Airflow and Volume Profiles Involve Some Respiratory Individual Peculiarities

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***Abstract* — The aim of our research was to evaluate the respiratory individuality during voluntary hyperventilation. 13 healthy subjects following voluntary hyperventilation protocol with the respiratory rate at 20 breaths per minute were recorded twice with one year interval. The airflow signal was decomposed by Fourier transformation into harmonics, the characteristics of first four harmonics made 8 variables complexes that can reproduce the mean airflow profile. The volume profile is represented by triplets including tidal volume, inspiratory and expiratory times. These multivariate complexes (8 variables complexes and respiratory triplets) of in two conditions (repeated recordings after one year interval) was compared by statistic test of similarity. The statistic comparison confirms the respiratory individuality in conditions of hyperventilation test.**

***Index Terms* — harmonic analysis of breathing, individuality of breathing pattern, voluntary hyperventilation.**

I. INTRODUCTION

Dejours and al. (1961) proposed the concept of “Dejours and al. (1961) proposed the concept of “personnalité ventilatoire” as an individual combination of respiratory rate, tidal volume and airflow shape for each subject [1]. Proctor and Hardly (1949) [2] performed the quantitative analysis of the pneumotachograms: acceleration, velocity time, relationships between the points of the airflow trace. These authors reported that the airflow characteristics were reproduced cycle by cycle and during repeated recordings [2].

An important problem is related with the studies of breathing pattern as an expression of oscillatory regulation by the respiratory center- process of obtaining a representative, or average trait of respiratory cycle. One approach is the calculation of averages for certain features of the respiratory cycle, such as the ratios of inspiratory time to duration of respiratory cycle, mean inspiratory flows, values for the peak inspiratory flow [3,4]. Another idea is to divide respiratory airflow into several segments and to calculate averages of these segments [5, 6].

But the study of fundamental individual characteristics of the breathing pattern needs the transformation of the airflow shape in a non-dimensional form. Gray and Grodins (1951) [7] have further proposed the transformation of respiratory tracings to a completely non- dimensional form. Several methods are proposed for obtaining mean airflow profiles (Bachy and al. 1986; Painter and al., 1987; Sato and Robbins, 1998) [8, 9, 10].

Lafortuna and al (1984) [11] performed harmonic analysis of the inspiratory airflow in order to compare the respiration at rest and that in the course of exercise. The harmonic analysis of the whole airflow cycle was proposed by Bachy and al. (1986) [8] and applied in studies concerning the individuality of breathing at rest and different from the rest conditions (Benchetrit and al. 1987, 1989; Shea and al. 1989; Calabrese and al., 1998; Eisele and al. 1989) [12, 13, 14, 15, 16]. However it must be pointed that harmonic analysis can be performed on the regulated airflow cycles were selected according certain criteria.

Our goal was to study the individual characteristics of respiration during voluntary hyperventilation and determine if the individual respiratory traits of the resting breathing are conserved during voluntary hyperventilation.

II. MATERIALS AND METHODS

Subjects: Thirteen healthy volunteers, 9 men and 4 women (mean ± SD height: 171.9 ± 6.5 cm; weight: 73.2 ± 13.8 kg) between 25 and 63 years of age (mean 36.5 ± 12.4) participated in the study. After a description of the experimental protocol, each subject signed a consent form. The experimental protocol was approved by the Institutional Ethics Review Board of the CHU Grenoble.

Experimental protocol (VHT): Volunteers were comfortably laid in semi supine position in a quiet room and were asked to relax and to breathe freely. They wore a face mask on which were mounted a flowmeter (Fleish head No.1) and a differential pressure transducer (163PC01D36, Micro Switch). Leaks from around the mask were checked for, prior to initiating recording, using an infra-red CO_2 analyzer (Engström Eliza/Eliza MC). End tidal CO_2 ($F_{ET}CO_2$) was subsequently measured continuously using the same apparatus. Volunteers were asked to keep their eyes open during the whole recording period. The sequence of the protocol VHT was 3 minutes of rest breath (REST), 3 minutes of voluntary hyperventilation at a breath rate of 20 per minute (VH) and nine minutes of posthyperventilatory period. In this study we made analysis only in the rest and hyperventilation periods. The breath rate of the voluntary hyperventilation period was driven by an auditory cue indicating to subject the beginning of the inspiration, and the depths of tidal volumes were set to decrease $F_{ET}CO_2$ less than 1% below the rest level. The conditions of described protocol were reproduced during second recording over time interval between a month and a year.

