Original

Respiratory Function Assessment through Kinematic Analysis of Chest Wall Movements: Effects of Position and Gender

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ABSTRACT

Background: The effect of position and gender on chest movements and respiratory volumes is controversial and investigated in only a few studies.

Objective: This study aimed to investigate the effects of position and gender on the breathing pattern during four different positions in healthy individuals.

Material and Methods: In this cross-sectional study, twenty-eight (14 males, 14 females) healthy individuals participated aged 20-45 years. The optoelectronic plethysmography (OEP) method was used for the three-dimensional evaluation of chest wall motions and the compartmental analysis of the breathing pattern in supine, sitting, standing, and active straight leg raised (ASLR) positions. Volume changes in different parts of the chest wall were also measured.

Results: Position affected total and compartmental respiratory volumes in both genders. Respiratory volumes decreased in the supine position compared to sitting and standing. Total and abdominal respiratory volumes also decreased in females when comparing supine positions with the ASLR. A higher pulmonary rib cage contribution was identified in females, and males exhibited higher abdominal rib cage volume compared with females.

Conclusion: The breathing pattern was affected by position and gender, and the respiratory volumes increased in more upright positions, perhaps due to a greater gravitational load. The ASLR decreases the respiratory volume, which is probably due to increased postural demand.

Citation: Shaghayeghfard B, Karimi MT, Abbasi L, Razeghi M. Respiratory Function Assessment through Kinematic Analysis of Chest Wall Movements: Effects of Position and Gender. *J Biomed Phys Eng*. 2024;14(1):67-78. doi: 10.31661/jbpe.v0i0.2105-1335.

Keyword

Plethysmography; Chest Wall; Lung Volume Measurements; Gender Differences; Position

Introduction

The assessment of chest wall kinematics and compartmental analysis of breathing provides information on respiratory function [1]. The position influences thoracoabdominal kinematics during tidal breathing [2]. Different positions affected respiratory patterns, such as breathing, which is predominantly done by the abdominal in more upright positions, and supine position during breathing, which affects the thoracic compartment volume [2].

The volume changes of the regional chest wall in supine and prone positions demonstrated the most changes in the abdominal com

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Received: 13 May 2021
Accepted: 22 August 2021

partment [3]. However, limited information is available about the effects of assuming positional demanding tasks on respiratory function, such as sitting and standing, and active straight leg raised (ASLR) on respiratory function. The ASLR is usually employed as a diagnostic clinical test to load the lumbar spine and pelvic girdle [4] as an example of demanding conditions requiring the body to employ more sophisticated motor control strategies [4]. The ASLR test can evaluate patients with lumbar-spine pain disorders [5]. However, different studies have investigated motor control strategies during the ASLR to improve the understanding of the motor control mechanisms associated with load transfer through the pelvis [5-7], little information is known regarding kinematics of the chest wall movement during the ASLR [6], a movement that challenges trunk postural stability [4]. The diaphragm muscle as the respiratory muscle maintained postural stability [8]. The respiratory effect of the diaphragm in a postural activity, such as the ASLR, provides more information about affecting position on respiration function [7, 8].

According to the previous studies on changes in the kinematics and motor control strategies in respiratory muscles, healthy individuals demonstrated a pattern of greater abdominal and chest wall activation to the side of performing ASLR, with minimal alterations in the intra-abdominal pressure and respiration pattern and position of the diaphragm [4, 9]. However, less information is available on compartmental respiratory volumes and the effects of gender on the chest wall, and kinematics are still controversial [6, 10-12]. In addition, some studies reported a relatively greater thoracic motion in females [10-12], and other studies reported little non-significant differences in chest wall motion [1, 13].

However, qualitative methods, such as observation are predominantly employed to assess respiratory patterns, they provide less information with low suitable accuracy [4, 5, 7]. Since visual assessment of breathing is not reliable enough to characterize respiratory patterns [5], a spirometer is used to measure respiratory volumes and provides quantitative data; however, its accuracy mostly depends on gas temperature, humidity, viscosity, and density [14].

