



# Is age rating enough to investigate changes in breathing motion pattern associated with aging of physically active women?

Isabella Martins Rodrigues<sup>a,1,\*</sup>, Eveline Torres Pereira<sup>a</sup>, Ana Luiza de Castro Lopes<sup>a</sup>, Carlo Massaroni<sup>b</sup>, Guido Baroni<sup>c</sup>, Pietro Cerveri<sup>c</sup>, Sergio Silvestri<sup>b</sup>, John Dickinson<sup>d</sup>, Karine Jacson Sarro<sup>e</sup>, Amanda Piaia Silvatti<sup>a</sup>

<sup>a</sup> Department of Physical Education, Universidade Federal de Viçosa, Viçosa, Brazil

<sup>b</sup> Unit of Measurements and Biomedical Instrumentation, Departmental Faculty of Engineering, Università Campus Bio-Medico di Roma, Rome, Italy

<sup>c</sup> Department of Electronics, Information and Bioengineering, Politecnico di Milano, Milan, Italy

<sup>d</sup> School of Sport and Exercise Sciences, University of Kent, Kent, United Kingdom

<sup>e</sup> Faculdade de Educação Física, Universidade Estadual de Campinas, Campinas, Brazil

## ARTICLE INFO

### Keywords:

Aging  
Breathing pattern  
Motion capture  
Biomechanics

## ABSTRACT

The most common way to analyze the effect of aging on breathing is to divide subjects into age groups. However, in addition to the fact that there is no consensus in the literature regarding age group division, such design critically influences the interpretation of the effects attributed to aging. Thus, this study aimed to investigate the feasibility to distinguish different age groups from the 3D kinematic variables of breathing motion (i.e., markers' coordinate as a function of time allowing the calculation of compartmental volume variations) and to analyze whether the aging could influence these variables. Seventy-three physically active women aged 19–80 years performed quiet breathing and vital capacity maneuvers. To record the thoracoabdominal breathing motion, the 3D coordinates of 32 retroreflective markers positioned on the trunk were used to estimate the volume variation of the superior thorax, inferior thorax, and abdomen. The percentage of contribution and the correlation coefficient were calculated to analyze the breathing motion pattern from the estimated volumes. The k-means cluster analysis was performed to analyze the age group classification. Linear regression was performed to investigate whether age can predict changes in the breathing motion pattern. The results showed that physically active women could not be classified into age groups from breathing motion. Despite significant *p* values of the linear regression, the high variability of the data suggested that age itself is not enough to predict the changes in breathing motion pattern when non-sedentary women are considered.

## 1. Introduction

The breathing motion pattern is characterized by the amplitude and synchrony of the thoracoabdominal compartments (Gallego et al., 1997). It is also characterized by the mechanical component of the ventilatory dynamics that are generally conducted according to the volume-pressure relationship (Gimbry et al., 1976), which allow indirectly investigate the respiratory muscle dynamics. In normal conditions, the diaphragm, the main inspiratory muscle, contracts shifting the lower ribs laterally and upwards, pushing down the abdominal organs and, consequently, turns outward the relaxed abdominal wall. In addition, the intercostal muscles and other upper chest muscles elevate the

upper ribs during inspiration. This interaction between the chest wall and the abdomen produces the pressure changes required to exchange the air in and out of the lungs and could be influenced by the aging process.

The age-related respiratory change is gradual, complex, and variable, including losses in neural, physiological, and anatomical optimum functionality. An example is a reduction in the recruitment of type II muscle fibers leading to decreased respiratory muscle strength (Lalley, 2013) that, consequently, reduces the maximal inspiratory and expiratory pressures. These changes are often accompanied by a decrease in rib cage compliance (Janssens et al., 1999; Lalley, 2013; Nikolić et al., 2010; Parreira et al., 2010) and pulmonary function. Thus, the

\* Corresponding author at: Department of Physical Education, Universidade Federal de Viçosa, Minas Gerais, Brazil.

E-mail address: [isabella.rodrigues@ufv.br](mailto:isabella.rodrigues@ufv.br) (I. Martins Rodrigues).

<sup>1</sup> Address: Departamento de Educação Física, Avenida P. H. Rolfs, s/n°, Campus Universitário.

occurrence of pathological processes is facilitated (Pappaléo Netto, 2002).

