Forward trunk lean with arm support affects the activity of accessory respiratory muscles and thoracoabdominal movement in healthy individuals

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A B S T R A C T

Despite the reported benefits of postures involving leaning the trunk forward with arm support for relieving dyspnea, how those postures influence the mechanics of breathing remains unclear. In response, the aim of the study reported here was to evaluate how posture (i.e., standing and sitting) and leaning the trunk forward with arm support affect the activity of accessory respiratory muscles and thoracoabdominal movement in healthy individuals. Thirty-five volunteers (15 males and 20 females) aged 18–29 years breathed with the same rhythm in standing and sitting positions while upright and while leaning the trunk forward with arm support. Surface electromyography was performed to assess the activity of accessory inspiratory (i.e., during inspiration) and abdominal (i.e., during inspiration and expiration) muscles, and a motion capture system was used to assess thoracoabdominal movement. Results revealed that upper *trapezius* activity was significantly lower in forward-leaning postures than in upright ones ($P = 005$; $_p = 0.311$), although the activity of the *sternocleidomastoideus* and *scalenus* ($P < 0.001$; $_p = 0.427–0.529$), along with the anterior-to-posterior movement of the upper ribcage ($P < 0.001$; $_p = 0.546$), were significantly greater in forward-leaning postures than in upright ones. The activity of the external oblique and *transversus abdominis*/internal oblique was significantly lower in sitting than in standing postures ($P < 0.050$; $_p = 0.206–0.641$), and though the activity of the *transversus abdominis*/internal oblique was significantly lower in forward-leaning than in upright postures ($P \leq 0.001$; $_p = 0.330–0.541$), a significantly greater anterior-to-posterior movement of the abdomen was observed ($P < 0.001$; $_p = 0.662$). However, the magnitude of the lower ribcage's medial-to-lateral movement was significantly lower in forward-leaning than in upright postures ($P = 0.039$; $_p = 0.149$). Leaning the trunk forward with arm support not only increased the use of accessory inspiratory muscles but also decreased the use of the *transversus abdominis*/internal oblique, which improved thoracoabdominal movement.

*Keywords:*Respiration; Postural control; Tripod position; Surface electromyographic activity; Breathing movement

1. Introduction

Postures involving leaning the trunk forward with arm support – that is, the so-called "tripod position" – are often assumed to relieve dyspnea and improve pulmonary function (Bott et al., 2009; Gosselink, 2003; O'Neill & McCarthy, 1983). Research has shown that leaning forward improves the length-tension relationship and geometry of the diaphragm, which increases its output for breathing (Sharp, Drutz, Moisan, Foster, & Machnach, 1980). At the same time, in postures involving leaning the trunk forward, the efficacy of diaphragm contraction improves the motion of the chest wall, thereby enhancing changes in lung volume (Delgado, Braun, Skatrud, Reddan, & Pegelow, 1982). Although abdominal muscles may also assume an improved position for contraction with some degree of forward leaning (Dean, 1985), evidence regarding the recruitment of individual abdominal muscles in such postures and its impact on the thoracoabdominal movement remains scarce.

Postures involving leaning the trunk forward can also involve arm support (i.e., resting the forearms on the thighs or a surface) (Booth, Burkin, Moffat, & Spathis, 2014); however, the effect of that position on the activity of accessory inspiratory muscles and thoracoabdominal movement remains debatable. Sharp, et al. (1980) indicated the decreased contribution of the upper ribcage muscles (e.g., *sternocleidomastoideus*, SCM, and *scalenus*, Sc) in postures involving leaning the trunk forward with arm support, which consequently reduced energy expenditure. Conversely, other authors have shown that arm support increases the recruitment of those muscles and thus contributes significantly to ribcage elevation (Banzett, Topulos, Leith, & Nations, 1988; Kim et al., 2012).