Since the measurement of chest wall surface motions could provide more valid quantitative information [3, 14], the optoelectronic plethysmography (OEP) method is introduced to accurately measure the volume variations of the chest wall and its compartments by three-dimensional coordinates of markers, placed on individuals' bodies to assess respiratory pattern. This cross-sectional study aimed to evaluate the hypothesis that positions and gender significantly affect the chest wall motion and breathing pattern. To the best of our knowledge, no studies have assessed various postural tasks with different loading demands yet [2, 10, 15].

Material and Methods

Participants

This cross-sectional study was conducted on twenty-eight healthy individuals aged 20-45 years (14 males and 14 females), who volunteered to participate and sign an informed consent form, into two groups based on their gender. The sample size was estimated according to a pilot study, in which five individuals were included in each group to create the exact size. Accordingly, 28 participants would provide 95% power and an alpha level of 0.05 to detect differences between the study groups. The participants were recruited via convenient sampling through advertisement and matched in terms of age and Body Mass Index (BMI).

Outcome measures

One of the outcome measures was the volume of the chest wall, and the following indices were calculated: pulmonary rib cage volume (ΔV_{RCp}), abdominal rib cage volume (ΔV_{RCa}), and the volume of the abdomen (ΔV_{AB}) [3, 14]. The distribution of the compartments (ΔV) was then presented as the percentage of the total chest volume (ΔV_{CW}) computed using the following formula:

$$\frac{\Delta V}{\Delta V_{CW}} \times 100 \qquad \text{Equation 1}$$

Inclusion/Exclusion criteria

Individuals aged between 18 and 45 years with a BMI ranging from 18 to 30 kg/m^2 were included in the study. The general exclusion criteria were dysfunctional entrapment of the nerve roots, radicular pain, lumbar surgery, lumbopelvic disorders or lumbar pain at least a year before participation, rheumatoid arthritis, cardio-respiratory disease, rib fracture, and any postural deformity observed in the general examination. Additionally, pregnant women and individuals with BMI>30 kg/m^2 were excluded.

Chest wall volume measurement

A motion analysis system (Qualysis®, Sweden) with eight high-speed cameras was used to record the chest wall motion during normal breathing, which was validated in another study, revealing a good Pearson's correlation coefficient (r=0.999), compared to gas volume spirometry [16]. For supine and the ASLR positions, 52 reflective markers were taped on the anatomical reference landmarks on the anterior and lateral parts of the trunk (Figure 1) [17]. The lung volume was calculated by connecting eight adjusted reflective passive markers with a diameter of 9 mm. The other 37 markers were attached for sitting and standing positions according to the protocol described in the previous articles [14, 18]. Changes in the chest wall volume from expiration to inspiration were measured in all four positions.

Setting and data collection

Before data collection, calibration of the motion capture system was done by continuously twisting the T shape wand over the L shape part of the motion analysis system on the ground in a variety of directions to cover all the capture volumes of interest. After calibration, the participants were instructed to breathe quietly, and the data were gathered for 15 s in each test position, i.e., supine, the ASLR, sitting on an unsupported chair with hands resting on thighs, and standing while feet were shoulder-width apart with 15 min interval between the tests.

For data acquisition in the ASLR position, the individuals lying in the supine position with their feet 20 cm apart were asked to raise their right legs and keep their heels 20 cm above the supporting surface for 15 s without bending their knees. Limb elevation was monitored using an erect ruler. The difference between inspiratory (Vi) and expiratory (Ve) volumes of each compartment (ΔV_{RCp}%, ΔV_{RCa}%,