Despite being reasonable to think that these changes might influence the breathing motion pattern, there is no consensus in the literature. On the one hand, studies reported an increase of thoracoabdominal asynchrony (Britto et al., 2009; Parreira et al., 2010) and a more significant displacement of the thorax at the xiphoid process level (Kaneko and Horie, 2012) in the elderly compared to the young. On the other hand, some studies pointed out that no differences exist between age groups in the thoracoabdominal compartmental contribution (Britto et al., 2009; Lunardi et al., 2014; Verschakelen and Dementds, 1995), movements (Ragnarsdóttir and Kristinsdóttir, 2006), and synchrony (Lunardi et al., 2014) during quiet breathing or vital capacity maneuvers.

Traditionally, when the effects of aging are analyzed, the subjects are divided into age groups (Britto et al., 2009; Lunardi et al., 2014; Parreira et al., 2010) or groups at 10-year intervals (Kaneko and Horie, 2012; Ragnarsdóttir and Kristinsdóttir, 2006), without consensus regarding the age range of each group. Many criteria to separate groups critically influence the interpretation of the effects attributed to aging and the comparison between the results of the studies. Furthermore, the diversity and complexity of changes may affect the division into age groups when analyzing thoracoabdominal breathing motion.

Therefore, in this study we investigated the feasibility to distinguish different age groups from the 3D kinematic variables of breathing motion (i.e., markers' coordinate as a function of time allowing the calculation of compartmental volume variations) and to analyze whether aging could affect these variables, avoiding a misinterpretation of the data.

## 2. Material and methods

### 2.1. Study design and subjects

This study was performed at the Universidade Federal de Viçosa (Viçosa, Brazil). Seventy-three physically active women aged 18 to 80 years were enrolled in this study (Table 1). Eligibility criteria included non-smokers physically active women, 18 years of age or older, all featuring at least 150 min per week of physical activity. The exclusion criteria were pregnancy, presence of both acute and chronic respiratory diseases, severe postural disorders, and sedentary lifestyle. This study was approved by the Ethics Committee of the Universidade Federal de Viçosa (number 56335515.8.0000.5153), and all the participants consented to participate.

### 2.2. Motion capture and kinematic analysis

The 3D kinematic analysis was performed by arranging eighteen OptiTrack Prime 17 W cameras (© NaturalPoint, Corvallis, OR, USA) around the participants, covering about 3 m × 2.5 m × 4 m. Thirty-two retro-reflective markers were placed on the subject's trunk, allowing the compartmental division in the superior thorax (ST), inferior thorax (IT), and abdomen (AB) (Ferrigno et al., 1994). The division of the trunk into three compartments allowed the indirect investigation of the respiratory muscle action, as it is known that the intercostal and upper chest muscles move the ST, the diaphragm move the IT. In contrast, the diaphragm and abdominal muscles move the AB (Ferrigno et al., 1994).

This reduced 32-marker model was selected due to its strong correlation in comparison with the gold standard model - i.e., 89 markers

(Aliverti and Pedotti, 2003) - to evaluate the motion pattern and synchrony (Massaroni et al., 2018). Moreover, the reduced number of markers allowed better comfort for the participant.

To acquire the breathing movement at rest, the participants sat straight on a chair without back support, shoulders abducted with arms supported on a stand, and both feet lying on the floor. Each participant completed a trial of the two breathing maneuvers in the same order: quiet breathing (QB) lasting one minute and vital capacity (VC), which was characterized by five cycles of maximum inspiration followed by maximum expiration with a verbal incentive (Sarro et al., 2008; Silvatti et al., 2012).

The estimation of the volumes of each trunk compartment was performed in the Visual3D software (C-motion, Rockville, MD, USA) through the 3D coordinates of the markers as a function of time, resulting in  $n$  breathing cycles (an inspiration followed by an expiration) of each trial (Fig. 1). Marker data were acquired with a sampling rate of 240 Hz.

