New insights into the scoring of respiratory events based on alternative sensors: A comparative effectiveness study

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Abstract— **In this study we compare the traditionally scoring of apnea hypopnea events (based on the respiratory flow with oxygen desaturation) with the obtained by applying an alternative methodology (based on the Respiratory Inductance Plethysmography flow estimation and oxygen saturation variability features: MAD and IQR), in 23 polisomnographic recordings. Two new models were proposed and compared with the standard one. The Apnea-Hypopnea Index was measured and root mean square was computed with the expert's scores. Patients were classified with the American Academy of Sleep Medicine recommended rules. Results indicate an improvement in AHI estimation using the model based on the RIPflow and the SpO_2MAD.**

Keywords— **Apnea, AHI, RIPflow, SpO_2 variability.**

I. Introduction

The sleep apnea-hypopnea syndrome (SAHS) is mainly characterized by the recurrence of both total breathing cessation (apnea events) and significant airflow reduction (hypopnea events) during sleep time [1]. It has been reported that SAHS affects severely to 1 in 15 adults, can induce a great amount of damage to all body systems and is associated with increased secondary cardiovascular morbidity and mortality [2].

The recommended rules for scoring respiratory events are detailed into the task force of the American Academy of Sleep Medicine [3]. Apnea in adults is scored when there is a drop in the peak respiratory signal excursion by $\geq$ 90% of pre-event baseline for $\geq$ 10 seconds. Hypopnea in adults is scored when the peak signal excursions drop by $\geq$ 30% of pre-event baseline for $\geq$ 10 seconds in association with either $\geq$ 3% arterial oxygen desaturation or an arousal.

Currently, oronasal airflow sensors (OAS), and blood oxygen saturation sensor are considered as the standard sensors for apnea and hypopnea diagnosis.

The respiratory inductance plethysmography (RIP) signals to be used as alternative sensors for apnea and hypopnea detection specified in the task force [3] included the RIPsum which is the sum of the thorax and abdomen belt signals and the RIPflow (the time derivative of the RIPsum), an estimation of the airflow signal. During apnea these two signals show absent or minimal excursions, and during hypopnea, the excursions are diminished compared with baseline breathing.

As regards the detection of blood oxygen, the desaturation associated with a respiratory event is defined as a drop from a baseline SpO_2 preceding the event. However, no "baseline SpO_2" has been considered as standard since it is a no linear signal: the same drop percentage in the SpO_2 implies different variations in the arterial oxygen pressure depending on the baseline considered [3].

Studies have evaluated the accuracy of RIPsum or RIPflow to detect apneas and hypopneas. The work of Thurnheer et al showed good agreement in the measured with these signals with the pneumotachograph [4]. Another study proposed a method based on ensemble learning to estimate the respiratory flow, the thoracic respiratory effort and the abdominal respiratory effort from acceleration of suprasternal notch, the thorax and the abdomen, respectively [5].

In a recent research, Kogan *et al* showed that an improvement in sensitivity and specificity could be obtained when scoring hypopneas by RIPsum channel when compared with both the recommended and acceptable criteria of the American Academy of Sleep Medicine [6].

In this work, we propose an alternative way to measure the alterations of the oxygen saturations during respiratory events in different models using the respiratory flow and the RIPflow, and compare them by the AHI and the patient classification, validating the results by comparing with the physicians scores available at the St. Vincent's University Hospital / University College Dublin Sleep Apnea Database [7].

II. Materials and Methods

A. Database

The database used is freely available in Physionet's web site [8]. It contains 25 full overnight PSG records of patients (age: 50±18 years, 21M and 4F) with suspected sleep-

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disordered-breathing. The recording lasts from 5.9 to 7.7 hours. It also includes sleep stages and respiratory annotations done by experts with the respiratory event start and last; and event classification (Central Apnea/Hypopnea, Obstructive Apnea/Hypopnea and Mixed events).

In this study, the Respiratory Flow, RIPSum and SpO_2 signals, sampled at 128Hz, were used. Respiratory Flow is a calibrated signal expressed in liters/seconds and SpO_2 is the percentage of blood oxygen saturation. The RIPSum signal is the sum of Thorax and Abdomen respiratory effort, which is a non-calibrated signal.

The records UCDDB006 and UCDDB011 were not used because they have problems in the recording of the signals of interest for our purpose.

B. Signal Pre-processing

A digital filter is applied to Flow and RIPSum signals, to obtain the spectral range that defines the respiratory process, which comes up to 0.5Hz [9]. The bidirectional 4th order Butterworth low-pass filter has been selected with cut-off frequency in 0.5Hz. It has the zero-phase distortion advantage.

In order to obtain the RIPFlow, a five points Differentiator-Integrator filter is applied to the RIPSum. It derives the input signal up to the desired 0.5 Hz frequency and attenuates the rest.

The filtered Flow, RIPSum and RIPFlow signals are shown in Fig. 1.