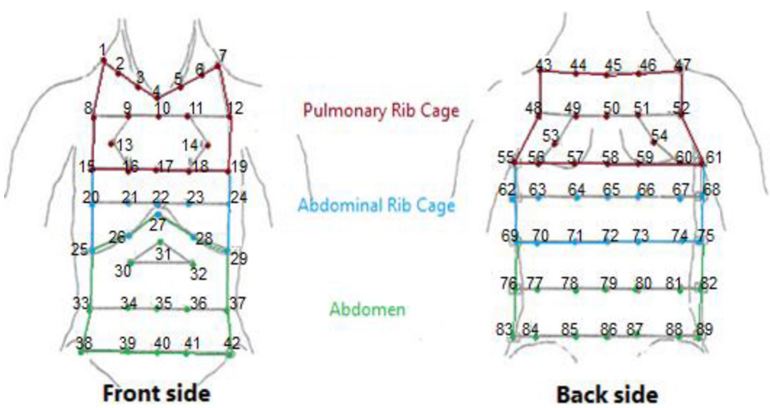

Figure 1: Marker placements on both sides of the trunk

and $\Delta V_{AB}\%$) and the total chest wall volume changes (ΔV_{CW}) were then computed using the following formula:

$$\Delta V = Vi - Ve \qquad \text{Equation 2}$$

Data analysis

Total and compartmental volumes were computed by importing 3D markers trajectories collected via the Qualisys Track Manager (QTM) system to the Motion Kinematic and Kinetic Analyzer (MOKKA) software manufactured in Canada. The outputs were then imported into MATLAB (R2018b) to obtain the final results. The geometric model of the trunk surface was created by the MATLAB code to measure the chest wall volumes by connecting eight adjusted passive markers to form a sit-faced polyhedron (each polyhedron was further divided into six tetrahedrons with a trigon shape). Each compartment volume was calculated by summing the tetrahedron volumes located within the compartment (Figure 2). The maximum and minimum volumes in every respiratory cycle were measured, and the differences demonstrated the volume changes between inspiration and expiration. Furthermore, the distribution of each compartment was reported as a percentage of the total volume [19].

Statistical analysis

The normality of data distribution was determined using the Shapiro-Wilk test. Accordingly, the two groups were compared regarding the demographic variables using the student t-test or Mann-Whitney test. A general linear model for repeated measures with gender as a between-subjects factor was employed to evaluate the impacts of position and gender on the respiratory volumes. Further, independent and paired t-tests were used to evaluate the differences between males and females in each position and compare positions in each group, respectively. The level of significance was set at a *P*-value<0.05 for all statistical comparisons.

Results

The characteristics of both groups of participants and male and female subgroups are presented in Table 1. Based on the results, the two gender subgroups were similar in terms of age and BMI, but not height and weight.

Pulmonary rib cage volume (V_{RCp}) measurement

The V_{RCp} was strongly influenced by position. The results revealed a significant increase in pulmonary rib cage compartment volume in the supine position compared to the sitting position (females: *P*-value<0.0001, males: *P*-value=0.001) and the standing position (*P*-value<0.0001 in both genders) in both groups. In addition, the male showed

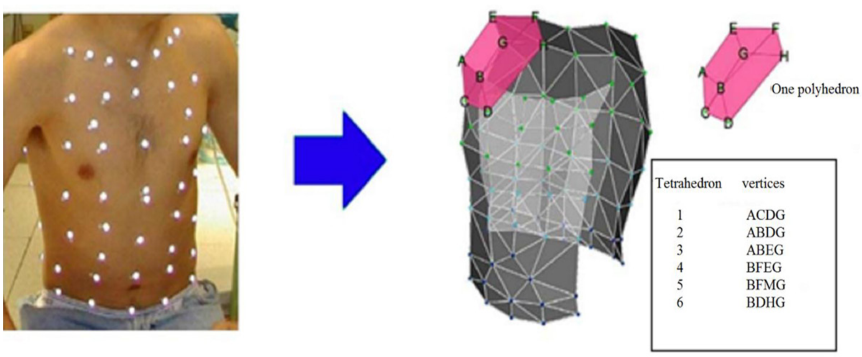

Figure 2: Polyhedrons placed within compartment volumes comprising six tetrahedrons. Left photograph: Markers placed on a front surface of the body. Right photograph: Thoraco-abdominal surface triangulation

