI under 30h⁻¹, G AHI >= 30: group of subjects with AHI above 30h⁻¹

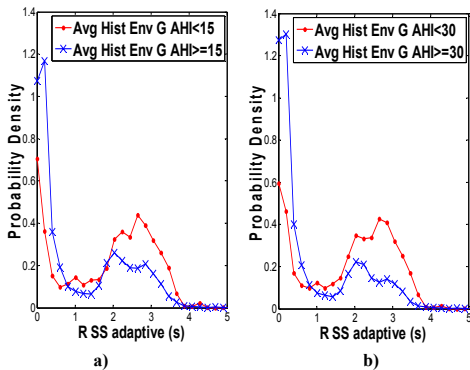


Fig. 2 Average histogram envelopes of $R_SS_{adaptive}$. a) for subjects with AHI above and under 15h⁻¹ b) for subjects with AHI above and under 30h⁻¹.

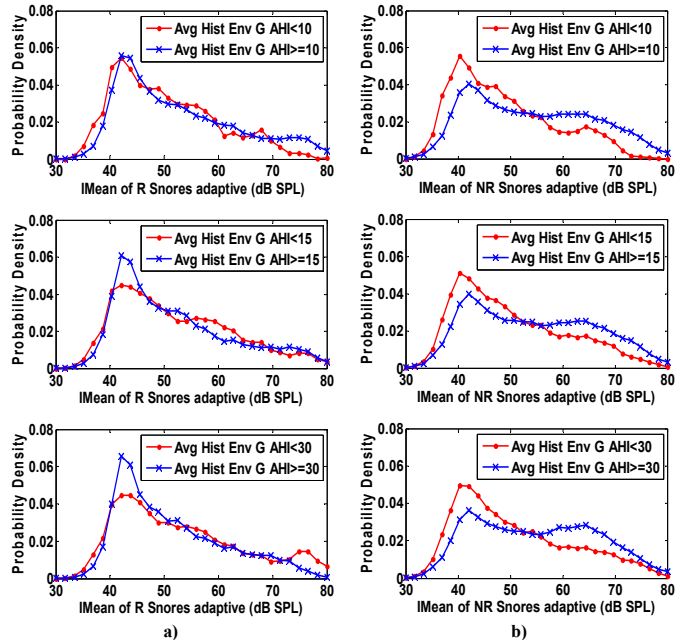


Fig. 3 Average histogram envelopes for I_{Mean} of a) $R_Snores_{adaptive}$ and b) $NR_Snores_{adaptive}$ with contrasting groups of AHI degrees of severity: 10h⁻¹, 15h⁻¹ and 30h⁻¹.

We can observe a clear distinction between the shape of the envelopes of subjects with AHI above and under 15h^{-1} and 30h^{-1} , which confirm the p-values obtained. Moreover, we can observe that the number of R_SS events under 1 second is much higher for subjects with AHI greater than 15h^{-1} or 30h^{-1} . This indicates that most severe patients tend to snore in consecutive breathing events, i.e. they snore in consecutive inspiration and exhalation events.

Since $TH_{adaptive}$ performed better than TH_{median} we decided to analyze quantitatively the mean intensity of $R_Snores_{adaptive}$ and $NR_Snores_{adaptive}$.

In the case of $R_Snores_{adaptive}$ there were no *Imean* features for which the p-value was under 0.05 significance level. On the other hand, there are 6 *Imean* features derived from non-regular snores that show high statistically significant differences ($p < 0.001$) between subjects from contrasting groups of AHI severity (Table IIIc).

We computed the *Imean* histograms for the regular and non-regular snores (Fig.3).

With respect to regular snores (Fig.3a) the shape of the histograms is very similar for the two groups with contrasting AHI. Conversely, the results obtained for non-regular snores (Fig.3b) show utterly different shapes for the two groups of subjects. All 3 plots shown on Fig.3b make evidence that non-regular snores from subjects with higher AHI have a mean intensity predominantly above 55dB SPL with respect to subjects of lower AHI.

IV. CONCLUSIONS

The application of two distinctly mathematically structured thresholds to the time interval between successive snores of 34 subjects was essential to properly select regular snores from all-night snore episode sequences. $TH_{adaptive}$ outperformed TH_{median} on that purpose which is intuitively explained since the former takes into account the evolution of $SS(i)$ through all night sleep as it is based on the concept of an adaptive estimation.

We observe that the time interval between successive regular snores has distinct distribution for subjects with high and low levels of AHI. The R_SS events under one second are much more frequent for subjects with high AHI index since they have propensity to snore in consecutive inspiration and exhalation events. In addition, several $R_SS_{adaptive}$ features allowed the statistical distinction of subjects with high and low levels of AHI.

Regular snores have very similar mean intensity values for all 4 levels of AHI severity considered: $AHI < 5\text{h}^{-1}$, $AHI < 10\text{h}^{-1}$, $AHI < 15\text{h}^{-1}$ and $AHI < 30\text{h}^{-1}$. On the other

hand, in the case of non-regular snores we can observe very different shapes on the mean intensity histograms for subjects with opposite AHI degrees of severity, which were confirmed by statistically significant differences between populations. Furthermore, we found that non-regular snores from the most severe SAHS subjects present very frequently mean intensity values above 55dB SPL with respect to subjects of lower AHI.

This makes evidence that non regular snores carry a large extent of information with respect to the screening of SAHS based on sound intensity.

Once we classify, from a whole sequence of snores, the ones that are regular and the ones that are non-regular, we can study these two groups of snores separately and explore its potential to screen subjects with SAHS.

The concept of regular snores is a new and promising approach to study the snore mechanism production and can help evaluating the performance of already available techniques being applied to snoring.

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