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Acute effects of different inspiratory efforts on ventilatory pattern and chest wall compartmental distribution in elderly women

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ABSTRACT

It is not completely described how aging affect ventilatory kinematics and what are the mechanisms adopted by the elderly population to overcome these structural modifications. Given this, the aim was to evaluate the acute effects of different inspiratory efforts on ventilatory pattern and chest wall compartmental distribution in elderly women. Variables assessed included: tidal volume (Vt), total chest wall volume (Vcw), pulmonary rib cage (Vrcp%), abdominal rib cage (Vrca%) and abdominal compartment (Vab%) relative contributions to tidal volume. These variables were assessed during quiet breathing, maximal inspiratory pressure maneuver (MIP), and moderate inspiratory resistance (MIR; i.e., 40% of MIP). 22 young women (age: 23.9 ± 2.5 years) and 22 elderly women (age: 68.2 ± 5.0 years) participated to this study. It was possible to show that during quiet breathing, Vab% was predominant in elderly ($p < 0.001$), in young, however, Vab% was similar to Vrcp% ($p = 0.095$). During MIR, Vrcp% was predominant in young ($p < 0.001$) and comparable to Vab% in elderly ($p = 0.249$). When MIP was imposed, both groups presented a predominance of Vrcp%. In conclusion, there are differences in abdominal kinematics between young and elderly women during different inspiratory efforts. In elderly, during moderate inspiratory resistance, the pattern is beneficial, deep, and slow. Although, during maximal inspiratory resistance, the ventilatory pattern seems to predict imminent muscle fatigue.

1. Introduction

With aging respiratory muscles performance decreases due to sarcopenia and changes in muscle fibers (Lalley, 2013) decreasing maximal strength development (Williams et al., 2002). Additionally, as a consequence of the calcification of costovertebral cartilages and joints, intercostal spaces and thoracic compliance are reduced (Rossi et al., 2008).

All these changes might affect ventilatory kinematics; however, the adaptive mechanisms adopted to overcome these structural changes in the elderly population are still not completely understood. Itís mandatory to differentiate the physiological changes induced by age from pathological changes.

The chest wall kinematics evaluation using opto-electronic plethysmography (OEP) has emerged as a useful method to evaluate the changes generated in different situations (Paisani et al., 2013; Wilkens et al., 2010). The OEP records each respiratory cycle in real time making it possible to evaluate the ventilatory pattern and the chest wall volume with its compartmental distribution (pulmonary rib cage, abdominal rib cage and abdomen) (Parreira et al., 2012). However, studies that observed the effects of senescence over chest wall kinematics using the OEP (Britto et al., 2009) are still scarce. Moreover, the changes generated in different inspiratory efforts have not been evaluated yet.

We hypothesized that elderly develop different chest wall kinematic and ventilatory patterns, compared to young, when they are submitted to different inspiratory loads. In the elderly population, this difference would be more noticeable in the abdominal volume contribution since, due to senile sarcopenia, the decrease in respiratory muscle strength would impair the capacity to overcome upper chest wall restrictive forces. Considering that after

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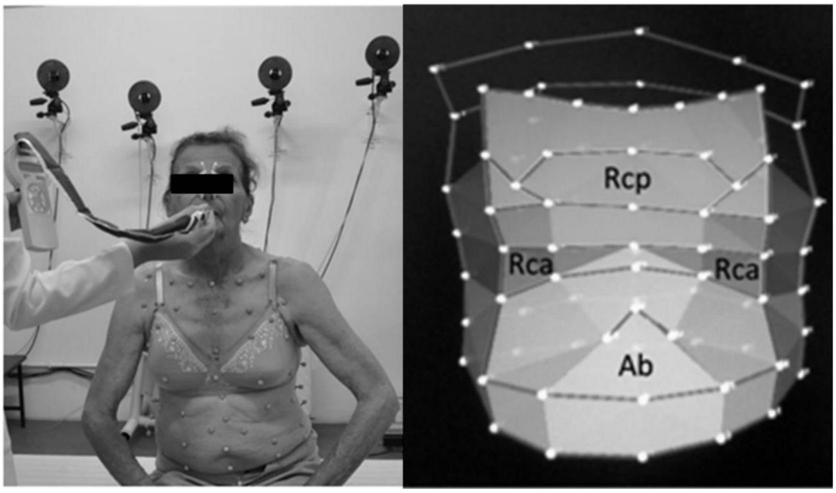
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Fig. 1. Maximal inspiratory pressure assessment during opto-electronic plethysmography evaluation (left) and three-dimensional model of rib cage compartments. Pulmonary rib cage (Rcp), abdominal rib cage (Rca), and abdomen (Ab) (right).