#### 2.2.1. Breathing motion pattern

To investigate the activity of each thoracoabdominal compartment during breathing, the percentage of contribution to total thoracoabdominal motion was computed. The compartmental tidal volumes (i.e., the range between the beginning and end of inspiration volumes of each compartment) produced at each  $i$ -th breathing cycle ( $ST^i$ ,  $IT^i$ ,  $AB^i$ ) were estimated. The percentage of contribution of each compartment to the total volume ( $CW^i$ ) for each  $i$ -th breathing cycle ( $\%ST^i$ ,  $\%IT^i$ ,  $\%AB^i$ ) was calculated according to the following equation:

$$\begin{cases} \%ST^i = \left( \frac{ST^i}{CW^i} \right) \times 100 \\ \%IT^i = \left( \frac{IT^i}{CW^i} \right) \times 100 \\ \%AB^i = \left( \frac{AB^i}{CW^i} \right) \times 100 \end{cases}$$

We calculated the cross-correlation among the compartmental volumetric time-varying signals of QB and VC to investigate the motion coordination between the compartment pairs. The linear correlation was used to fit experimental data ( $ST^i$  against  $IT^i$ ,  $ST^i$  against  $AB^i$ , and  $IT^i$  against  $AB^i$ ). The use of the correlation coefficient as a variable in the analysis of movement coordination during breathing was previously described by Massaroni (2018), Rodrigues et al. (2017), and Silvatti et al. (2012). The values of the correlation coefficients equal to or near 1 indicated a high positive correlation (quality of linear fitting). In such a case, high coordination of the assessed trunk compartments was assumed. Values equal to or near -1 indicated a high negative correlation, which points to the presence of asynchronous movements between trunk compartments.

For both percentages of contribution and correlation coefficients, the average of all the values considering the  $i$ -th breathing cycles collected in the trials were computed. As a result, each participant produced only one value of each compartment/compartment pairs per maneuver.

### 2.3. Statistical analysis

K-means cluster analysis was applied to investigate the feasibility of the participants' classification into age groups from the 3D kinematic

**Table 1**

According to age group division, the mean ( $\pm$ SD) of age, height, body mass, and Body Mass Index (BMI) of the participants.

	n	Age (years)	Height (m)	Body mass (kg)	BMI (kg/m <sup>2</sup> )
18–44	23	25.04 $\pm$ 5.22	1.61 $\pm$ 0.06	59.57 $\pm$ 9.70	23.05 $\pm$ 3.28
45–64	25	58.84 $\pm$ 5.37	1.61 $\pm$ 0.06	65.56 $\pm$ 8.71	25.23 $\pm$ 3.42
>65	25	68.56 $\pm$ 6.13	1.54 $\pm$ 0.05	62.87 $\pm$ 7.39	26.63 $\pm$ 3.44

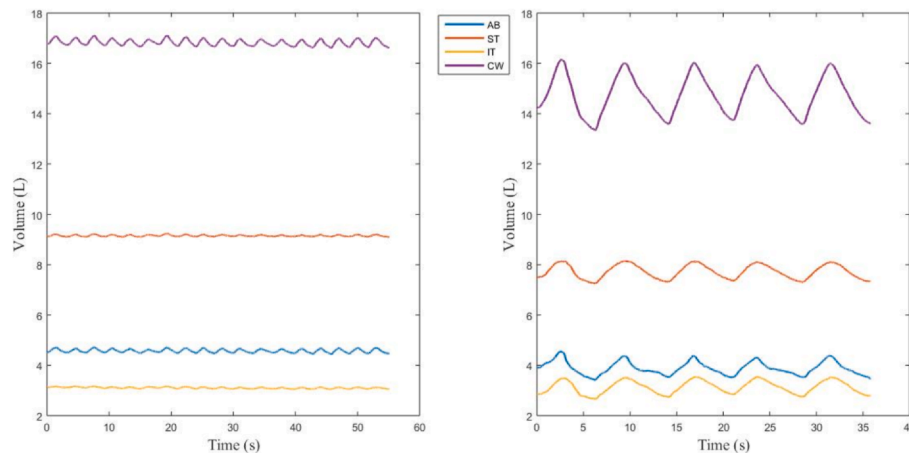


Fig. 1. Reconstructed volumes of chest wall (CW), superior thorax (ST), inferior thorax (IT) and abdomen (AB) in quiet breathing and vital capacity, respectively.

variables of breathing motion in both maneuvers. As all variables were used, the percentage of contribution values was divided by 100 so that there were no significant discrepancies between the correlation coefficient and contribution percentage values. Considering the age group division proposed by the United Nations and WHO ([Provisional Guidelines on Standard International Age Classifications, ST/ESA/STAT/SER.M74, 1982](#)), (i.e., 15–44 years; 45–64 years and >65 years), we set the test to divide the participants into three clusters. Then, we checked how many participants of each age group were classified into each cluster.