Despite the reported benefits and physiological mechanisms of the tripod position, evidence to the contrary persists (Santos, Ruas, Sande de Souza, & Volpe, 2012). In response, we sought to elucidate the activity of inspiratory and abdominal muscles in postures involving leaning the trunk forward with arm support, as well as how the recruitment of accessory respiratory muscles in those postures affects thoracoabdominal movement. Thus, the aim of the study reported here was to evaluate how posture (i.e., standing and sitting) and leaning the trunk forward with arm support influence the activity of accessory respiratory muscles and thoracoabdominal movement in healthy individuals.

2. Methods

2.1. Sample

A study with a repeated measures design was conducted with a sample of 35 (15 males; 20 females) healthy higher education students (age: 21.43 ± 2.75 years; body mass: 61.95 ± 9.22 kg; height: 1.66 ± 0.08 m) volunteered to participate. Demographic and anthropometric data regarding the sample are described in Table 1. Participants had not participated in aerobic physical activities of moderate (i.e., at least 30 min on 5 days per week) or vigorous intensity (i.e., at least 20 min on 3 days per week) for more than 1 year. Aerobic training decreased the minute ventilation at a given absolute submaximal intensity, which appeared to relate closely to improved skeletal muscle oxidative capacity in peripheral and respiratory muscles (Thompson, 2014). Individuals with abdominal obesity (i.e., a waist-to-height ratio less than 0.5 and a waist-to-hip ratio less than 0.9 for men and 0.85 for women) (World Health Organization, 2011) were excluded from the sample, as were habitual smokers and individuals with chronic nonspecific lumbopelvic pain (i.e., recurrent episodes of lumbopelvic pain for a period exceeding 3 months), scoliosis, length discrepancy of the lower limbs or other postural asymmetries, neurological or inflammatory disorders, metabolic or cardiorespiratory diseases, pregnancy or delivery in the previous 6 months, long-term corticosteroid therapy, a history of spinal, gynecological, or abdominal surgery in the previous year, or any conditions that could have interfered with data collection. All participants provided their written informed consent in compliance with the Declaration of Helsinki, and their anonymity and the confidentiality of their data were guaranteed. The Institutional Research Ethics Committee also approved the study.

2.2. Instruments and procedures

2.2.1. Sample selection and characterization

An online questionnaire was sent to all participants to verify their fulfillment of inclusion criteria and to collect sociodemographic information. Anthropometric and body composition measures were assessed in all participants who met the criteria. Height (m) and body mass (kg) were measured respectively using a seca 222 stadiometer with a precision of 1.0 mm and a seca 760 scale with a precision of 1.0 kg (seca – Medical Scales and Measuring Systems, Hamburg, Germany). Waist circumference (cm) was measured

Table 1
Sample characterization: demographic, anthropometric and body composition data, with mean, standard deviation, minimum and maximum.

	Mean	Standard deviation	Minimum	Maximum
Demographic and anthropometric data				
Age (years)	21.43	2.75	18	29
Body mass (kg)	61.95	9.22	48.40	84.20
Height (m)	1.66	0.08	1.53	1.84
Body composition data				
Waist/height ratio	0.44	0.03	0.38	0.50
Waist/hip ratio	0.80	0.04	0.74	0.90

around the obvious narrowing between the ribs, while the perimeter of the iliac crest and hip (cm) was measured around the hips horizontally at the greatest gluteal protuberance (Eston, Hawes, Martin, & Reilly, 2009). The mean of three measured values was calculated for each of those measurements to determine the waist-to-height and waist-to-hip ratios. Lower limb length (cm) was also measured and a postural assessment performed to inform the final sample selection. Women in the luteal phase of the menstrual cycle were contacted for data collection at a later date, because the presence of estrogen and progesterone receptors in bone, skeletal muscle, ligaments, and the nervous system can affect the structure and function of those tissues. Evidence suggests a relationship between hormonal fluctuations during the menstrual cycle and altered neuromuscular control (Dedrick et al., 2008).