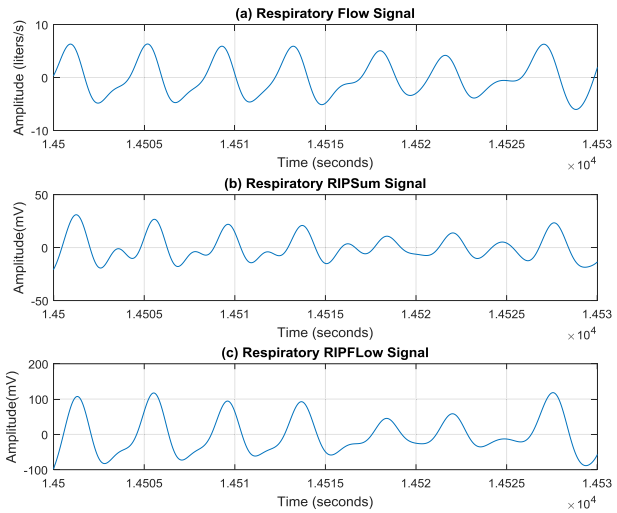

Fig. 1: (a) Respiratory Flow Signal; (b) Respiratory RIPSum Signal, and (c) Respiratory RIPFlow signal.

The SpO_2 signal is resampled to 32 Hz to decrease the computational cost, according to AASM – Manual for the Scoring of Sleep and Associated Events that recommends a minimum of 25 Hz [10].

C. Breathing and SpO_2 signal processing

The breathing baseline (BB) is defined as 3 largest breaths in the 2 minutes preceding onset of the event, in individuals without a stable breathing pattern, and it is valid for Flow and RIPFlow signals [3]. In the present work, BB is estimated to determine Thresholds (*Th*) that are used to convert a respiratory signal (RS) in square signals (SQS).

The RS is divided into 1 minute last segments and each one is associated with a *Th*. In order to compute it for a present segment (PS), the 2 minutes previous are analyzed. This previous segment (PRS) is divided into 3 sub-segments (SS) and for each one the mean of the 3 largest local maximum is calculated. Then the *Th* for PS is computed as the median of the 3 means of the 3 SS.

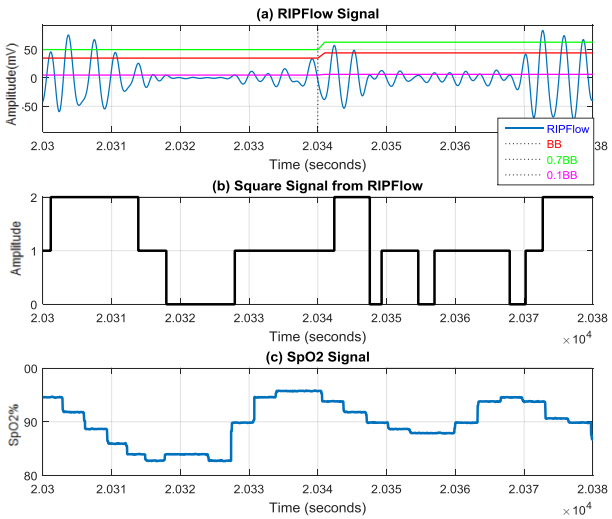

Fig. 2: (a) RIPFlow with Breathing baseline (BB), 0.7BB and 0.1BB; (b) Square signal from RIPFlow and SpO2 signal.

The SQS is generated for each RS, based on definition of apnea and hypopnea. If RS was lower than 70% of *Th*, then SQS was assigned with 1, and with be 0 if the RS is lower than 10% of *Th*. The SQS was assigned with 2 if the RS is larger than 70% of *Th*. This process and the estimated BB are shown in Fig. 2 (a) y (b).

The intervals where SQS is 1 or 0 were computed. If an interval is 0 for 10 or more seconds, it is scored as respiratory event (RE). On the other hand, if an interval is 0 or 1 for 10 or more seconds, it is scored as possible respiratory event (PRE) and the SpO_2 is then analized. In this sense, the following 3 approaches were used.

The first is based on the traditional method, which is the SpO_2 drop of 3% of pre-event SpO_2 baseline (SB). The SB

is estimated to obtain a *Th* for each minute segment using the same method that in RS. Then, the detected event is scored as RE, if SpO_2 signal drop 3% of *Th* during a PRE ± 2 seconds.

The second is the Mean Absolute Deviation (MAD) of SpO_2 and the third is Interquartile Range (IQR), of SpO_2 signal during a PRE ± 2 seg. These two features estimate the variability of the SpO_2 signal. Then a fixed *Th*, previously set in the algorithm, is used to score the event. The Fig. 1 (c) shows the SpO_2 signal.

Table 1 describes the signals and features used in each analyzed model.

