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Respiratory Inductance Plethysmography is suitable for voluntary hyperventilation test.

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Abstract—. **The aim of this work was to evaluate the goodness of fit of a signal issued of the respiratory inductance plethysmography (RIP) derivative to the airflow signal during rest, voluntary hyperventilation, and recovery. RIP derivative signal was filtered with an adjusted filter based on each subject airflow signal (pneumotachography). For each subject and for each condition (rest, voluntary hyperventilation, and recovery) comparisons were performed between the airflow signal and the RIP derivative signal filtered with an adjusted filter obtained either on rest signal or on the studied part of the signals (voluntary hyperventilation or recovery). Results show that the goodness of fit was : (1) higher than 90% at almost all comparisons (122 on 132), (2) not improved by applying an adjusted filter obtained on the studied part of the signals. These results suggest that RIP could be used for studying breathing during voluntary hyperventilation and recovery using adjusted filters obtained from comparison to airflow signal at rest.**

I. INTRODUCTION

RESPIRATORY inductance plethysmography (RIP) is a noninvasive method for measurement of breathing providing rib cage and abdomen cross sectional area changes. The linear combination between rib cage and abdomen cross sectional area changes allows to estimate breathing volume changes. There are very few comparison between airflow and RIP derivative signal in physiological conditions. Eberhard et al. [1] have compared airflow and RIP derivative signal in three different postures (seated, lateral and dorsal supine) and also in control and in two resistive loaded conditions. The fit of RIP derivative to the airflow signal remained well in control condition and at a resistance of ~5 cm H_2O/l/s but lesser at a resistance of ~14 cm H_2O/l/s. The RIP derivative signal was smoothed by using the same low-pass filter for all subjects and all conditions.

Voluntary hyperventilation test have been proposed to test predisposition to the hyperventilation syndrome [2] which is used to describe patient with the somatic symptoms of both hypocapnia and anxiety [3]. RIP allows recording of breathing without using mask (needed for pneumotachography) and thus subjects may not be aware that their breathing is recorded. The aim of the present work was to evaluate the consistency between airflow (pneumotachography) and RIP derivative during voluntary hyperventilation. Airflow and RIP signals were both recorded in healthy subjects during rest, voluntary hyperventilation, and recovery. The RIP derivative signal was processed by a filter calculated with airflow (pneumotachography) taken as the reference signal, for each subject in each of all circumstances. Comparison of the goodness of fit of the filtered RIP derivative to the airflow signal in different conditions was performed in order to determine if the adjusted filter obtained on rest recording could be applied to the other conditions and thus allows to go without the mask during voluntary hyperventilation and recovery.

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II. MATERIALS AND METHODS

A. Materials and experimental protocol

We studied twelve healthy volunteers between 24 and 65 years of age, five of whom were men. All study participants provided informed consent. The study was approved by the relevant ethics committee (CHU Grenoble). Breathing was recorded simultaneously with a flowmeter (Fleish head no.1) and a differential transducer (163PC01D36, Micro Switch) placed on a face mask and with a RIP (Visuresp, RBI). Leaks from around the mask were checked for before the recording was initiated using an infrared CO_2 analyser (Engström Eliza/Eliza MC). End-tidal CO_2 fraction ($F_{ET}CO_2$) was measured continuously using the same apparatus. Subjects were in semi-supine position. Two series of recordings were performed successively: (1) at *rest* (three minutes, Rest1), during *voluntary hyperventilation at each subject's spontaneous breathing rate* (three minutes, HV1), during *recovery* (ten minutes, Rec1), and (2) successively at *rest* (three minutes, Rest2), during *voluntary hyperventilation at 20 breaths/min* (three minutes, HV2), during *recovery* (ten minutes, Rec2). Subjects were encouraged to increase tidal volume in order to descend $F_{ET}CO_2$ to 3.5 %. To impose the breathing rate, an auditory cue was used, which signaled only for the inspiration to begin.

B. Methods

All signals were digitized at a rate of 100Hz. For each recording, we obtained a minimum of 25 breaths at rest up to 150 for the recovery period. The 15 most regular (duration) consecutive breaths of the airflow signal were chosen and formed the reference part. A least squares method was used over this part of signal to obtain a RIP volume signal (VRIP) by combination of rib cage (RCRIP) and abdominal (ABDRIP) signals compared to the integrated flow signal (VPNT):

$$\mathrm{VRIP}_k = \tau\ \mathrm{RCRIP}_k + \alpha\ \mathrm{ABDRIP}_k \qquad (1)$$

where $\tau=2\ \alpha$ was imposed [4]. The derivative of VRIP (FRIP) was then calculated by using centered divided differences:

$$\mathrm{FRIP}_k = (\mathrm{VRIP}_{k+1} - \mathrm{VRIP}_{k-1}) / 2\Delta t \qquad (2)$$