The linear regression was computed to investigate whether age can predict changes in the breathing motion pattern. The test was applied between 1) age and percentage of contribution (%) in QB; 2) age and percentage of contribution (%) in VC; 3) age and correlation coefficient in QB; 4) age and correlation coefficient in VC. Statistical tests were performed using the SPSS software ( $p \leq 0.05$ ) (SPSS Statistics v.20, IBM Corporation, Armonk, USA).

### 3. Results

All participants completed one minute of QB and five cycles of VC maneuver. The percentage of contribution and correlation coefficient results are summarized in [Table 2](#). It was possible to observe that the AB had major contributions to breathing in both maneuvers, while ST and IT also substantially contributed.

The correlation coefficient values showed that all values were positive, indicating that the breathing movements of all participants were coordinated.

Based on the percentage of contribution and correlation coefficient

variables, it was not feasible to classify the participants into age groups. As we can see in [Figs. 2 and 3](#), all three clusters had participants of all age groups.

Propelled from the cluster results, to investigate whether age could predict changes in the breathing motion pattern, we applied the linear regression test, where age group classification was not necessary.

In the percentage of contribution, the results showed a significant contribution of ST and an increase of AB with aging in QB. In the VC maneuver, the ST decreased and the IT increased with aging. However, despite these significant results, the coefficient of determination values was very low. The variability of the data was high, indicating a weak relationship between age and percentage of contribution ([Table 3](#)).

The correlation coefficient results showed that there was a decrease in the correlation between STxIT and ITxAB with aging in QB. The VC maneuver exhibited a decrease in all compartment pairs correlations with aging. However, similarly to the percentage of contribution, the relationship between age and correlation coefficient was weak ([Table 4](#)).

### 4. Discussion

In this study, we investigated whether physically active women can be distinguished into age groups by analyzing the 3D kinematic variables of breathing motion and explored the possible age influences on it. Our main results suggested that the participants could not be classified into age groups. Furthermore, the subsequent analysis showed that age itself could not predict changes in the breathing motion pattern of physically active women.

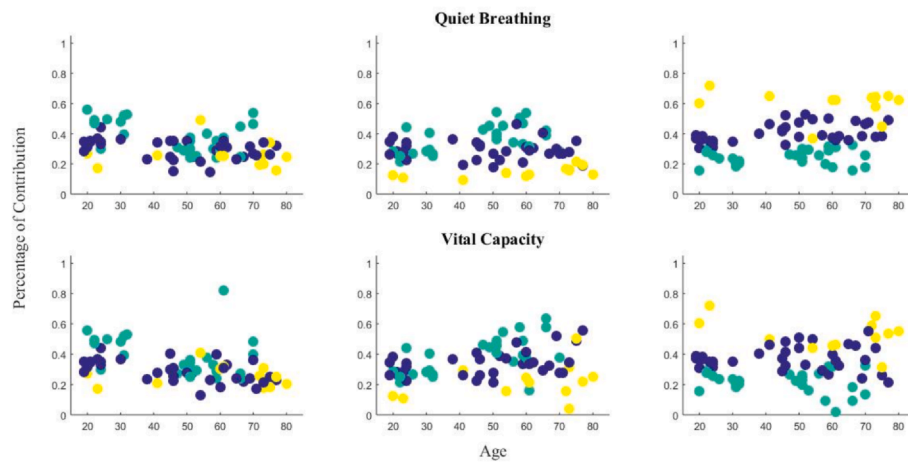
Unlike previous studies that used different age groups to characterize