Table 1: The individuals' demographic and anthropometric parameters

Quantitative data	Male (n=14)	Female (n=14)	Total (n=28)
Age (year)	31.69±7.36 (20-40)	31.78±4.94 (22-39)	31.73±6.15 (20-40)
BMI (kg/m^2)	24.38±2.44 (21.09-26.1)	23.48±1.87 (20.77-24.08)	23.93±2.15 (20.77-26.1)
Weight (kg)	66.7±8.4 (61-83)	**51.6±9.0 (48-72)	59.15±8.7 (48-83)
Height (cm)	171.2±7.2 (167-178)	**159.3±8.6 (152-173)	165.25±7.9 (152-178)

BMI: Body Mass Index, All data have been presented as means±SD

***P*<0.01 in female subjects vs. male subjects

significantly greater volume changes in pulmonary rib cage (V_{RCp}) compared to the female in supine and standing positions (*P*-value=0.012 and, *P*-value=0.035, respectively) (Table 2, Figure 3).

Abdominal rib cage volume (V_{RCa}) measurement

The position alters the V_{RCa} between the supine and the sitting positions in both genders (females: *P*-value<0.0001, males: *P*-value=0.026) as well as between supine and standing positions in females (*P*-value<0.0001). Moreover, males showed significantly greater volume changes compared to females in the four positions (Table 3, Figure 3).

Abdominal volume (V_{AB}) measurement

The position affected the V_{AB} with a reduction in volume between the supine and the ASLR only in female subjects (*P*-value=0.004). The differences between the groups were significant only in standing position (*P*-value=0.03) (Table 4, Figure 3).

Total chest wall volume measurement

The total volume changes of the chest wall

Table 2: Volume changes of V_{RCp} (pulmonary rib cage volume) in different positions measured by optoelectronic plethysmography

Variables		Positions				*P*-value		
		Standing(L)	Sitting(L)	Supine(L)	ASLR(L)	[a]Position	[b]Group	[c]Interaction of group and position
Group	Female	0.34±0.07	0.32±0.15	0.12±0.02	0.12±0.05	*P<0.0001	0.145	0.639
	Male	0.40±0.08	0.34±0.16	0.15±0.03	0.13±0.09			
P-value		*0.035	0.792	*0.012	0.816			

Values have been expressed as mean±standard deviation.

ASLR: Straight Leg Raise Position, L: Liter

*Significantly different

a: $F_{(1.77-44.25)}$=49.79, b: $F_{(1)}$=2.26, c: $F_{(1.77-44.25)}$=0.41

were significantly influenced by position and gender. Between the supine and sitting positions, the chest wall volume increases in both groups (females: *P*<0.0001; males: *P*=0.003). Between the supine and standing positions, the chest wall volume increased significantly in both genders (*P*<0.0001 in both groups). Between the supine and ASLR positions, the total chest volume decreased significantly in female subjects (*P*=0.001). The differences