menopause women have lower levels of estrogen and that this intensifies the senile sarcopenia (Kenny et al., 2003), the aging related changes in chest wall kinematics might be more evident in this gender. Given this, we decided to test our hypothesis in a group formed exclusively by women. Therefore, the aim was to evaluate the acute effects of different inspiratory efforts on ventilatory pattern and chest wall compartmental distribution in elderly women.

2. Methods

2.1. Study design

This was a cross-sectional study approved by the Research Ethics Committee of the Center for Health Sciences at the Federal University of Pernambuco (CEP/CCS/UFPE No 457/11). The research was conducted in the Laboratory of Cardiopulmonary Physiotherapy, Department Physiotherapy, Federal University of Pernambuco (UFPE) from August to December 2014. All volunteers signed a free and informed consent form.

2.2. Participants

The sample was formed by 22 elderly women and 22 young women. A pilot study was made with five individuals in each group to calculate the sample. A total of 34 participants would provide 95% power and alpha level of 0.05 to detect difference between groups in the pulmonary rib cage contribution. The following inclusion criteria were adopted: age between 20 to 80 years; to be able to walk without assistance; to have cognitive integrity in the elderly group, assessed by the Mini-Mental State Examination (MMSE). The exclusion criteria were: contraindication or difficulty to perform the evaluation procedures; respiratory muscle strength lower than 70% of the predict (Neder et al., 1999); smoking; hemodynamic instability; neuromuscular degenerative diseases; pulmonary comorbidities; heart disease and users of medications that change the bone metabolism or the muscle strength.

2.3. Data collection

All volunteers were initially submitted to an anthropometric, clinical, and demographic evaluation. The level of physical activity was evaluated through a self-reported instrument adapted to the Brazilian population, the Profile of Human Activity (PHA) (Souza et al., 2006). This instrument quantifies the level of physical activity through the adjusted activity score (AAS) sorting the individual into three categories: inactive (AAS < 53), moderately active ($53 \leq \text{AAS} \leq 74$), and active (AAS > 74). Afterwards, the volunteers were instructed to breathe with a moderate inspiratory resistance, to ensure the correct performance of the technique several days before the measurements. The evaluation was conducted in two stages. In the first, we assessed pulmonary function and maximal respiratory pressures. In the second, ventilatory pattern and chest wall compartmental distribution were assessed by the OEP.

2.3.1. Pulmonary function tests

Tests were performed using a portable spirometer (Micro Medical, Microloop, MK8, England). The highest value in forced vital capacity (FVC), forced expiratory volume in one second (FEV_1), forced expiratory flow 25–75% (FEF25–75%), and the FEV1/FVC ratio was used, after three acceptable maneuvers. Reference values for Brazilian adult population were considered (Pereira et al., 2007).

2.3.2. Maximal respiratory pressures

The measurement of the maximum inspiratory pressure (MIP) and maximum expiratory pressure (MEP) was performed using a digital manometer (MVD300, Globalmed, Brazil) from residual volume and total lung capacity, respectively (Neder et al., 1999). At least five measurements were carried out until three acceptable and reproducible measurements were obtained, i.e., without air leakage and with less than 10% difference among them, with the highest value obtained being registered (Evans and Whitelaw, 2009).

2.3.3. Breathing with moderate inspiratory resistance (MIR)

The moderate inspiratory resistance was performed with an inspiratory muscle training device, the Threshold®IMT (Respironics, NJ, USA), commonly used to train healthy people (Downey et al., 2007; Enright and Unnithan, 2011) as well as others populations (Gosselink et al., 2011; Plentz et al., 2012). The volunteers performed the MIR in a seated position and were oriented to breathe quietly and keep a regular respiratory rate prior to the test. During the evaluation, there was no incentive or verbal instructions to the volunteers. The device was coupled to the volunteer through a mouthpiece that provides a linear resistive load (De Andrade et al., 2005) established at 40% of the previously obtained MIP. Nasal clips were also used during MIR. The duration of the MIR session was three minutes (Souza et al., 2014). During expiration, there was no resistance and no respiratory rate was imposed.

Table 1
Characteristics of study sample.