2.2.2. Muscle activity

Surface electromyography (sEMG) was performed to assess the muscle activity of the upper *trapezius* (UT), SCM, Sc, *rectus abdominis* (RA), and the external oblique (EO), as well as the *transversus abdominis*/internal oblique (TrA/IO) of the dominant-hand side, for which the participant was asked to throw a ball. Muscle activity was recorded using BioPlux research device (Plux wireless biosignals S.A., Arruda dos Vinhos, Portugal) with 12-bit analog channels and a sampling frequency of 1000 Hz, using double differential electrode leads. To perform sEMG, the participant's hair was shaved, an abrasive cream was used to remove dead cells from the skin's surface, and the skin was cleaned with isopropyl alcohol (70%) to remove oil and remaining dead cells. An electrode impedance checker (Noraxon Corporate, Scottsdale AZ, United States of America) was used to ensure that impedance levels were less than 5 KΩ, which was considered to signify the satisfactory acquisition of the sEMG signal (Hermens, Freriks, Disselhorst-Klug, & Rau, 2000). Disposable, self-adhesive Ag/AgCl dual snap electrodes (Noraxon Corporate, Scottsdale AZ, United States of America) with circular conductive areas 1 cm in diameter and spaced 2 cm apart were used for sEMG. The electrodes were connected to bipolar active sensors (emgPLUX) with a gain of 1000, an analog filter at 25–500 Hz, and a common-mode rejection ratio of 110 dB. A disposable self-adhesive Ag/AgCl snap electrode (Noraxon Corporate, Scottsdale AZ, United States of America) with a circular conductive area 1 cm in diameter served was used as the reference electrode. All self-adhesive electrodes were placed on participants while standing 5 min after the skin preparation. The electrodes were placed parallel to the muscle fiber's orientation according to the following references: UT, distance between the seventh cervical vertebrae and acromion; SMC, distance between the mastoid process and the sternal notch, slightly posterior to the center of the muscle belly; Sc, at a slightly oblique angle just above the clavicle in the hollow triangle immediately posterior to the SMC, above the clavicle, and anterior to the UT; RA, 2 cm lateral to the umbilicus, over the muscle mass; EO, lateral to the RA and directly above the anterior superior iliac, halfway between the crest and ribs at a slightly oblique angle; and TrA/IO, 2 cm medially and below the anterior superior iliac spine, at which the *transversus abdominis* and inferior internal oblique muscle fibers unite, thereby precluding the differentiation of their surface electromyographic activity (Fig. 1) (Criswell, 2011; Marshall & Murphy, 2003). Electrode placements were confirmed by palpation and muscle contraction. The reference electrode was placed in the anterior superior iliac spine of the contralateral dominant-hand side. The sensors were connected via Bluetooth on the sEMG device to a laptop. MonitorPlux version 2.0 was used to display and acquire sEMG signals. All electrodes were tested to control the cross-muscular signal (crosstalk), electrical noise, and other forms of interference to the sEMG signals (Hermens et al., 2000).

2.2.3. Maximal respiratory pressures

MicroRPM (CareFusion Corporation, San Diego CA, United States of America), a respiratory pressure meter, was used to assess maximal inspiratory (MIP) and expiratory (MEP) pressures. Quasistatic maximal maneuvers were used to normalize the sEMG signal of the inspiratory and expiratory muscles (i.e., maximal muscle activity of each muscle during breathing). MIP and MEP were