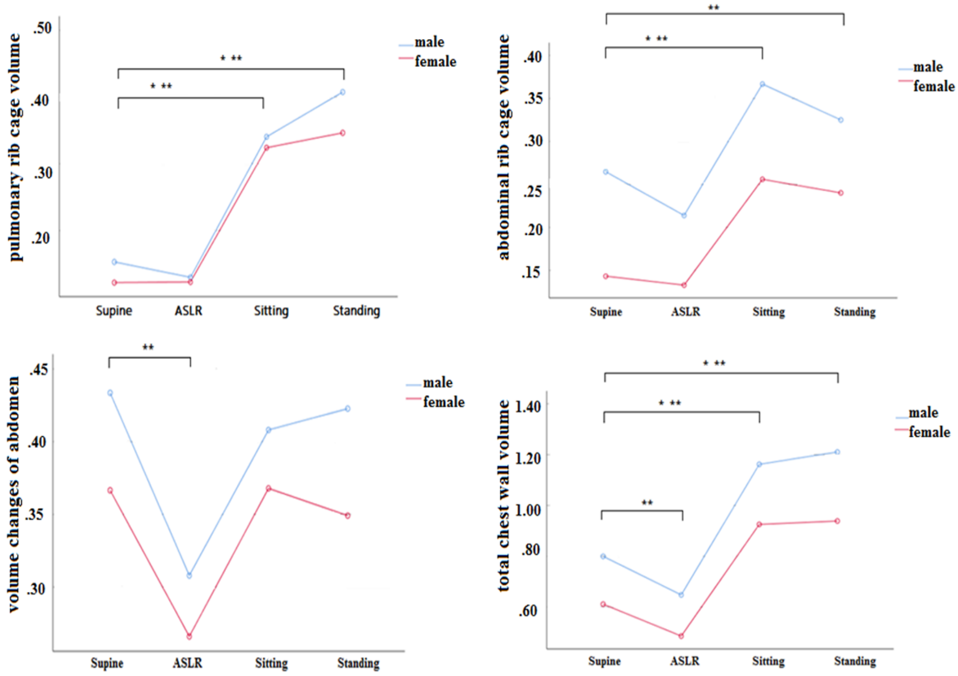

Figure 3: Influence of position and gender on compartmental and total trunk volumes. Data have been shown as mean values. Upper left: Pulmonary rib cage volume; Upper right: Abdominal rib cage volume; Lower left: Volume changes of abdomen; Lower right: Total volume. **P*: Significant difference for males; ***P*: Significant difference for females.

Table 3: Volume changes of V_{RCa} (abdominal rib cage volume) in different positions measured by optoelectronic plethysmography.

Variables		Positions				*P*-value		
		Standing(L)	Sitting(L)	Supine(L)	ASLR(L)	[a]Position	[b]Group	[c]Interaction of group and position
Group	Female	0.24±0.06	0.25±0.08	0.14±0.01	0.13±0.02	*<0.0001	*<0.0001	0.772
	Male	0.32±0.20	0.36±0.12	0.26±0.07	0.21±0.06			
P-value		0.147	*0.010	*0.0001	*0.002			

Values are expressed as mean±standard deviation.

ASLR: Straight Leg Raise Position, L: Liter

*Significantly different.

a: $F_{(2.25\text{-}54.01)}$=12.73, b: $F_{(1)}$=23.28, c: $F_{(2.25\text{-}54.01)}$=0.294

between males and females were significant in all the positions, with male subjects showing greater chest wall volume changes (Table 5, Figure 3).

Contribution of each compartmental volume in females and males

Evaluation of the contribution of each compartment to the respiratory pattern demonstrated that the V_{RCp} had a greater contribution to chest wall motion in ASLR, sitting, and standing positions in females (*P*-value<0.05), and a greater contribution of the V_{RCa} in supine, ASLR, and sitting positions in males (*P*-value<0.05). The differences between males and females regarding abdomen compartments were not statistically significant (Figure 4).

Discussion

The effects of position and gender on the total and compartmental volumes of the trunk

Table 4: Volume changes of V_{AB} (the volume of the abdomen) in different positions measured by optoelectronic plethysmography

Variables		Positions				*P*-value		
		Standing(L)	Sitting(L)	Supine(L)	ASLR(L)	[a]Position effects	[b]Group effects	[c]Interaction of group and position
Group	Female	0.34±0.08	0.36±0.09	0.36±0.07	0.26±0.09	*0.003	0.116	0.864
	Male	0.42±0.09	0.40±0.13	0.43±0.22	0.30±0.17			
P-value		*0.03	0.36	0.32	0.44			

Values have been expressed as mean±standard deviation

ASLR: Active straight leg raise position, L: Liter

*Significantly different.