Table 2

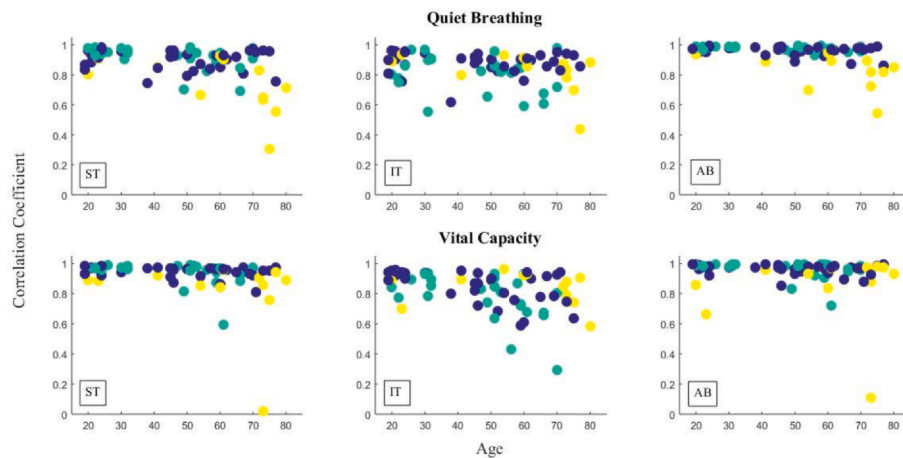
Mean ( $\pm$ SD), median, percentiles, minimum, maximum, and range values of percentage of contribution (%) and correlation coefficient in QB and VC maneuvers.

		Mean ( $\pm$ SD)	Percentiles			Minimum	Maximum	Range
			25	50	75			
Percentage of contribution								
QB	ST	32.67 $\pm$ 9.91	25.06	31.32	36.71	14.59	55.92	41.33
	IT	29.54 $\pm$ 10.40	22.43	28.58	35.85	9.24	54.33	45.09
	AB	37.79 $\pm$ 13.88	27.16	36.56	46.86	15.50	71.99	56.49
VC	ST	32.27 $\pm$ 11.31	24.48	30.20	36.71	12.77	81.90	69.13
	IT	33.65 $\pm$ 11.92	26.17	32.39	40.98	3.88	63.74	59.85
	AB	34.09 $\pm$ 13.67	24.48	32.46	44.13	1.86	71.99	70.12
Correlation coefficient								
QB	STxIT	0.88 $\pm$ 0.12	0.84	0.92	0.95	0.31	0.99	0.68
	STxAB	0.85 $\pm$ 0.11	0.82	0.87	0.92	0.44	0.98	0.54
	ITxAB	0.95 $\pm$ 0.07	0.94	0.97	0.99	0.55	0.99	0.45
VC	STxIT	0.92 $\pm$ 0.12	0.92	0.96	0.97	0.02	0.99	0.97
	STxAB	0.83 $\pm$ 0.13	0.75	0.87	0.92	0.29	0.96	0.67
	ITxAB	0.94 $\pm$ 0.12	0.94	0.98	0.99	0.11	1.00	0.89

Note: QB = quiet breathing; VC = vital capacity; ST = superior thorax; IT = inferior thorax; AB = abdomen.



**Fig. 2.** Percentage of contribution of ST, IT, and AB versus age in quiet breathing and vital capacity. Each point in the graphic represents one participant. The clusters 1, 2, and 3 are represented by the colors yellow, red and blue, respectively. ST = superior thorax; IT = inferior thorax; AB = abdomen.



**Fig. 3.** Correlation Coefficient (ST  $\times$  IT, ST  $\times$  AB, and IT  $\times$  AB) versus age in quiet breathing and vital capacity. Each point in the graphic represents one participant. The clusters 1, 2, and 3 are represented by the colors yellow, red and blue, respectively.

**Table 3**

Coefficient of determination ( $r^2$ ), F statistic, and  $p$ -value of the linear regression between age and percentage of contribution in QB and VC maneuvers.

		Percentage of Contribution		
		ST	IT	AB
QB	$r^2$	0.089	0.001	0.054
	F	6.920	0.087	4.030
	P	0.011*	0.770	0.049*
VC	$r^2$	0.140	0.053	0.004
	F	11.521	3.979	0.275
	P	0.001*	0.050*	0.601

Note. QB = quiet breathing; VC = vital capacity; ST = superior thorax; IT = inferior thorax; AB = abdomen. (\* $p \leq 0.05$ ).

the age-related breathing motion changes, our results pointed out that the participants could not be distinguished into three age groups from the 3D kinematic variables of breathing motion. Considering that this result could have been influenced by a transition phase between different age-related physiological and structural changes that could occur not precisely at the same age for all the women, we applied linear regression to investigate whether age can predict changes in the breathing motion pattern.