Analysis: A breath-by-breath analysis was performed on periods of the protocol ($REST_1$and VH_1 for the first recording, $REST_2$ and VH_2 for the second recording) only for those breaths where swallowing or sighing was not observed.

On the remaining breaths the shape of the airflow profile was quantified for each breath using Fast Fourier transforms of 64 interpolated equidistant points from original digitised airflow cycle (figure 1).

The eight cartesian coordinates (ASTER) of the first four harmonics are enough to quantify the shape of airflow profile (contain more than 95% of the power of breath (Bachy and al., 1986) [8]. Similarly, a mean airflow profile can be reconstructed from a mean ASTER (figure 1). For each recording, a mean ASTER was calculated which allows the reconstruction of a mean airflow profile (Benchetrit and al., 1989; Calabrese and al., 1998) [13, 15].

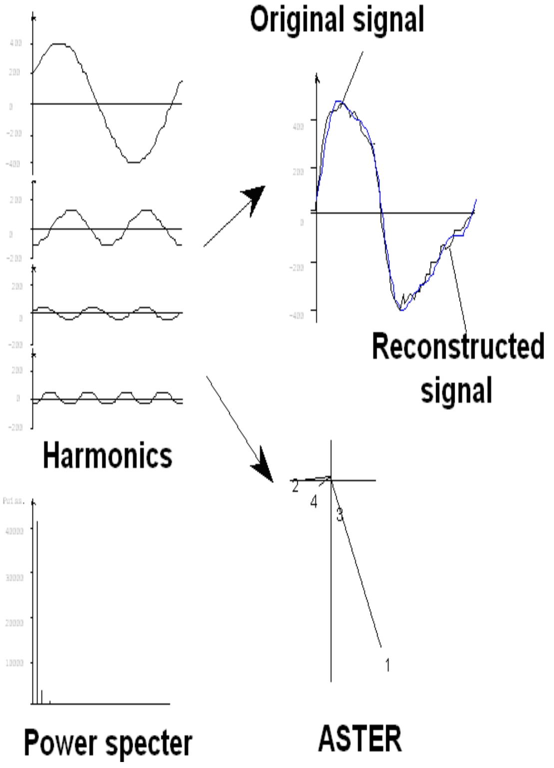

Figure 1. Harmonic analysis of airflow signal. Superposition of original signal and reconstructed signal from the first four harmonics. Fresnel representation-Aster of these harmonics (amplitude and phase). Power specter of harmonics.

In addition, the flow signal was analyzed breath-by-breath in order to obtain tidal volume (VT) by integration of the flow signal, breath duration (TTOT), and inspiratory (TI) and expiratory (TE) durations, minute ventilation VE, VT/TI, TI/TTOT and $F_{ET}CO_2$ were calculated for each breath. Mean values of these variables were then calculated for each recording. The shape of the volume trace, which was termed TRIAD (fig. 2), was also quantified by taking mean TI, TE and VT together (Benchetrit and al., 1989; Calabrese and al., 1998) [13, 15].

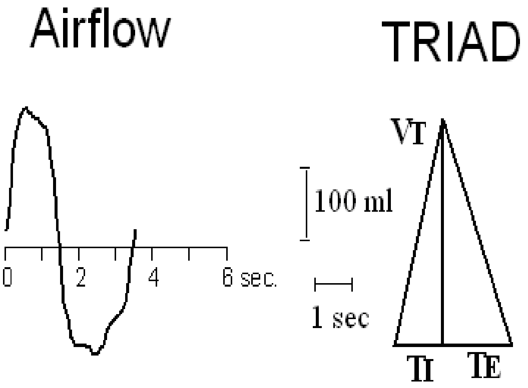

Figure 2. Représentation of air flow cycle and resulting respiratory triplet - TRIAD (VT, TI, TE).

