Respiratory Pattern Analysis for Different Breathing Types and Recording Sensors in Healthy Subjects

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Abstract—Accurate monitoring of respiratory activity can lead to early identification and treatment of possible respiratory failure. However, spontaneous breathing can vary considerably. To quantify this variability, this study aimed at comparing the breathing pattern characteristics obtained from several recording sensors during different breathing types. Respiratory activity was recorded with a pneumotachograph and two inductive plethysmographic bands, thoracic and abdominal, in 23 healthy volunteers (age 21.5 ± 1.2 years, 13 females). The subjects were asked to breathe at their natural rate, in successive stages: first freely, then through their nose, nose and mouth, mouth alone, and finally deep and shallow. Both band signals were compared to the pneumotach-derived (gold standard) volume signal. The time series of inspiratory and expiratory duration, total cycle duration and tidal volume were estimated from each of these signals, and also from the sum of the thoracic and abdominal bands. This composite signal showed the highest correlation with the volume signal for almost all subjects, and also had a significantly higher correlation with those obtained from the gold standard volume, compared to either band. In general, breathing parameters increased from basal to nose-mouth breathing, and from the gold standard volume, compared to either band. Women exhibited a significantly longer exhalation phase than men during deep breathing, in the combined bands and the gold standard volume. In conclusion, variations in respiratory cycle morphology in different breathing types can be well captured by the simple addition of abdominal and thoracic band signals.

Clinical Relevance—Breathing pattern variability can be identified by the combination of abdominal and thoracic bands.

I. INTRODUCTION

In clinical practice, respiration is most commonly measured visually, by counting the movements of a patient’s chest over 30 seconds. However, more and more devices and tools are generated to describe the behavior of the respiratory system, and there is a growing demand to generate parameters that measure it. Further, there are many applications related to the recording of these parameters, such as monitoring in clinical and work environments, sports and exercise activities, or when resting at home, among others.

Respiratory rate (RR) is one of the main parameters to measure, a vital sign that responds to a variety of stressors. Tidal volume (Vt), the other determining parameter of minute ventilation, is directly related to the metabolic requirements of the human body. RR and Vt are behavioral and metabolic components of minute ventilation, respectively [1,2]. These parameters can be measured by contact-based devices (such as pneumotachograph, inductance plethysmography, etc.) or contactless (such as vison systems, temperature cameras, etc.). Massaroni et al (2019) presents an overview of contact-based methods available to record respiratory airflow, sounds, air temperature, air humidity, air components, chest wall movements, and modulation of the cardiac activity [3-6].

The gold standard of respiratory flow measurement is the pneumotach; however, the thoracic and abdominal inductive plethysmographic bands allow to record the volume signal. Respiratory activity can also be derived from other signals such as ECG or photo-plethysmographic (PPG) [7-9]. All these signals are of clinical interest and their quality must be evaluated. Respiratory patterns show great variability in healthy subjects, patients with different diseases, and with different ways of breathing: through the nose, mouth, shallow, deep, etc.

In this work, we propose to compare the characteristics of the respiratory pattern obtained from the volume signals, analysing their variability for different breathing modes through the time series: inspiratory time (Tins), expiratory time (Texp), total breathing time (Ttot), inspiratory volume (Vins) and expiratory volume (Vexp).

II. MATERIAL AND METHODS

A. Database

The respiratory flow signal and the thoracic and abdominal activity were recorded with a pneumotachographic transducer TSD117 and two Respiratory Inductance Plethysmography (RIP) bands, connected to an MP160 Biopac Pro system. A group of 23 randomly selected healthy young volunteers (non-smokers, age 21.5 ± 1.2 years, 13 women) were analyzed. All the subjects gave their written consent to participate in the study and it is part of the clinical protocol.
PR047/21 to study the respiratory pattern of patients with pneumonia.

B. Breathing protocol

Subjects were asked to breathe at their natural rate while carrying out several breathing types: first, a 10 minute period of undirected breathing (basal), followed by three 5 minute periods of inhaling and exhaling through the nose (NN), nose inhaling and mouth exhaling (NM), and mouth inhaling and exhaling (MM); and, finally, two 2 minute periods of shallow (SH) and deep (DP) breathing, respectively (Fig 1).

The time series were post-processed with an 8-cycle median filter to automatically get rid of possible misdetections or false detections.