Regarding the percentage of contribution, the results suggested a decrease of the superior thorax contribution in both maneuvers with

**Table 4**

Coefficient of determination ( $r^2$ ), F statistic, and  $p$ -value of the linear regression between age and correlation coefficient during QB and VC maneuvers.

		Correlation Coefficient		
		STxIT	STxAB	ITxAB
QB	$r^2$	0.139	0.039	0.188
	F	11.471	2.936	16.459
	P	0.001*	0.091	<0.001*
VC	$r^2$	0.148	0.155	0.079
	F	12.330	13.039	6.131
	P	0.001*	0.001*	0.016*

Note. QB = quiet breathing; VC = vital capacity; ST = superior thorax; IT = inferior thorax; AB = abdomen. (\* $p \leq 0.05$ ).

aging. Meanwhile, as a compensatory mechanism, there was an increase in the contribution of the abdomen in QB and inferior thorax in VC. The correlation coefficients showed that all participants had coordinated movements during breathing, observed by the positive correlation values, which was expected. However, the linear regression suggested a decrease in the thoracoabdominal movement coordination in both maneuvers with aging, observed in all compartment pairs. Table 5 summarized the main differences between our and former studies. We could observe that no former study specified whether the participants were physically active, as we did in this study.

**Table 5**

Main differences between our and former studies regarding sample, groups, variables, and main results.

	Sample	Groups	Variables	Main Results
<b>Our Study</b>	73 physically active women aged between 18 and 80 years	No age group division 18–80 y	Percentage of Contribution Correlation Coefficient	High data variability Weak relationship between age and the breathing motion variables
<b>Ragnarsdóttir and Kristinsdóttir (2006)</b>	100 healthy men and women aged between 20 and 69 years	20–29 y 30–39 y 40–49 y 50–59 y 60–69 y	Abdominal, lower, and upper thoracic displacements Breathing pattern (dominant movement)	Symmetrical movements No significant relationships between thoracoabdominal movements and age
<b>Britto et al. (2009)</b>	43 healthy men and women aged between 20 and > 69 years	20–59 y 60–69 y >69 y	FVC, FEV1, FEV1/FVC Tidal volume, Respiratory frequency, Minute Ventilation, Mean inspiratory flow, Inspiratory duty cycle, Labored breathing index, Rib cage and abdominal percentage of contribution, MIP and MEP	No significant differences between the groups in the pulmonary function and breathing pattern variables Labored breathing index showed a greater asynchrony in the 60–69 years group MIP decreased significantly in the groups > 60 years
<b>Parreira et al. (2010)</b>	104 healthy men and women aged between 20 and 80 years	20–39 y 40–59 y 60–80 y	Tidal volume, respiratory frequency, minute ventilation, inspiratory duty cycle, mean inspiratory flow, rib cage percentage of contribution, phase angle, inspiratory and expiratory phase relation	The 60–80 years group showed greater inspiratory phase relation and phase angle compared to the 20–39 years group
<b>Kaneko and Horie (2012)</b>	100 healthy men and women aged between 20 and 74 years	20–29 y 30–39 y 40–49 y 50–59 y 60–74 y	Tridimensional marker distances of the clavicle, sternal angles, third rib, xiphoid process, eighth rib, tenth rib, abdomen, and lateral abdomen	The xiphoid process movement was greater in the sitting position in the 60–74 years than 20–29 years group. Multiple regression analysis did not show significant relationships between marker distances and age in sitting position

Note: FVC = forced vital capacity; FEV1 = forced expiratory volume in the first second; MIP = maximal inspiratory pressure; MEP = maximal expiratory pressure.

Despite the significant results of linear regression found in this study, we should consider a high data variability, which indicated that the relationship between age and breathing motion pattern is weak. Some factors beyond age, such as physical conditioning and different structural changes, may have influenced the results.

Much is known about the physiological and structural age-related respiratory changes as a decrease in chest wall compliance, calcification of cartilage in the rib cage joint, degenerative changes affecting the spine, loss of mass and muscle strength, and reductions of the lungs elastic recoil (Janssens et al., 1999; Lalley, 2013; Muniz de Souza et al., 2016; Pappaléo Netto, 2002). Structural changes could also modify the curvature of the diaphragm, compromising its ability to generate force (Janssens et al., 1999). The manifestation of these structural changes can occur at different ages in each woman, as it depends on several factors, such as menopause, physical activity, and physical conditioning.