A transfer function was calculated over the reference part between RIP derivative and airflow signal to take out an adjusted filter. Then the adjusted filter calculated on the reference part of signals was applied on the entire recording. The goodness of fit of the filtered RIP derivative to the airflow signals (concordance ρ) was calculated on the entire recording :

$$\rho = 1 - \sum_{k=1}^{N}\left(\mathrm{FRIP}_k - \mathrm{FPNT}_k\right)^2 / \sum_{i=1}^{N}\left(\mathrm{FPNT}_k - \overline{\mathrm{FPNT}}\right)^2 \quad (3)$$

where FPNT_k and FRIP_k are respectively the airflow and the filtered RIP derivative signals at each instant and $\overline{\mathrm{FPNT}}$ is the mean value of FPNT_k over the whole recording. For one subject the concordance was calculated between the standard airflow signal and RIP derivative signal filtered with an adjusted filter based either on reference signals (Rest1) or on HV1, Rec1, Rest2, HV2 and Rec2 signals. For each subject 11 concordances were then obtained applying an adjusted filter calculated on different conditions: concordance of "Rest1 filter" applied to Rest1 signal (Rest1/Rest1), to HV1 (HV1/Rest1) and all other conditions (total 6 concordances) and concordances of adjusted filters calculated on their own conditions (HV1/HV1, Rec1/Rec1, …, total 5 concordances).

III. Results

Fig.1 shows airflow signal (pneumotachography) and RIP derivative signal for HV1 obtained with adjusted filter calculated (a) on Rest1 (concordance = 97.03%), and (b) on HV1 (concordance = 97.88%) for subject #5.

Fig.2 and Fig.3. show concordances expressed in percentage for each subjects and each conditions. The goodness of fit was: (1) higher than 90% at almost all comparisons (122 on 132), (2) not improved by applying a filter adjusted on the studied condition except for subject #4 for which concordance increase from 29.19% to 85.18% when filters are calculated on Rest1, and on HV1 (Fig.3. b)

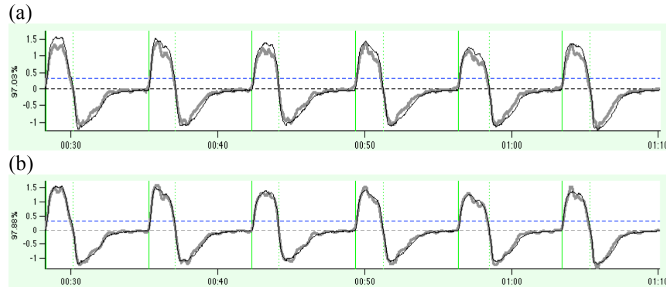

Fig. 1. Subject # 5 - Airflow signal measured by pneumotachography (black thin line) and RIP sum derivative signal for HV1 (grey line) obtained applying an adjusted filter calculated (a) on Rest1, and (b) on HV1.

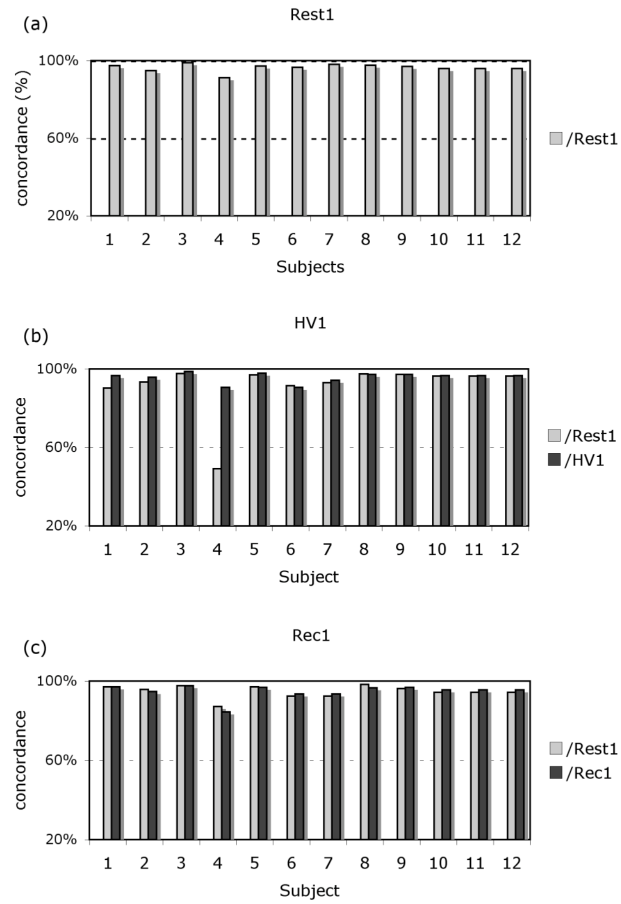

Fig. 2. Concordance- goodness of fit of the RIP derivative to the standard airflow signals expressed in percentage for each subject and each condition: (a) at rest (Rest1), (b) during voluntary hyperventilation at each subject's spontaneous breathing rate (HV1), and (c) during recovery (Rec1). For Rest1 an adjusted filter calculated respectively on Rest1 (grey square, /Rest1) was applied; for HV1 adjusted filters calculated respectively on Rest1 (grey square, /Rest1) and on HV1 (black square, /HV1) were applied; for Rec1 adjusted filters calculated respectively on Rest1 (grey square, /Rest1) and on Rec1 (black square, / Rec1) were applied.