Variables	Control groupMean ± SD($n = 22$)	Elderly groupMean ± SD($n = 22$)	p Value
Age (years)	23.9 ± 2.5	68.2 ± 5.0	<0.001
BMI (kg/m^2)	22.8 ± 2.2	28.9 ± 4.0	<0.001
HAP	77.7 ± 5.6	60.5 ± 10.0	<0.0001
FEV$_1$ (predict)	91.5 ± 5.6	92.2 ± 11.3	0.787
FVC (predict)	87.3 ± 5.6	85.5 ± 10.8	0.733
FEV$_1$/FVC (predict)	108.3 ± 5.7	111.1 ± 9.7	0.473
FEF$_{25–75}$% (predict)	95.4 ± 14.3	117.1 ± 7.6	0.054
MIP (cmH$_2$O)	107.4 ± 9.8	91.7 ± 18.7	0.003
MIP (% predict)	108.9 ± 11.3	135.5 ± 5.8	<0.001
MEP (cmH$_2$O)	120.1 ± 13.8	98.7 ± 14.2	<0.001
MEP (% predict)	119.0 ± 14.6	124.0 ± 15.8	0.318
VtQB (L)	0.6 ± 0.2	0.4 ± 0.1	<0.001
Vrcp%QB	42.2 ± 9.1	32.3 ± 9.1	0.001
Vrca%QB	18.8 ± 4.9	17.3 ± 6.3	0.348
Vab%QB	39.0 ± 11.6	50.4 ± 11.6	0.001
VtMIR (L)	0.9 ± 0.5	1.3 ± 0.5	0.001
Vrcp%MIR	46.3 ± 10.4	35.1 ± 11.3	0.003
Vrca%MIR	22.6 ± 5.5	24.7 ± 12.3	0.639
Vab%MIR	31.1 ± 13.5	40.2 ± 13.7	0.046
VcwMIP (L)	19.3 ± 3.2	25.9 ± 5.2	<0.001
Vrcp%MIP	55.0 ± 3.9	50.0 ± 4.9	0.003
Vrca%MIP	15.5 ± 2.5	16.4 ± 2.4	0.197
Vab%MIP	29.5 ± 3.1	33.6 ± 4.3	0.002

BMI: body mass index; HAP: human activity profile; FEV1: forced expiratory volume in the first second; FVC: forced vital capacity; FEF$_{25–75}$: forced expiratory flow 25% e 75%; MIP: maximal inspiratory pressure; MEP: maximal expiratory pressure; QB: quiet breathing; MIR: moderate inspiratory resistance; Vt: tidal volume; Vcw: chest wall volume; Vrcp%: pulmonary rib cage contribution volume; Vrca: abdominal rib cage contribution volume; Vab: abdominal contribution volume.

2.3.4. Opto-electronic plethysmography (OEP)

The OEP (BTS Bioengineering, Milano, Italy) was used to assess the ventilatory pattern and the chest wall compartmental distribution. Eighty-nine reflective markers were placed according to anatomical references and attached to the trunk of volunteers seated without a backrest with hypoallergenic adhesive (Aliverti and Pedotti, 2005).

Eight infrared cameras (four in front and four behind the volunteers) traced the three-dimensional coordinates of the reflective markers as they moved and the device software calculated the chest wall volume (Vcw) through surface triangulation (Brandão et al., 2012). The chest wall compartmental distribution was composed of three compartments: pulmonary rib cage (Vrcp—portion of the rib cage in contact with the lungs), abdominal rib cage (Vrca—portion of the rib cage opposed to the diaphragm), and abdomen (Vab) (Parreira et al., 2012) (Fig. 1).

The chest wall compartmental distribution was assessed in three different conditions: (a) during 3 min of quiet breathing (QB); (b) during 3 min with moderate inspiratory resistance (MIR); (c) while performing 2 maneuvers of maximal inspiratory pressure (MIP) (Fig. 1). The ventilatory pattern was evaluated during the QB and MIR. The data was assessed with 5 min rest between each conditions. During QB and MIR, the following variables were assessed: tidal volume (Vt), chest wall volume compartmental distribution (Vrcp%, Vrca% and Vab%), respiratory rate (RR), inspiratory time (Ti), expiratory time (Te), total respiratory cycle time (Ttot), and work of breathing (WOB). During MIP, chest wall total volume and its compartmental distributions (Vrcp%, Vrca% and Vab%) were evaluated.