For each subject and each recording the mean value of the respiratory variables duration of respiratory cycle (TTOT), inspiratory (TI) and expiratory (TE) times, the rate of inspiratory time (TI/TTOT), tidal volume (VT), mean inspiratory flow (VT/TI), minute pulmonary ventilation (Ve) and fraction of CO_2 in expired air ($F_{ET}CO_2$), and the multivariate ASTER and TRIAD was calculated. Paired tests (t-paired test for variables with normal distribution and Wilcoxon for non normal distributions) were applied to compare respiratory variables between the following two periods of test: $REST_1$ versus VH_1, and between same period of repeated recordings: $REST_1$ versus $REST_2$ and VH_1 versus VH_2. A statistical analysis for similarity (Benchetrit and al., 1989; Calabrese and al., 1998) [13,15] was designed to test whether a breathing pattern (flow profile-ASTER and volume profile-TRIAD) is maintained within an individual during hyperventilation, relative to the differences occurring between different individuals in the same group under two conditions. The test was applied to compare: VH_1 versus $REST_1$, $REST_1$ versus $REST_2$, VH_1 versus VH_2) for all subjects recorded with the VHT protocols. For the comparisons between ASTERs in order to take into account only the airflow shape, each ASTER was normalized in amplitude. The normalization consisted of dividing each coordinate by the square root of the sum of the square of all eight coordinates. The similarity test was also applied to compare univariate variables: TTOT, TI, TI/TTOT, VT, VT/TI. The differences between two recordings were expressed in terms of distance. The Mahalanobis distance (Mahalanobis, 1936) [17] was used because it is equally applicable to single variables as to the multivariate ASTER and TRIAD. For a single variable (TTOT, TI, TI/TTOT, VT, VT/TI.), this distance is calculated as the square of the difference between the means, divided by the pooled variance. For more than one variable the difference between the means is divided by the pooled covariance matrix for the calculation of the distance. The statistical analysis was designed (Benchetrit and al., 1989; Calabrese and al., 1998) [13, 15] to compare differences between 2 periods within individuals with those differences observed between random pairs of recordings from the two conditions in the same 13 individuals. Statistical significance was set at $p<0.05$.

III. RESULTS

The values of respiratory variables (presented as: mean ± standard deviation) of the rest and hyperventilation periods of 13 subjects recorded twice with VHT protocol and results of paired comparisons between rest and hyperventilation periods are presented on the figure 3

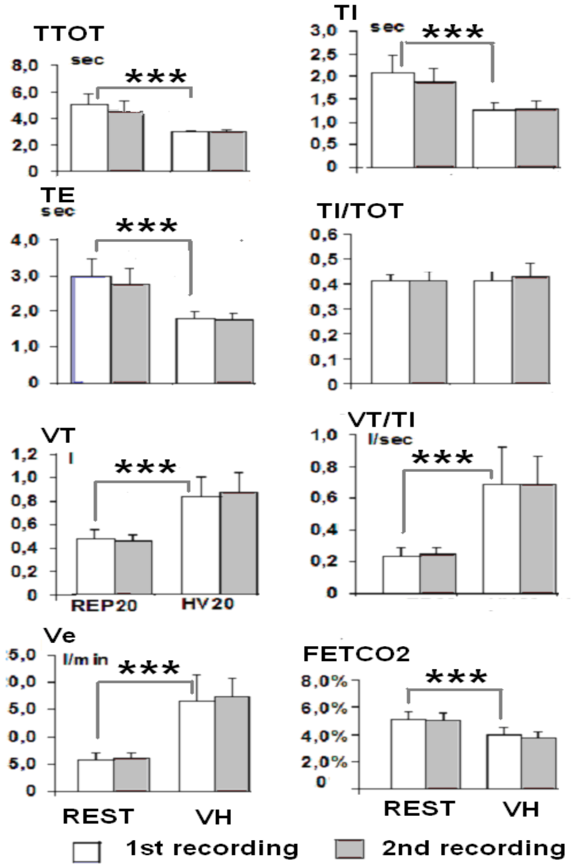

Figure 3. Respiratory variables of the 13 subjects recorded twice following VHT.***points significant difference $p<0.001$

The comparisons of periods of first recording ($REST_1$ versus VH_1) show significant differences between all variables ($p<0.001$) excepting TI/TOT. And comparisons between periods of repeated recordings ($REST_1$ versus $REST_2$ and VH_1 versus VH_2) did not find any significant difference.