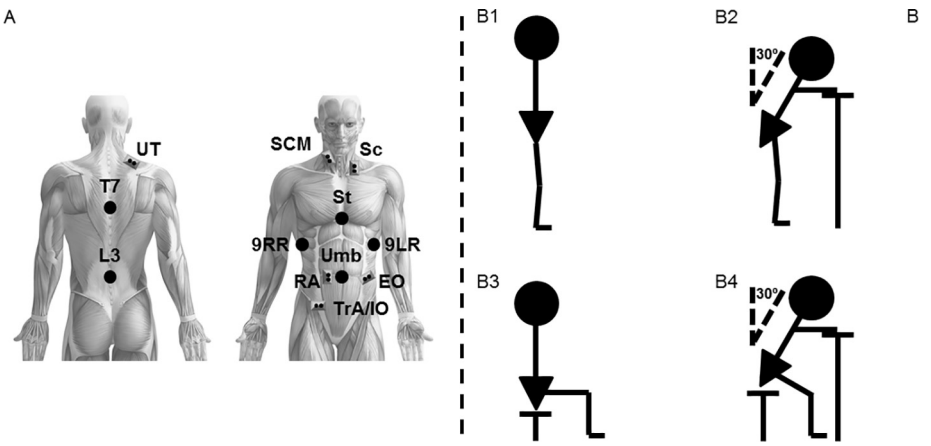

Fig. 1. (A) Schematic representation of the reflector markers (xiphoid process of sternum – St; spinous process of seventh thoracic vertebra – T7; ninth right – 9RR – and left – 9LR – ribs; umbilicus – Umb; spinous process of third lumbar vertebra – L3) and the electrode (upper *trapezius* – UT; *sternocleidomastoideus* – SCM; *scalenus* – Sc; *rectus abdominis* – RA; external oblique – EO; *transversus abdominis*/ internal oblique – TrA/IO) placement. (B) Schematic representation of the postural sets (upright standing – B1; standing and leaning the trunk forward with arm support – B2; upright sitting – B3; sitting and leaning the trunk forward with arm support – B4).

assessed in participants while standing, with a mouthpiece firmly held around the lips to prevent leakage and support the cheeks, and with a disposable nasal clip to prevent nasal breathing (Biopac Systems Inc., Goleta CA, United States of America). To assess MIP, participants performed forceful maximal inspiration (i.e., the Müller maneuver) in residual volumes, whereas to assess MEP, they performed forceful maximal expiration (i.e., the Valsalva maneuver) at total lung capacity. Each maneuver was encouraged verbally and performed during a 6-s period, with a resting time of 3 min. To normalize the sEMG signal of the inspiratory and expiratory muscles, three reproducible maneuvers were selected, according to American Thoracic Society/European Respiratory (2002) standards.

2.2.4. Chest wall motion

Qualisys Motion Capture system (Qualisys AB, Gothenburg, Sweden) was used to assess thoracoabdominal movement from the anterior to posterior of the upper ribcage, from the medial to the lateral of the lower ribcage, and from the anterior to the posterior of the abdomen. Six reflector markers were placed on the trunk: one above the xiphoid process, one over the spinous process of the seventh thoracic vertebra, one bilaterally on each of the ninth right and left ribs in the midaxillary line, one over the umbilicus, and the last over the spinous process of third lumbar vertebra (Fig. 1). The spatial position of reflector markers was collected using four infrared cameras (Oqus 1) with a sampling frequency of 100 Hz placed around the measurement volume. The wand calibration method was performed for 30 s, during which calibration results display a standard deviation of wand length less than 0.75 mm. Qualisys Track Manager was used to display and acquire kinematic data. A digital trigger signal from the BioPlux research device to the Qualisys Motion Capture system was used to synchronize sEMG signals and kinematic data.

2.2.5. Data collection protocol

The study's procedures were executed in a controlled environment at a biomechanical laboratory. To avoid inter-rater error, each researcher was responsible for only one task.

Each participant breathed while standing upright (UStand), standing and leaning the trunk forward with arm support (StandAS), sitting upright (USit), and sitting and leaning the trunk forward with arm support (SitAS). The order of postures was randomized. Participants were barefoot, with feet shoulder-width apart and knees in a loose-packed position. In UStand, the participant stood with upper limbs hanging along the sides of the body; in StandAS, the participant stood with 30° sagittal trunk flexion and upper limbs supported on a table with 90° shoulder flexion along the scapular plane; in USit, the participant sat with 90° hip flexion and upper limbs hanging along the side of the body; and in SitAS, the participant sat with 30° of sagittal trunk flexion, 90° hip flexion, and upper limbs supported on a table with 90° shoulder flexion along the scapular plane (Fig. 1). All joint amplitudes were confirmed using the Bubble® Inclinometer for trunk amplitude and Baseline® Plastic Goniometer 360° Head for hip and knee amplitudes, both with a precision of 1°. A single repetition of each task was performed for 10 consecutive respiratory cycles, with a resting time of 3 min. The respiratory rhythm (inspiratory time: 2 s; expiratory time: 4 s) was marked by a prerecorded voice, and all participants had been familiarized with the rhythm prior to data collection. A mouthpiece and a noise clip were used during all tasks.