2.4. Statistical analysis

The sample characteristics and statistical analysis of the data were expressed as mean and standard deviation (SD). The Shapiro–Wilk test was used to evaluate the normality of the data. Differences between controls and elderly women were evaluated by the Mann–Whitney test. The comparison between the ventilatory pattern in QB and MIR was done with the Wilcoxon test. To compare the percentage of the contribution of the compartments in each situation (QB, MIR or MIP) and between situations (QB × MIR × MIP), we used the nonparametric Friedman test. Where statistical significance was found, the differences among the data were evaluated using the Wilcoxon test. The Spearman correlation test was used to evaluate the relationship between age and ventilatory variables. The analysis was conducted using the program SPSS for Windows (version 20.0, Chicago, IL) and a significance level of $p < 0.05$ was established.

3. Results

The study included 22 elderly women and a control group with 22 young women (Fig. 2). Anthropometric data, spirometric variables, respiratory muscle strength, level of physical activity (evaluated through PHA), total volumes, and chest wall compartmental distribution are in Table 1. The control group did not use medications. In the elderly group, ten volunteers (45%) used medications for hypertension control, three (14%) for diabetes control, two (9%) for both, and seven volunteers (32%) did not use medications.

The pattern ventilatory variables in the elderly and the control groups during the QB and MRI were exposed in Table 2. During MIR, the ventilatory pattern showed changes compared to QB in both groups.

The comparison of chest wall volume compartmental distribution (Vrcp%, Vrca% and Vab%) in each situation (QB, MIR or MIP) is shown in Fig. 3. We observed that in the QB, the Vab% was predominant in elderly while Vrcp% and Vab% were similar in control group. In both groups during the MIR, the Vrcp% predominated, followed by Vab% and Vrca%. In the MIP, the Vrcp% increased in both group.

In the comparison of each chest wall compartment (Vrcp%, Vrca% and Vab%) between situations (QB × MIR × MIP), we observed that the behavior was similar in both groups. The Vrcp% increased during MRI and MIP in relation to QB. The Vab% decreased when the inspiratory effort was major (MIR and MIP) while Vrca% increase during the MIR but decreased in the MIP.

The age showed significative ($p < 0.05$) correlation with: Vt,QB ($r = -0.524$), Vrcp%,QB ($r = -0.585$), Vab%,QB ($r = 0.585$), Ttot,QB ($r = -0.464$), Ti,QB ($r = -0.494$), Te,QB ($r = -0.430$), RR,QB ($r = 0.460$),