a: $F_{(2.15\text{-}53.75)}$=6.15, b: $F_{(1)}$=2.65, c: $F_{(2.15\text{-}53.75)}$=0.16

Table 5: Total volume changes (ΔV_{CW}) in different positions measured by optoelectronic plethysmography

Variables		Positions				*P*-value		
		Standing(L)	Sitting(L)	Supine(L)	ASLR(L)	[a]Position	[b]Group	[c]Interaction of group and position
Group	Female	0.93±0.18	0.92±0.18	0.48±0.09	0.61±0.08	*<0.0001	*<0.0001	0.720
	Male	1.21±0.17	1.16±0.31	0.64±0.19	0.79±0.27			
P-value		*0.001	*0.024	*0.034	*0.01			

Values have been expressed as mean±standard deviation.

ASLR: Straight leg raise position, L: Liter

*Significantly different.

a: $F_{(3\text{-}75)}$=46.83, b: $F_{(1)}$=23.38, c: $F_{(3\text{-}75)}$=0.44

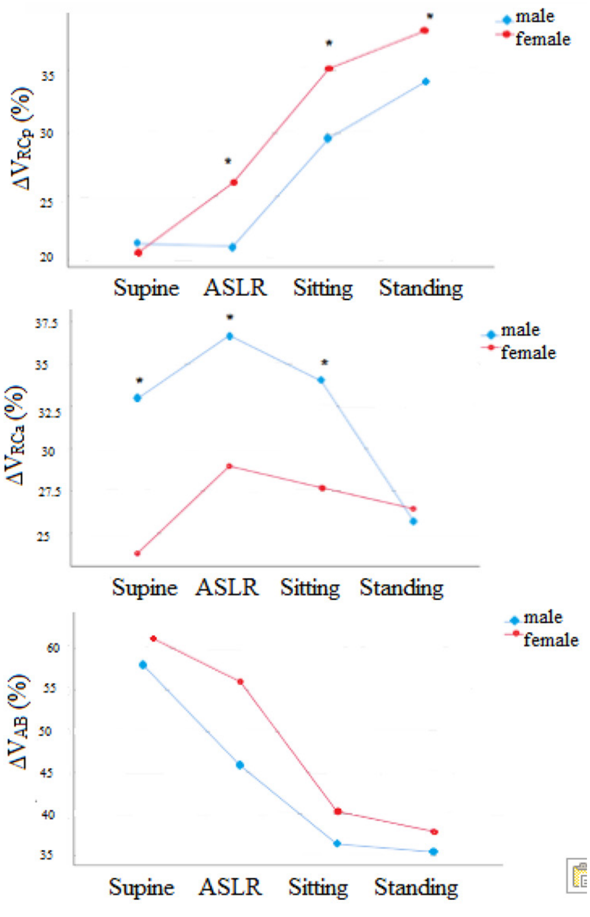

Figure 4: Contribution of RCp (pulmonary rib cage), RCa (abdominal rib cage), and AB (abdomen).
**P*<0.05 in female subjects vs. male subjects

during breathing were investigated among healthy individuals in the present study. The present study evaluated the chest wall kinematics using the OEP technique during ASLR and standing positions.

The effect of position

The total and compartmental volume changes were influenced by positional changes. The results revealed an increase in the rib cage respiratory volumes (V_{RCp} and V_{RCa}), and total volumes as the participants assumed more upright positions (sitting and standing versus supine). Additionally, postural load increases, and all the respiratory volumes, including V_{RCp}, V_{RCa}, V_{AB}, and V_{CW} decrease during the ASLR.