Results of similarity test (p values) applied on the airflow (ASTER) and the volume (TRIAD) profiles and of univariate variables: TTOT, TI, TE, VT, TI/TTOT, VT/TI of 13 subjects recorded twice with hyperventilation test VHT after time interval (1month- 1 year) are presented in the table 1. The individual averaged volume profiles (TRIAD) and airflow profiles (ASTER) of these 13 subjects are represented on the fig. 4 and 5.

The ASTERS, TRIADS and univariate respiratory variables are not similar between REST and VH periods. But comparisons between two recordings ($REST_1$ /$REST_2$; VH_1/VH_2) show significant similarity for multivariate ASTER and TRIAD and some univariate variables: TI and TI/TTOT.

Table 1. P values of similarity test applied on ASTER, TRIAD and unvaried variables of 13 subjects recorded twice following VHT.

	VH_1 /VH_2	**$REST_1$ /$REST_2$**	**$REST_1$ /VH_1**
ASTER	<0.001	<0.001	0.9
TRIAD	<0.05	<0.01	0.9
TTOT	0.86	0.07	0.9
TI	<0.01	<0.05	0.9
VT	0.18	0.08	0.9
TI/TTOT	<0.01	0.26	0.9
VT/TI	0.19	0.07	0.9

$p<0.05$ shows significant similarity

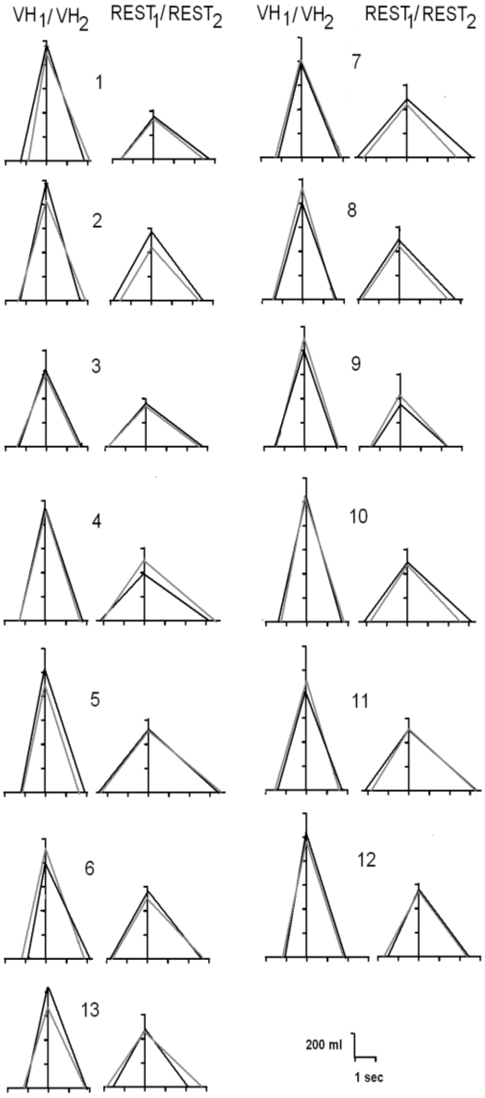

Figure 4. Volume profiles –TRIADS of 13 subjects recorded twice following VHT