Miranda et al. (2015) showed that even irregular or short-duration physical activity could preserve respiratory muscle function. Also, they indicated that regular physical activity is capable of improving the strength of respiratory muscles, whereas a sedentary lifestyle can lead to a more significant loss of strength. The authors also showed that different levels of physical activity could lead to varying levels of respiratory muscle strength. All participants in our study were physically active. However, they may have different levels of physical conditioning, leading to different breathing motion adaptations. Furthermore, healthy aging is highly influenced by lifelong physical fitness affecting the analysis based on chronological age (Land et al., 2011). We were able to observe an increase in the variability of the data with increasing age, mainly in the correlation coefficient.

The greater action of the diaphragm, observed through the higher contribution of inferior thorax and abdomen compartments, acts as a compensatory mechanism to decrease superior thorax muscle motion, mainly in VC. Mendes et al. (2020) and Muniz de Souza et al. (2016) also observed this compensatory mechanism in their studies. However, although the results suggest such a compensation mechanism, some participants could have compensated in different ways or did not compensate at all. Therefore, this fact, plus the different levels of physiological and structural changes and physical conditioning influence mentioned above may have contributed to the high data variability observed in our study.

As all the participants were physically active, it was impossible to

assess whether these changes would occur in sedentary individuals. Another limitation of our study was the lack of control of the level of physical conditioning of the participants and the time of physical activity practiced during life.

Based on our results, we can suggest that, when evaluating the effects of aging on breathing motion patterns, other factors, such as similar physical conditioning and time of physical activity practice, lifestyle, and health conditions must be taken into account since the age-related respiratory changes appear to have multifactorial causes.

In conclusion, our study suggested that, based on 3D kinematic variables of breathing motion, physically active women could not be classified into age groups; thus group division based solely on chronological age may not be the best choice when investigating breathing motion patterns in an aging perspective. Unlike what is commonly known in the respiratory physiology field, where age-related changes are well established, age itself turned out to represent a weak predictive factor for changes in breathing motion patterns. Further studies, including other factors as level of physical condition, time of physical activity practiced throughout life, and sedentary lifestyle are essential to deeply understand the multifactorial relationships of aging and breathing motion pattern.

### Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

### Acknowledgments

This work was supported by Coordenação de Aperfeiçoamento de Pessoal de Nível Superior (CAPES) [Grant Number 08/2017 and 27/2014].

### References

- Aliverti, A., Pedotti, A., 2003. Opto-electronic plethysmography. *Monaldi Arch. Chest Dis.* 59 (1), 12–16.
- Britto, R.R., Zampa, C.C., Oliveira, T.A., Prado, L.F., Parreira, V.F., 2009. Effects of the aging process on respiratory function. *Gerontology* 55 (5), 505–510. <https://doi.org/10.1159/000235853>. In press.