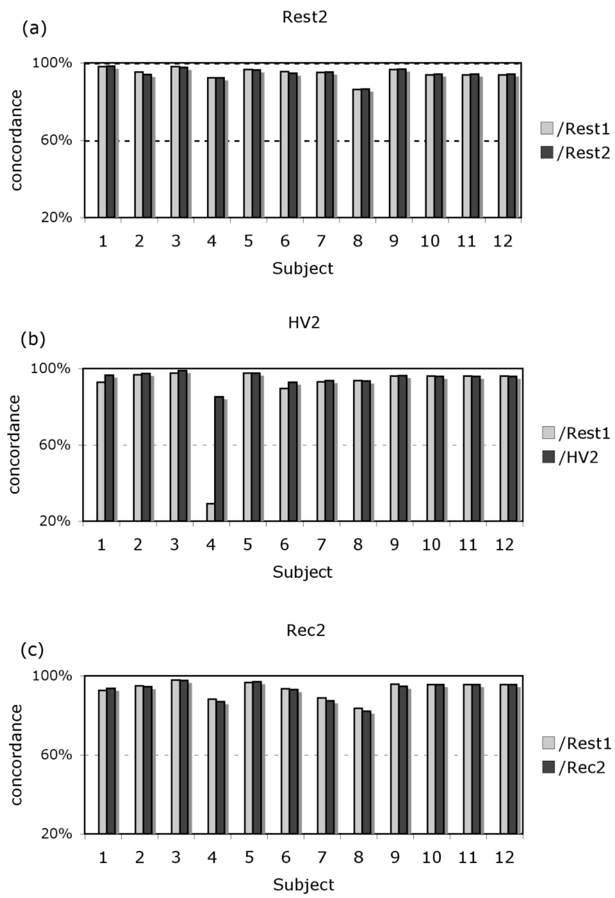

Fig. 3. Concordance- goodness of fit of the RIP sum derivative to the standard airflow signals expressed in percentage for each subject and each condition: (a) at rest (Rest2), (b) during voluntary hyperventilation at 20 breaths/min (HV2), and (c) during recovery (Rec2). For Rest2 adjusted filters calculated respectively on Rest1 (grey square, /Rest1) and on Rest2 (black square, /Rest2) were applied; for HV2 adjusted filters calculated respectively on Rest1 (grey square, /Rest1) and on HV2 (black square, /HV2) were applied, for Rec2 adjusted filters calculated respectively on Rest1 (grey square, /Rest1) and on Rec2 (black square, / Rec2) were applied.

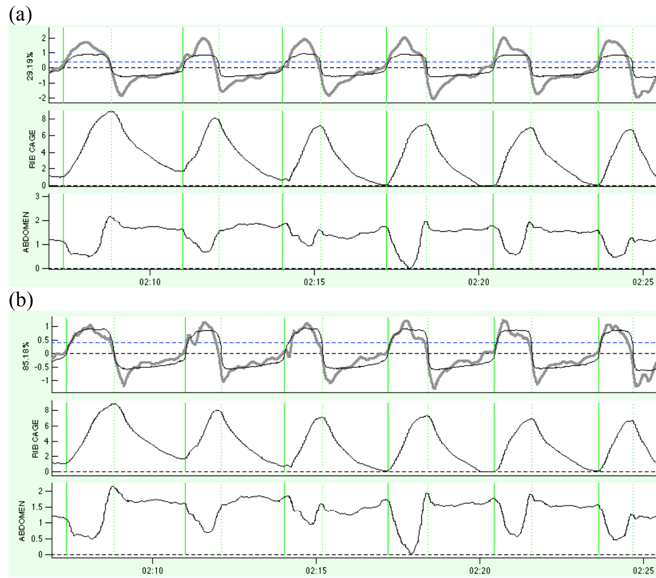

Fig. 4. Subject # 4 - Airflow signal measured by pneumotachography (black thin line) and RIP sum derivative signal for HV2 (grey line) obtained applying an adjusted filter calculated (a) on Rest1, and (b) on HV2, rib cage and abdomen cross sectional area changes.

IV. Discussion

The superimposed airflow and RIP derivative signals (Fig.1) and concordance values presented (Fig. 2 and 3) show that the fit of RIP derivative to the airflow signal is well and not improved by applying a filter adjusted on the studies condition, except for subject #4 (Fig.3.b). Fig.4 shows airflow signal (pneumotachography) and RIP sum derivative signal for HV2 obtained applying an adjusted filter calculated (a) on Rest1 (concordance = 29.19%), and (b) on HV1 (concordance = 85.18%) for subject #4. The unusual (plateaued) shape of abdominal signal may explain the differences obtained by the two methods for this subject.

These results indicate that RIP could be used for studying breathing during voluntary hyperventilation and recovery without a mask, provided that airflow signal was recorded at rest during a short period (about 15 breaths). A limiting condition seems to be that rib cage and abdomen signals show no disturbance. This work suggests that respiratory signals recorded at rest contain a pertinent information usable for respiratory signals recorded in other conditions (voluntary hyperventilation and recovery).

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