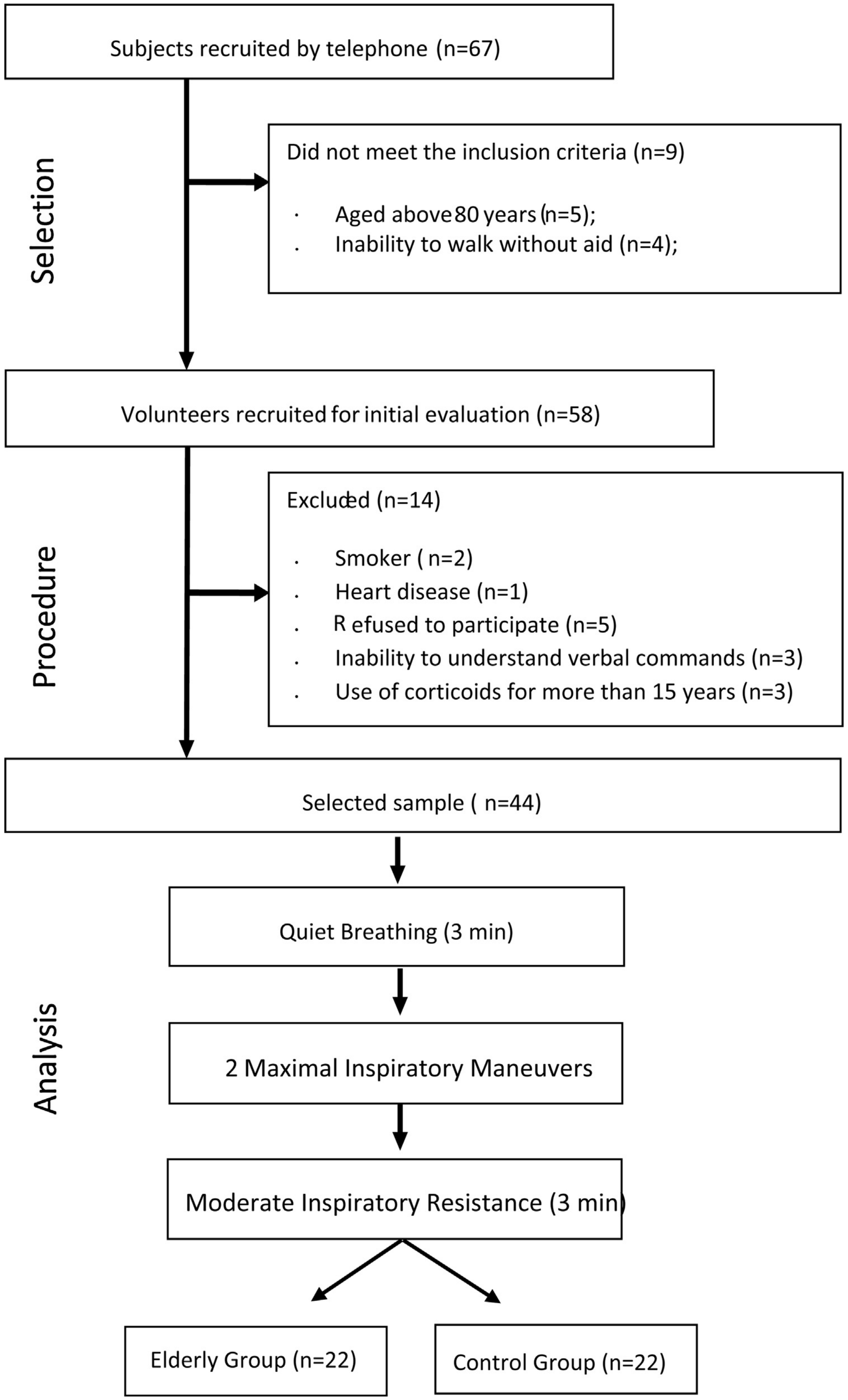

Fig. 2. Flowchart of participants.

Vt,MIR ($r = 0.407$), Vrcp%,MIR ($r = -0.307$), Ti,MIR ($r = 0{,}324$), WOB,MIR ($r = 0.034$), Vcw,MIP ($r = 0.596$), Vrcp%,MIP ($r = -0.391$) and Vab%,MIP ($r = 0{,}457$). There were no correlations between age and others variables.

4. Discussion

To the best of our knowledge, this is the first study that evaluates the ventilatory kinematics in elderly during three progressive inspiratory efforts (basal, moderate and maximum). Our results