The previous studies demonstrated that the pulmonary static and dynamic resistance decreased and lung compliance increased from the supine to the sitting positions in both female and male populations [12, 20-22], probably due to the increase of the V_{RCp} and the V_{RCa} from supine to sitting position in males and females. Barnas et al. reported that sitting posture, compared with supine position, caused an almost 24% reduction in pulmonary resistance, resulting in a decrease in the total resistance of lung and chest wall components [21], probably due to the increase in the total chest wall volume from supine to sitting position in both groups. Mendes et al. evaluated the respiratory pattern and chest wall motion from supine to inclined and sitting positions in healthy participants using the OEP and reported significant differences among the positions regarding V_{RCp}, V_{RCa}, V_{AB}, and V_{CW} [22]. The findings of the present research are in agreement with those of Mendes et al. showing the respiratory pattern (V_{CW}) and chest wall motion were influenced by position variation in all compartments (V_{RCp}, V_{RCa}, and V_{AB}). However, the ASLR and standing positions were not assessed in Mendes et al. study. The V_{RCa} is assumed to reflect the diaphragm and the effects of abdominal and pleural pressures, and the V_{AB} shows the movement of the diaphragm and its effect on the abdominal muscles [19].

The results of the present study are in line with those of the previous studies, indicating an increase in the R_{Ca} from supine to sitting position [12, 21, 22]. It has been postulated that diaphragm contraction during assuming sitting and standing positions causes the lower ribs [9, 10, 11] to expand. This leads to an abdominal contraction to provide more stability in more upright positions [23, 24]. Based on the results, the V_{AB} has a reduction from the supine to sitting and standing positions with insignificant differences. Rome et al. measured the chest wall volume variation from the supine to sitting position and found a progressive increase in the rib cage displacement and a reduced abdominal contribution to the total chest volume when the trunk became more erect. In that study, the rib cage was considered a summation of the pulmonary volume and V_{RCa}. Additionally, the ASLR and standing positions were not evaluated [12].

The diaphragm affects the rib displacement in two ways, as follows: 1) with the "zone of apposition"; during inspiration, lower ribs are expanded due to the transmitted force of the diaphragm, which is attached to those ribs and depends on the size of the zone of apposition and intra-abdominal pressure and 2) with relation to the muscle force direction on lower ribs. A cranially oriented force of the diaphragm is applied on the lower ribs, leading to raising and turning outwards. However, abdominal contents should resist diaphragm movement to work efficiently. With slight resistance, the diaphragm would not be able to create sufficient force [25]. On the other hand, more postural stability is required in more demanding positions like upright positions (sitting and standing) and the ASLR, causing the diaphragm and abdominal muscles to contract to maintain sufficient trunk stabilization [23, 26].

These findings can justify the significant reduction of abdominal and total chest volume changes from the supine to the ASLR positions in females, and the slight reduction of this compartment from the supine to sitting and standing positions in both genders. In the research by O'Sullivan et al. electromyog raphy and ultrasonography findings showed a greater abdominal and respiratory muscle contraction on the side of the ASLR performance, with a slight change in abdominal pressure and rate of respiration and a minimal displacement of the diaphragm in a group of healthy subjects. In that study, the chest wall motion was not evaluated and the respiratory pattern was evaluated by a spirometer, which is not able to detect compartmental volume changes during respiration [4, 9].

The effect of gender

The results of the present research demonstrated that the kinematics of the trunk, particularly V_{RCa} and V_{CW} were considerably influenced by gender. Accordingly, the female individuals showed greater pulmonary rib cage contribution to tidal breathing and the male demonstrated more abdominal rib cage contribution.

Mendes et al. compared chest wall motion from the supine to inclined and sitting positions among males and females in healthy participants and reported a significant difference between the two genders regarding V_{RCp}, V_{CW}, and V_{AB} [22]. In contrast, the results of the present research showed significant differences between males and females considering V_{RCa} and V_{CW}. In addition, differences between genders with respect to V_{RCp} and V_{AB} were limited to the standing position. In Mendes' study, the participants were mostly female. The difference in the number of participants in the age groups might yet be another reason for the inconsistency between the findings. Moreover, the means of the participants' height and weight were not reported [22].