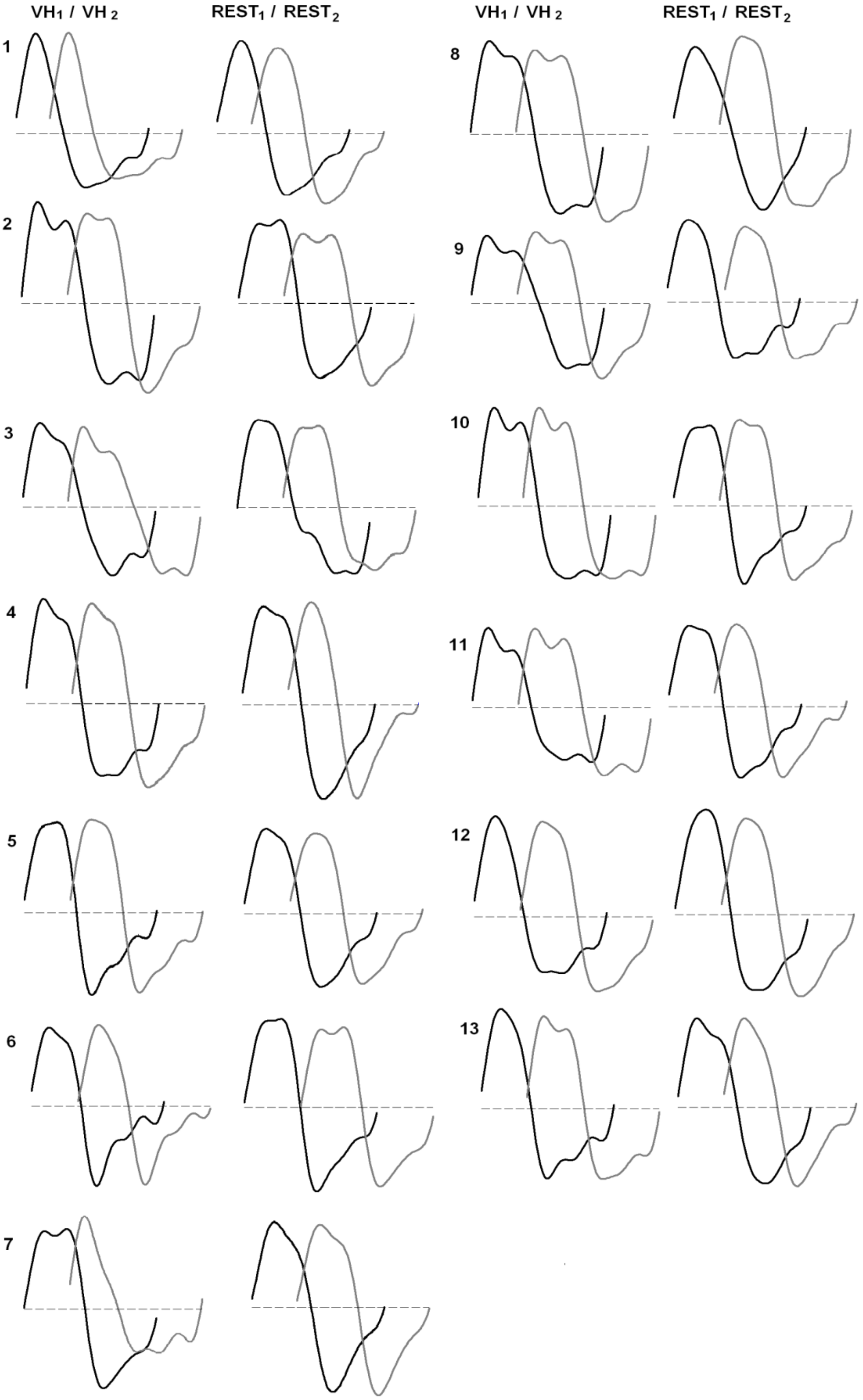

Figure 5. Reconstructed averaged airflows of 13 subjects recorded twice. VH1/VH2 and REST1/REST2: reconstructed airflows of hyperventilation and rest periods of two repeated recordings

IV. DISSCUSION

The averaged airflow of an individual of the hyperventilation (VH_1/VH_2) or rest periods ($REST_1/REST_2$) can be more similar as those of subject 1 or can be different like airflow shapes for hyperventilation periods of the subject 7 (figure 5). But individual differences between hyperventilation periods (HV_1/HV_2) and between rest periods ($REST_1/REST_2$) are significantly smaller than inter- individual differences. The same situation can be observed in comparisons of volume profiles (figure 4): despite some differences between TRIADs of repeated recordings the inter-individual differences are significantly greater than intra-individual variations.

The similarity of multivariate or univariate variables of one subject in two conditions (repeated recordings) is reported to inter- individual differences of the group. The between individual variability is used as the basis for assessing whether intra-individual variability is meaningful or not.