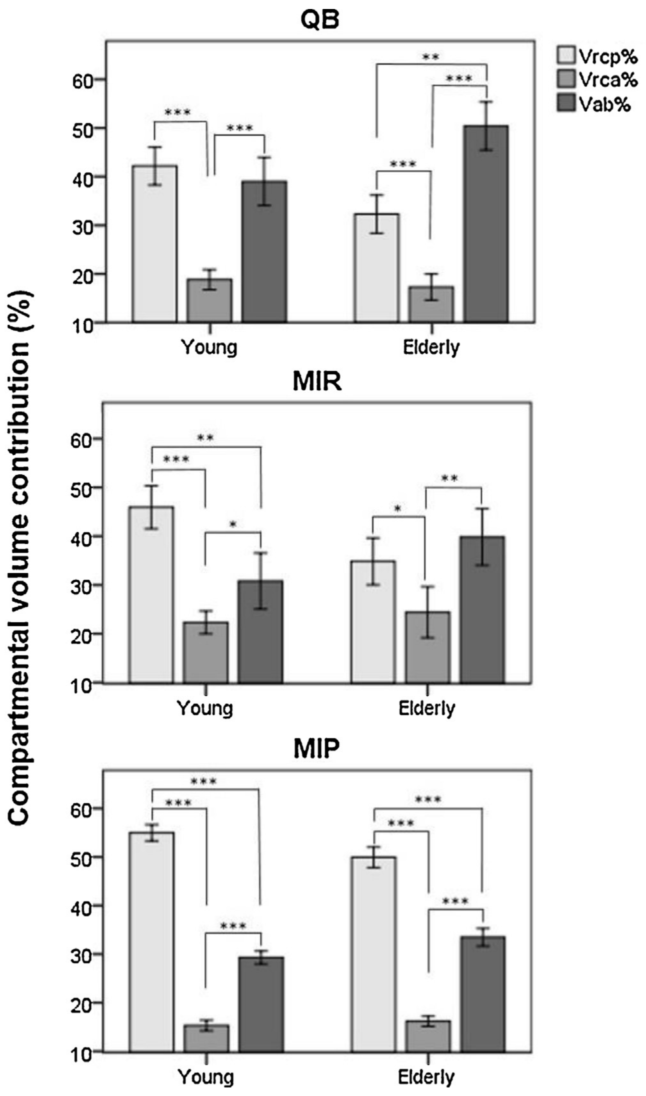

Fig. 3. Comparison between pulmonary rib cage (Vrcp%), abdominal rib cage (Vrca%), and abdominal (Vab%) contributions in each situation: quiet breathing (QB), breathing with moderate inspiratory resistance (MIR), and maximal inspiratory pressure measurement (MIP). (Graph represented as mean and standard error. $^{*}p < 0.05$, $^{**}p < 0.01$ and $^{***}p < 0.001$; Wilcoxon test).

revealed that during QB, Vab% is predominant in the elderly, while in young women, Vrcp% prevails. Furthermore, ventilatory pattern changes when moderate inspiratory loads are added. There were differences on chest wall volume distribution from QB to maximal inspiratory efforts. Although, despite the differences in the chest wall volume distribution, both groups behaved similarly during the increase in inspiratory resistance. We observed a moderate correlation between age, Vrcp%, and Vab% during the QB.

Since healthy individuals without previous clinical limitations formed both groups, it was possible to compare their baseline values and all differences observed might be restricted to the aging process (Table 1).

During QB, Vab% was predominant in the elderly group but similar to the Vrcp% in the control group. Our findings agree with the reports of Britto et al. (2009) where abdominal contribution was prevalent in elderly subjects during QB (Britto et al., 2009). The decline of chest wall movement due to the aging process (Berg et al., 2012) is reinforced in our study, where a relationship was found between age and decreased tidal volume and Vrcp%, as well as with an increased Vab%. This suggests that abdominal contribution prevails during the QB as an adaptive response to the decreased compliance of the chest wall in elderly.

During MIR, the Vrcp% was predominant in the control group but was similar to the Vab% in the elderly group. Despite the fact that there were differences in compartmental distribution between groups, young and elderly behaved similarly during the MIR by increasing the Vrca% rather than Vab% (Fig. 3).

Illi et al. (2013) found that young subjects undergoing respiratory training protocol with normocapnic hyperpnea increased the tidal volume compared to QB. However, in their study, Vrcp% remained the same in both situations. A higher relative contribution of the Vrcp% was observed by Hostettler et al. (2011) assessing young volunteers during 3 min of MIR. Similarly, Wang et al. (2009) evaluated healthy adults with OEP during an incremental cycle ergometer test. These authors showed an increased Vrcp% without difference between genders. Another study from our group (Nobre et al., 2007) with young women observed an increased muscle activity of the lower rib cage and the lung ventilation in the middle third while moderate inspiratory loads were set.

Although we did not find previous literature in elderly population, our results reinforce the hypothesis that the decrease of the chest wall compliance alters the volume distribution and moderate inspiratory efforts are insufficient to overcome the resistive forces of the upper chest wall. However, the healthy elderly presented a similar ventilatory behavior compared to young volunteers in these conditions. This suggests that during senescence ventilatory behavior in moderate efforts remains the same despite all particular structural changes (Lalley, 2013).

In the present study, it was possible to observe that respiratory pattern changes in both groups during the MIR (Table 2). This suggests that breathing becomes deeper and slower in order to overcome the resistance imposed. Moreover, despite the increased work of breathing, ventilatory pattern adopted during MIR differed from respiratory muscles fatigue prediction model (Berg et al., 2012; Phillips et al., 2015). In this model the breathing often becomes rapid and superficial (Hostettler et al., 2011). Our results suggest that changes in the ventilatory patterns and ventilatory kinematics during MIR in the elderly might be a beneficial ventilation strategy. Thus, we reinforce the idea that the application of exercise protocols and activities that require moderate inspiratory efforts can be safely performed in this population.

When the volunteers were evaluated during MIP, Vrcp% prevailed in both groups. However, the increase in Vrcp% in the elderly group occurred with a decrease in Vab%. Meanwhile, in the control group, the higher values of Vrcp% happened due to a decrease in Vrca% and Vab%, compared to QB (Fig. 3).