After data collection, the electrodes were removed, and a moisturizing cream was applied.

2.2.6. Data processing

A routine was developed in MatLab Student software (MathWorks, Natick MA, United States of America) to synchronize and process sEMG signal and kinematic data. First, the sEMG signal was converted into volts, and a second-order digital filter Infinite Impulse Response (Butterworth) – one of 30 Hz (i.e., high pass) and another of 500 Hz (i.e., low pass) – was applied to the sEMG signal to remove electrical noise and cable movement, as well as the cardiac signal. The root mean square (RMS) of the sEMG signal was calculated using a moving average window set to 10 samples. For kinematic data, anterior-to-posterior distances of the upper ribcage between the xiphoid process and seventh thoracic vertebra, the medial-to-lateral distances of the lower ribcage between the ninth right and left ribs, and the anterior-to-posterior of the abdomen between the umbilicus and third lumbar vertebra were exported via Qualisys Track Manager. Last, the Moving Average filter in Qualisys Track Manager was applied to kinematic data. For each frame, the filter first identified the average of the data in the filter window around the current frame. Later, the filter set the data of the current frame to the average.

AcqKnowledge software version 4.1 (Biopac Systems Inc., Goleta CA, United States of America) was used to analyze the data. Inspiratory muscle activity was analyzed during inspiration, whereas abdominal muscle activity was analyzed independently during both inspiration and expiration. Both inspiration and expiration phases were determined from the kinematic data. For the 10 respiratory cycles collected, the mean RMS of four central respiratory cycles of each muscle was analyzed in each task, with a subsequent analysis of its average (Fig. 2).

To normalize data of the inspiratory and abdominal muscles, the mean RMS of the central 3 s of the MIP' inspiratory phase for inspiratory muscles and MEP' expiratory phase for abdominal muscles was analyzed. Next, the average of the mean RMS of three reproducible MIP and MEP maneuvers was calculated. The percentage of the activation intensity of each muscle was determined according to the equation: muscle activation intensity (%) = (mean RMS of each task/RMS of the MIP or MEP) × 100.

The magnitude of thoracoabdominal movements from the end expiration to end inspiration was determined. For the 10 respiratory cycles collected, the peak-to-peak amplitude of four central respiratory cycles was analyzed for each task, with a subsequent analysis of its average.

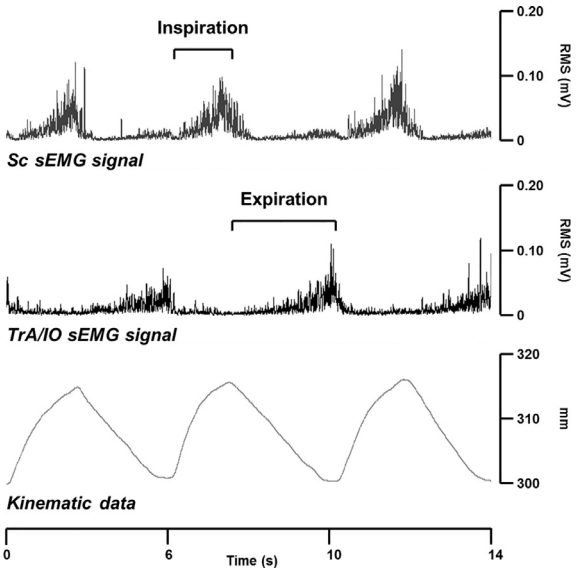

Fig. 2. Identification of one respiratory cycle (inspiration and expiration phases) and corresponding root mean square (RMS) of surface electromyography (sEMG) signal of the *scalenus* (Sc) and *transversus abdominis/* internal oblique (TrA/IO), through the kinematic data (an example).