- Ferrigno, G., Cavernali, P., Aliverti, A., Molteni, F., Beulcke, G., Pedotti, A., 1994. Three-dimensional optical analysis of chest wall motion. *J. Appl. Physiol.* 77 (3), 1224–1231.
- Gallego, J., Benammou, S., Vardon, G., Chambille, B., Denjean, A., Lorino, H., 1997. Influence of thoracoabdominal pattern of breathing on respiratory resistance. *Respir. Physiol.* 108, 143–152.
- Gimby, G., Goldman, M., Mead, J., 1976. Respiratory muscle action inferred from rib cage and abdominal V-P partitioning. *J. Appl. Physiol.* 41 (5), 739–751. <https://doi.org/10.1152/jappl.1976.41.5.739>. In press.
- Janssens, J.P., Pache, J.C., Nicod, L.P., 1999. Physiological changes in respiratory function associated with ageing. *Eur. Respir. J.* 14 (6), 1454–1455.
- Kaneko, H., Horie, J., 2012. Breathing movements of the chest and abdominal wall in healthy subjects. *Respiratory Care* 57 (9), 1442–1451.
- Lalley, P., 2013. The aging respiratory system – Pulmonary structure, function and neural control. *Respir. Physiol. Neurobiol.* 187, 199–210.
- Land, K.C., Michalos, A.C., Sirgy, J., 2011. Handbook of social indicators and quality of life research. Springer Science & Business Media.
- Lunardi, A.C., et al., 2014. Effect of volume-oriented versus flow-oriented incentive spirometry on chest wall volumes, inspiratory muscle activity, and thoracoabdominal synchrony in the elderly. *Respiratory Care* 59 (3), 420–426.
- Massaroni, C., 2018. The use of kinematics for pulmonary volume assessment. In: Müller, B., Wolf, S. (Eds.), *Handbook of Human Motion*. Springer International Publishing, pp. 847–862.
- Massaroni, C., Silvatti, A.P., Levai, I.K., Dickinson, J.W., Winter, S., Schena, E., Silvestri, S., 2018. Comparison of marker models for the analysis of the volume variation and thoracoabdominal motion pattern in untrained and trained participants. *J. Biomech.* 76, 247–252.
- Mendes, L.P.S., Vieira, D.S.R., Gabriel, L.S., Ribeiro-Samora, G.A., Andrade, A.D., Brandão, D.C., Goes, M.C., Fregonezi, G.A.F., Britto, R.R., Parreira, V.F., 2020. Influence of posture, sex, and age on breathing pattern and chest wall motion in healthy subjects. *Brazilian J. Phys. Therapy* 24 (3), 240–248. <https://doi.org/10.1016/j.bjpt.2019.02.007>. In press.
- Miranda, A.P.B., Gastaldi, A.C., Souza, H.C.D., Santos, J.L.F., 2015. The influence of physical fitness on respiratory muscle strength in the elderly. *Am. J. Sports Sci.* 3 (1), 6–12. <https://doi.org/10.11648/j.ajss.20150301.12>. In press.
- Muniz de Souza, H.M., Rocha, T., Campos, S.L., Brandão, D.C., Fink, J.B., Aliverti, A., de Andrade, A.D., 2016. Acute effects of different efforts on ventilator pattern and chest wall compartmental distribution in elderly women. *Respir. Physiol. Neurobiol.* 227, 27–33.
- Nikolić, M., Vranid, T.S., Arbanas, J., Cvijanovic, O., Bajek, S., 2010. Muscle loss in elderly. *Collegium Antropologicum* 34 (2), 105–108.
- Pappaléo Netto, M., 2002. O estudo da velhice: historico, definicao do campo e termos basicos. *Tratado de Geriatria e Gerontologia*. Guanabara Koogan, Rio de Janeiro, pp. 2–12. In press.
- Parreira, V.F., Bueno, C.J., França, D.C., Vieira, D.S.R., Pereira, D.R., Britto, R.R., 2010. Padrão respiratório e movimento toracoabdominal em indivíduos saudáveis: influência da idade e do sexo. *Revista Brasileira de Fisioterapia* 14 (5), 411–416.
- Ragnarsdóttir, M., Kristinsdóttir, E.K., 2006. Breathing movements and breathing patterns among healthy men and women 20–69 years of age Reference values. *Respiration* 73 (1), 48–54.
- Rodrigues, I.M., Bernardina, G.R.D., Sarro, K.J., Baroni, G., Cerveri, P., Silvatti, A.P., 2017. Thoracoabdominal breathing motion pattern and coordination of professional ballet dancers. *Sports Biomech.* 18 (1), 51–62.
- Sarro, K.J., Silvatti, A.P., Barros, R.M.L., 2008. Coordination between ribs motion and thoracoabdominal volumes in swimmers during respiratory maneuvers. *J. Sports Sci. Med.* 7, 195–200.
- Silvatti, A.P., Sarro, K.J., Cerveri, P., Baroni, G., Barros, R.M., 2012. A 3D kinematic analysis of breathing patterns in competitive swimmers. *J. Sports Sci.* 30 (14), 1551–1560.
- United Nations, 1982. Provisional Guidelines on Standard International Age Classifications, ST/ESA/STAT/SER.M74. New York: United Nations.
- Verschakelen, J.A., Demendts, M.G., 1995. Normal thoracoabdominal motions: influence of sex, age, posture, and breath size. *Am. J. Respir. Crit. Care Med.* 151, 399–405.