Table 2
Ventilatory pattern changes between quiet breathing (QB) and breathing with moderate inspiratory resistance (MIR) in both groups.

Variables	QB	MIR	*P* value
Vt EG(l)	0.4 ± 0.1	1.3 ± 0.5	<0.001
Vt CG(l)	0.6 ± 0.2	0.9 ± 0.5	0.035
RR EG(ipm)	18.5 ± 4.4	11.8 ± 6.3	<0.001
RR CG(ipm)	14.2 ± 3.6	12.9 ± 4.1	0.372
Ttot EG(s)	3.5 ± 0.8	7.0 ± 4.0	<0.001
Ttot CG(s)	4.6 ± 1.2	5.4 ± 1.9	0.101
Ti EG(s)	1.4 ± 0.4	4.4 ± 2.8	<0.001
Ti CG(s)	2.0 ± 0.6	2.9 ± 1.3	0.003
Te EG(s)	2.1 ± 0.5	2.6 ± 1.6	0.527
Te CG(s)	2.6 ± 0.8	2.5 ± 1.0	0.123
WB EG	41.0 ± 4.4	61.8 ± 9.5	<0.001
WB CG	42.1 ± 4.4	61.8 ± 9.5	<0.001

QB: quiet breathing; MIR: moderate inspiratory resistance; EG: elderly group; CG: control group; Vt: tidal volume; RR: respiratory rate; Ttot: total respiratory cycle time; Ti: inspiratory time; Te: expiratory time; WB: work of breathig; l: liters; s: seconds; ipm: incursions per minute.

The MIP maneuver is performed with a maximal isometric contraction of diaphragm muscle without volume change (Cohn et al., 1997). Given this, when the subjects are under maximal respiratory efforts, accessory respiratory muscles might have to overcome chest wall stiffness and this could be the reason for an increased Vrcp%. However, in the elderly, the increase in Vrcp% occurred with a decrease in Vrca% and Vab%. It is known that Vab% is highly related to diaphragm mobility (Aliverti and Pedotti, 2005; Illi et al., 2011). Therefore, we hypothesize that against high respiratory resistances, the elderly presents a decreased activation of diaphragm muscle (i.e., lower Vrca%) as well as a decreased diaphragm mobility (i.e., lower Vab%). According to this behavior, the elderly might be more vulnerable to ventilatory muscle fatigue when maximal efforts are required. This reinforces the need to establish specific therapeutic strategies for the prevention of senile muscle weakness since maximal efforts will be necessary in extreme situations. After performing a protocol of normocapnic hyperpnea in healthy adults, Illi et al. (2013) observed a decrease in Vab% starting from the middle of the test, with a simultaneous increase in Vrcp% and reduction of the end inspiratory volume suggesting impending fatigue of costal inspiratory muscles. Thus, this study suggests that the ventilatory kinematics observed during maximal efforts should not be performed for long periods, since its continuity might predispose to the development of respiratory muscle fatigue.

The increase in Vrca% during MIR and Vcrp% during MIP in both groups suggest that, depending on the intensity of the negative pressure generated, the lung volume can be shifted to specifics segments, which may be useful to implementing techniques of selective pulmonary re-expansion. However, it is still necessary to understand the impact of this ventilatory behavior during maximum inspiratory efforts in the clinical practice. Thus, at this moment, treatment protocols that require exhaustive inspiratory work should still be indicated with caution in elderly patients.

4.1. Limitations

It was not possible to stratify the statistical analysis by neither age (i.e., 60–69 years and above 69 years) neither by BMI (i.e., <18; 18–24; >24), in order to understand the relationship of these subgroups to chest wall volume compartmental distribution due to the baseline heterogeneity between groups. Despite this, our research contributed to exploit the peculiarities of ventilatory pattern and thoracoabdominal kinematics during different inspiratory efforts in elderly women.

5. Conclusion

The present study showed that there are differences between young and elderly ventilatory kinematics during inspiratory efforts. However, we also found that both groups have a similar ventilatory behavior as the inspiratory effort resistance increases. During moderate efforts, the ventilatory pattern is beneficial with slow and deep breaths. However, when high resistance is imposed, the ventilatory behavior seems to predict imminent muscle fatigue. Given this, in order to adopt safer exercise protocols to this age group, these respiratory differences must be considered.

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