2.3. Statistical analysis

IBM's Statistical Package for the Social Science® software version 20.0 (IBM Corporation, Armonk NY, United States of America) was used for descriptive and inferential data analysis, with significance set at 0.05. The Shapiro–Wilk test was used to test the normality of the data. Central tendency (mean) and dispersion (standard deviation) measures were used for descriptive statistics. Two-way repeated measures analysis of variance with two factors – posture (i.e., standing and sitting) and leaning the trunk forward with arm support (i.e., upright positions and forward-leaning postures) – was used to compare the percentage of the activation intensity of the inspiratory (i.e., during inspiration) and abdominal muscles (i.e., during inspiration and expiration), as well as the magnitude of thoracoabdominal movement (i.e., during breathing). (Marôco, 2014). To quantify the effect size, the partial eta square (η_p^2) values were calculated using cut-off values provided by Cohen: $\eta_p^2 = 0.01$ – small effect, $\eta_p^2 = 0.06$ – medium effect, and $\eta_p^2 = 0.14$ – large effect (Cohen, 1988).

3. Results

3.1. Muscle activity

3.1.1. Accessory inspiratory muscles

During inspiration, no significant interaction between the factors (i.e., posture and leaning the trunk forward with arm support) emerged in the muscle activation intensity of the accessory inspiratory muscles. With a large effect ($P = 0.014$ and $\eta_p^2 = 0.234$), UT activation intensity was significantly lower in forward-leaning postures (StandAS and SitAS) than in upright ones (UStand and USit) (Table 2). However, the activation intensity of the SCM ($P < 0.001$ and $\eta_p^2 = 0.427$) and Sc ($P < 0.001$ and $\eta_p^2 = 0.529$) was significantly greater in forward-leaning postures (StandAS and SitAS) than in upright ones (UStand and USit), also with a large effect (Table 2; Figs. 3 and 4).

3.1.2. Abdominal muscles

During both inspiration and expiration, no significant interaction between posture and leaning the trunk forward with arm support surfaced in the activation intensity of any abdominal muscle. The activation intensity of the EO (Inspiration: $P = 0.015$ and $\eta_p^2 = 0.206$; Expiration: $P = 0.001$ and $\eta_p^2 = 0.342$) and TrA/IO (Inspiration: $P < 0.001$ and $\eta_p^2 = 0.621$; Expiration: $P < 0.001$ and $\eta_p^2 = 0.641$) was significantly lower in sitting postures (USit and SitAS) than in standing ones (UStand and StandAS), with a large effect. Moreover, TrA/IO activation intensity was significantly lower in forward-leaning postures (StandAS and SitAS) than in upright ones (UStand and USit), also with a large effect (Inspiration: $P < 0.001$ and $\eta_p^2 = 0.541$; Expiration: $P < 0.001$ and $\eta_p^2 = 0.330$). Last, no significant differences were found in RA activation intensity in the factors (i.e., posture and leaning the trunk forward with arm support) during either breathing phase (Table 2; Figs. 3 and 4).

Table 2
Muscle activation intensity (expressed as %) and magnitude of thoraco-abdominal movements (expressed as millimetres) during breathing, in upright standing (UStand), standing and leaning the trunk forward with arm support (StandAS), upright sitting (USit) and sitting and leaning the trunk forward with arm support (SitAS). Data are presented as mean and standard deviation. *P* values and partial eta squared for the comparison between postural sets, according posture and leaning the trunk forward with arm support factors, as well as the interaction between them, are also presented.