Table 1 Models for Respiratory Events

Model	Respiratory Signal	SpO_2 Analysis
Model 1 (M1)	Flow	Standard
Model 2 (M2)	Flow	MAD
Model 3 (M3)	Flow	IQR
Model 4 (M4)	RIPFlow	Standard
Model 5 (M5)	RIPFlow	MAD
Model 6 (M6)	RIPFlow	IQR

To compare the models performance, the apnea/hypopnea per hour index (AHI) is computed as in eq (1) [10].

$$\mathrm{AHI} = \frac{\text{Respiratory Events (apneas/hypopneas)}}{\text{Total Sleep Time (in seconds)}} \cdot 60 \qquad (1)$$

III. Results

Respiratory Apnea/Hypopnea events were scored for each record using all 6 studied models and the AHI was computed. The results were contrasted with the physician's score available from database and the Root Mean Square Error (RMSE) was computed for each model with eq (2).

$$\mathrm{RMSE} = \sqrt{\frac{1}{n}\sum_{i=1}^{n}\left(\mathrm{AHI}_{DB(i)} - \mathrm{AHI}_{E(i)}\right)^2} \qquad (2)$$

n: Total Records
AHI_{DB}: AHI from database
AHI_{E}: AHI Estimated with algorithm

The AHI is used to diagnose patients with breathing disordered. The index values < 5/h are considered as Normal, AHI ≥ 5/h but ≤ 30/h are considered Moderate and ≥30/h are Severe (3). Based on these criteria, patients were classified using AHI with the proposed models and physicians' database.

In order to compare models' performance patients were grouped as apneic or not apneic and the following parameters were calculated for each model: Specificity (Sp); Sensitivity (Se); and Accuracy (Acc).

Table 2 shows these results. The RIPFlow combined with SpO_2-MAD model (M5) present the lowest RMSE value (5.4), as well as highest Se, Sp and Acc combination.

Table 2 RMSE, Sensitivity, Specificity and Accuracy

	M1	M2	M3	M4	M5	M6
RMSE (RE/h)*	14.32	9,84	10,84	10,70	5,49	5,67
Se%	100	94,736	94,736	100	100	100
Sp%	25	25	75	25	75	75
Acc%	86,956	91,304	91,304	86,950	95,652	95,652

*RE/h: Respiratory Event per hour

IV. Discussion and Conclusions

The AASM recommended methodologies to detect respiratory events are based in the usage of the oxygen desaturation or arousals to determine a hypopnea event.

In this work, 6 different models (Table 1) to detect respiratory events have been computed and the results have been compared by the AHI in 23 subjects. The model M1 uses the recommended methodology based in the drop of respiratory flow signal and 3% oxygen desaturation, needing the baseline measures for both signals, with the inconvenient that there is no consensus on how to measure the SpO_2 baseline. We have introduced a new alternative method to detect respiratory events changing this measure by an estimation of the SpO_2 variability. In models M2 and M3 the respiratory flow signal is combined with the MAD and IQR of the SpO_2, respectively. We also studied what happens when the respiratory flow signal is changed by the RIPflow estimation. In this sense, the models M4 – M6 represent the RIPflow (also defined in the AASM) combined with the 3% oxygen desaturation, the SpO_2MAD and the SpO_2IQR, respectively.

As it can be seen in the first line of Table 1, the RMSE for models based on the flow signal are generally higher than the ones based on the RIPflow, except for M4, in which the arterial oxygen is measured in the traditionally 3% drop. Lower RMSE values are obtained when the arterial oxygen variations are estimated with MAD and IQR. As regards patient diagnostic, when severe and moderate SAHS are grouped, the Sensitivity, Specificity and Accuracy values for all models are acceptable and consistent with the indicated by physicians, but the higher values are obtained

with M5 and M6, which used the RIPflow and SpO_2 variability features. On the other hand, only 4 subjects had AHI<5, so, the lower values in Specificity reflect the false negatives misclassifications. The best model may identify 3 of the 4 normal subjects. However, we consider for that knowledge more normal recordings are needed.

We supposed that the improvement observed between M1 and M2 is related to the apnea/hypopnea events are associated with desaturation and re-saturation changes in arterial oxygen [3].

Based on these results we may assure that using the RIPflow with the MAD of SpO_2 signal instead of the baseline 3% drop may improve the AHI and consequently, the patient diagnostic. The RIPflow improvement is consistent with the recently published Kogan's work [6], who showed better results by using RIPsum.

Another important advantage of the proposed methodology is the simplicity in the signal acquisition; it also is no invasive and does not affect patient comfort, as opposite to the oronasal flow sensor, which comfortless produce a lower quality in the polisomnography study.

Besides, the threshold analysis of the RIPflow and the variability SpO_2 measurements implies a low computational cost; it is easily computed and may be implemented in any processor. These qualities make it suitable for wireless applications. In this sense, the following expectations will focus in the event classification and the implementation in a portable device.

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Conflict of Interest

The authors declare they have no conflict of interest.

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