In the current study, the female group was lighter in weight and shorter in height compared to the male group, which might have adversely influenced the reported results regarding the observed gender effects. The previous study conducted by McClaran et al. reported that female participants are characterized by smaller volumes of the chest wall, attributed to their smaller body dimensions. The difference between the two genders in terms of respiratory function might also be associated with their smaller body [27]. Romei et al. emphasized that females were characterized by a higher rib cage volume contribution, whereas the males had a greater abdominal volume contribution to tidal breathing. Also, they considered the rib cage volume as the sum of both pulmonary and abdominal rib cages. In that research, a significant difference was observed between the males and females with regard to height and weight [12]. A part of these findings regarding the pulmonary rib cage was consistent with those of the present investigation. However, different results were reported in terms of abdominal contribution to a breathing pattern, which might be attributed to different positions under assessment. In that study, different compartmental classifications were considered, and the standing and the ASLR positions were not evaluated [12].

In the current study. The gender difference was significant for the total chest volume in all four positions and RCp in three out of the four positions (supine, sitting, and the ASLR). This gender-influenced difference might be explained by the dissimilarity in the abdominal, pelvic floor, and diaphragm muscle activation patterns. There are only two studies by Romei, et al. and Mendes et al. with potentially similar aims to the present study [12, 22]. In both studies, the supine and sitting positions were explored. In the research by Romei, et al. the total lung volume changes were reported, but the compartments of the lung were not assessed separately. Mendes et al. aimed to investigate the respiratory motion in the supine and sitting positions and determine the difference between the two genders. However, the number of male participants was three folds higher than females, which might interfere with the results.

The previous studies indicated that more upright positions required a greater contribution of the chest wall to the total breathing volume [12, 22]. In addition, females presented a higher RCP contribution to tidal breathing compared to males [12, 22]. Bellemare et al. reported that in comparison with males, females exhibited a smaller rib cage size relative to height. A higher inclination angle of ribs was also reported in chest radiography in females, resulting in more rib cage contribution to breathing compared to males. Besides, they showed a greater inspiratory rib cage muscle contraction during quiet breathing, leading to higher pulmonary rib cage volume variations [28].

The present research had a number of limitations: a) the values were indirectly estimated by placing markers on the external surface of the body and were not directly validated by a pneumotachograph, b) there was a lack of information on diaphragm movement by ultrasonography to provide another direct assessment tool for confirming the results, and c) some potentially confounding factors, such as female breast size and its possible mass loading effects on the chest wall kinematics were not investigated.

Conclusion

The present study demonstrated that position plays a vital role in the breathing pattern. Furthermore, this study might indicate that the diaphragm as the main respiratory muscle, predominately provides postural stabilization rather than respiration during postural-demanding tasks. Studies with motor control strategies may cause to confirm this speculation about the role of the diaphragm and shed some light on the responsible underlying mechanisms. The present research findings also suggested that the breathing pattern, as indicated by compartments volume contribution, was strongly influenced by gender.

Acknowledgment

This article was derived from research done by Bahar Shaghayegh Fard, as a part of her PhD dissertation. The project was financially supported by Shiraz University of Medical Sciences, as a student research grant (No. 97-01-06-18490). Hereby, the authors would like to thank Ms. A. Keivanshekouh at the Research Consultation Center (RCC) of Shiraz University of Medical Sciences for her invaluable assistance in editing the manuscript. All the individuals who contributed to the study are appreciated, as well.

Authors' Contribution

B. Shaghayeghfard contributed to idea formation, proposal writing, data collection and analysis, and drafting the manuscript. MT. Karimi took part in developing the idea and supervision of the project and reviewing the manuscript. L. Abbasi did the idea development and was consulted during data collection and interpretation processes. M. Razeghi supervised the research project as the principal person and reviewing the manuscript. All authors reviewed and approved the final manuscript.

Ethical Approval

Research Center at Shiraz University of Medical Sciences (SUMS) and approved by the Research Ethics Committee of SUMS (ethics code: REC.1397.023).

Informed Consent

A consent form was signed by each participant before data collection.

Conflict of Interest

None

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