E. Statistical analysis

The different respiratory signals and time series were compared through the coefficient of correlation, defined as

\[ \rho_{xy} = \frac{\text{Cov}[x(t), y(t)]}{\text{Var}[x(t)]^{1/2} \text{Var}[y(t)]^{1/2}} \]

where

\[ \text{Cov}[x(t), y(t)] = \text{E}[(x(t) - \bar{x})(y(t) - \bar{y})] \]

\[ \text{Var}[x(t)] = \text{E}[(x(t) - \bar{x})^2] \]

\[ \text{E} \{ x \} \]

The different respiratory cycle parameters were statistically compared among the different breathing types by means of the Wilcoxon signed rank test for paired samples. Gender differences in each breathing type were analysed using Mann-Whitney U test.

III. RESULTS

Figure 4 shows, for each of the subjects, the correlation coefficient between the pneumotachograph-derived volume signal and the thoracic and abdominal band signals, as well as their summation. It can be observed that in some subjects the abdominal band correlates better than the thoracic band, and in some others the behaviour is exactly the opposite. This might indicate that some subjects have a predominantly thoracic respiration, whereas some others breath on their abdomen. In either case, what we see is that the two bands combined with a simple summation have the highest
correlation with the volume signal in all but one subject. In this particular subject, the thoracic and abdominal band signals were almost out of phase, which is not the general case.

The result of correlating the time series of the respiratory parameters ($T_{\text{ins}}$, $T_{\text{exp}}$, $T_{\text{tot}}$, and $V_T$) obtained from the volume signal, with those obtained from the thoracic and abdominal band signals, as well as their summation, are shown in Figure 5. The parameters obtained from the combined abdominal plus thoracic bands show the highest correlation, compared to any of the bands alone. Differences in the abdominal band were statistically significant in all parameters, while, in the thoracic band, differences were statistically significant only for $T_{\text{ins}}$ and $T_{\text{exp}}$. This suggests that in a practical situation, when only one band can be used, the thoracic band would provide a more similar respiratory pattern to that obtained with a pneumotachograph.

In Figure 6, we can observe the dynamical evolution of the respiratory pattern parameters across the different breathing types, depending on the signal used for their computation. The inspiratory time $T_{\text{ins}}$ has been normalized with respect to the cycle duration $T_{\text{tot}}$ to allow the comparison between subjects, who do not necessarily breathe at the same rate. The parameter $T_{\text{exp}}/T_{\text{tot}}$ has been excluded, as its dynamics are exactly the opposite of its complementary $T_{\text{ins}}/T_{\text{tot}}$.

The respiratory cycle duration (Figure 6–b) – equivalent to the inverse of breathing rate – exhibits the same trend in all signals: increasing in basal respiration, in nose-nose and nose-mouth breathing, decreasing in mouth-mouth breathing, with a minimum value during shallow breathing, and a maximum value during deep breathing. Many of these differences were statistically significant (Table 1, 2nd row), and the significance was very similar in all signals. Therefore, as far as breathing rate is concerned, it appears that any of these signals is useful.
for monitoring its evolution, either over time or across different breathing types.

Tidal volume (Figure 6–a) shows the same trend across the different breathing types as the cycle duration, but this trend is poorly visible in the parameters derived from the abdominal signal. The combination of both RIP bands seems to provide lower inter-subject variability in this parameter, as compared to the thoracic band alone, but similar to the one observed in the pneumotach-derived parameters.

Finally, the normalized inspiratory time (Figure 6–c) exhibits a marked decrease during shallow breathing in all of the RIP signals, but this is not visible in the pneumotach-derived parameter. Therefore, it seems that any of the RIP bands, or the combination of both, tend to underestimate the derived parameter.

All respiratory parameters were similar in men and women for most breathing types and signals. However, we have observed a significantly higher relative exhalation time in women in the deep breathing phase for the pneumotach-derived parameters:

\[
\frac{T_{\text{in}}}{T_{\text{tot}}} = 0.478 \pm 0.03 \quad \frac{T_{\text{in}}}{T_{\text{tot}}} = 0.515 \pm 0.03 \quad p < 0.05.\]

This significant difference is also observed in the parameters obtained from the abdominal plus thoracic bands, with almost the same values, but not in any of the two bands alone.

IV. CONCLUSION

In conclusion, dynamic variations in respiratory cycle morphology across different breathing types seems to be well captured by the simple summation of abdominal and thoracic inductance plethysmography band signals. If a single band is to be used, the thoracic one seems to offer the best correlation with the breathing parameters obtained from the pneumotach-derived volume. The present results need to be validated on a bigger database that should also include subjects of a wider age range.

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REFERENCES