Father studies: Benchetrit and al. (1989) found the conservation of respiratory individuality of the spontaneous quiet breathing in repeated recordings performed over long term period [5]. Calabrese and al., (1998) determined that airflow profile inspiratory time ratio TI/TTOT at rest are preserved over a certain increase in ventilator effort or minute ventilation, beyond which airflow profile is changed as evidenced at high resistive load [7]. Eisele and al. (1989) found the individuality of breathing between breathing in condition of physical exercise performed in conditions of hypobaric hypoxia and normobaria [9]. These results [7, 9] suggest the possibility of some individual peculiarities that appears in some conditions different from the rest.

In our study we also observed the conservation of air flow and volume profiles of the rest periods recorded over time despite some respiratory irregularities that occurs during steady quiet breathing. The variation of chemical stimulations or/and some behavioural influences can produce these variations (Benchetrit, 2000) [18]. We determined also “another respiratory personality” that appears in conditions of voluntary hyperventilation: the airflow and volume profiles of VH periods were conserved during second recording.

The respiratory individuality of the rest period was lost during voluntary hyperventilation at 20 respirations per minute: The inter- individual differences in the increase of tidal volume (to decrease the $F_{ET}CO_2$ with 1%), associated with the same duration of respiratory cycle for all subjects (≈ 3 sec) made airflow and volume profiles different from the rest profiles but reproducible in similar conditions.

Individuality of breathing is probably an inherent peculiarity of respiratory system. Factors that determine this individuality are not completely elucidated. Dejours and al. (1961) [1] did not found causal relations of individual tidal volumes and duration of respiratory cycles to height, value of vital capacity (VC), reserve inspiratory and expiratory volumes, forced expiratory volume in 1 sec (FEV1) and to the ratio FEV1/VC. These authors did not found correlation between respiratory rate and the respiratory compliance, resistance or resistance x compliance product.

Benchetrit and al. (1987) [12] did not found features of mean airflow profiles attributable to height, weight, body surface area sex or smoking habits of individuals.

The activity of brainstem respiratory center, chemical influences, forebrain influences upon breathing, activity of respiratory muscles, morphological peculiarities of the respiratory system or more any combination of these factors can be a source of respiratory individuality. The similarity of breathing of pairs of identical twins (Shea and al., 1989) [14] improves the role of the complex of traits determined genetically: morphology of respiratory ways and probably peculiarities of respiratory control.

The breathing pattern at rest is controlled by brainstem oscillator. Pre-Bötzinger complex is considered to be a pacemaker, the interactions between its neurons and other neurons of central generator of respiratory rhythm (Smith and al. 1991, 2009) [20, 21], as well as variations of the $PaCO_2$ determine respiratory characteristics and breath by breath variability at rest (Benchetrit 2000) [18]. The conservation of individual respiratory traits during deep NON REM sleep is important argument for the importance of medullar-pontine oscillator for respiratory individuality during resting breathing [22].

The voluntary control of breathing involves cortical and subcortical structures (Shea, 1996) [23]. In order to explore the functional neuroanatomy of voluntary respiratory control, McKay and al. (2003) [24] investigated healthy individuals during voluntary hyperpnea by functional magnetic resonance imaging. The increase in neuronal activity was determined bilaterally in the primary sensory and motor cortices, supplementary motor area, cerebellum, thalamus, caudate nucleus, and globus pallidum. The raised activity within the medulla suggests that the brain stem respiratory centers may have a role in mediating the voluntary control of breathing in humans [24].

The respiratory airflow can be regarded as the output of brainstem respiratory controller. Some mechanical conditions (as the tonus of respiratory airways and others) can also change the shape of airflow profile. The precise role of these factors and their interrelationships are not completely elucidated.

Our study of individuality did not involve respiratory irregularities (sigh and deglutition) and is possible than irregular breathing pattern can involve some individual peculiarities (Benchetrit, 2000) [18].

V. CONCLUSIONS

The individuality of breathing during voluntary hyperventilation is proved by conservation of airflow and volume profile and TI in two repeated recordings performed over time. This respiratory individuality seems to be independent than the rest individuality.

The description of respiratory personality represented by the shape of mean airflow should be completed by results of similarity test applied on univariate variables and multivariate complexes of respiratory variables.

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