Breathing phase	Variable	UStand	StandAS	USit	SitAS	Posture factor		Forward-leaning trunk with arm support factor		Interaction between factors	
						P value	Partial eta squared	*P* value	Partial eta squared	*P* value	Partial eta squared
Inspiration	UT	57.69	41.15	57.51	39.41	0.626	0.011	0.005	0.311	0.674	0.008
	(%)	(25.39)	(22.77)	(25.63)	(22.90)						
	SCM	4.50	7.82	4.80	7.92	0.541	0.015	< 0.001	0.427	0.747	0.004
	(%)	(3.12)	(5.01)	(3.72)	(5.90)						
	Sc	8.62	15.25	9.44	15.29	0.486	0.021	< 0.001	0.529	0.530	0.017
	(%)	(3.98)	(7.44)	(3.87)	(7.16)						
	RA	17.59	17.95	17.82	17.45	0.655	0.008	0.969	< 0.001	0.205	0.066
	(%)	(9.75)	(9.91)	(9.61)	(9.61)						
	EO	11.24	10.05	9.32	8.54	0.015	0.206	0.071	0.120	0.528	0.016
	(%)	(5.94)	(5.86)	(6.11)	(4.84)						
	TrA/IO	13.62	9.33	7.69	5.14	< 0.001	0.621	< 0.001	0.541	0.063	0.122
	(%)	(7.13)	(5.83)	(5.94)	(4.05)						
Expiration	RA	18.67	19.38	18.44	18.35	0.097	0.111	0.356	0.036	0.221	0.062
	(%)	(9.64)	(10.65)	(9.83)	(10.06)						
	EO	14.12	14.08	10.88	10.49	0.001	0.342	0.770	0.003	0.717	0.005
	(%)	(7.88)	(9.19)	(7.78)	(7.01)						
	TrA/IO	16.64	13.65	9.34	7.39	< 0.001	0.641	0.001	0.330	0.373	0.030
	(%)	(8.89)	(8.35)	(7.57)	(6.75)						
Both	APT	6.41	7.93	6.14	7.55	0.174	0.057	< 0.001	0.546	0.700	0.005
	(mm)	(2.99)	(3.14)	(2.95)	(3.55)						
	MLT	10.85	10.11	10.96	9.73	0.698	0.006	0.039	0.149	0.449	0.021
	(mm)	(5.33)	(4.83)	(5.20)	(5.64)						
	APA	9.45	14.63	11.27	14.71	0.159	0.075	< 0.001	0.662	0.071	0.120
	(mm)	(3.34)	(4.33)	(4.77)	(4.92)						

UT – upper *trapezius*; SCM – *sternocleidomastoideus*; Sc – *scalenus*; RA – *rectus abdominis*; EO – external oblique; TrA/IO – *transversus abdominis*/ internal oblique; APT – anterior-to-posterior of the upper ribcage; MLT – medial-to-lateral of the lower ribcage; APA – anterior-to-posterior of the abdomen.

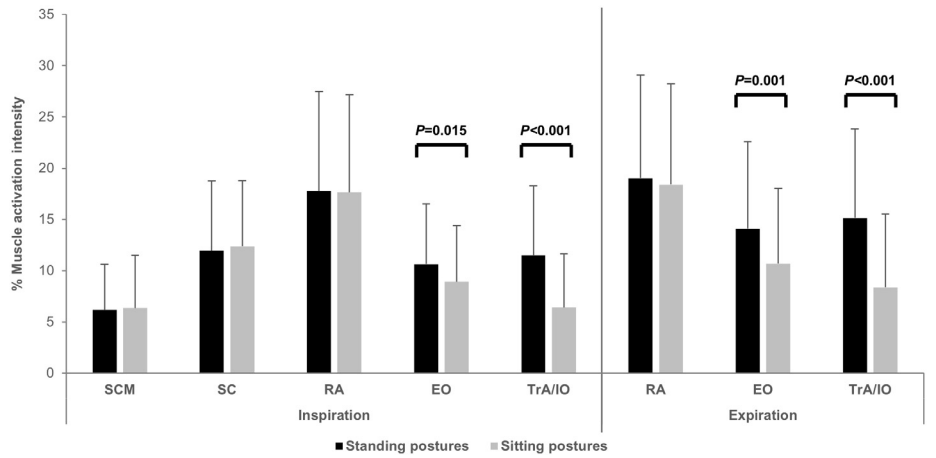

Fig. 3. Muscle activation intensity (expressed as %) of upper *trapezius* (UT), *sternocleidomastoideus* (SCM) and *scalenus* (Sc) during inspiration, and *rectus abdominis* (RA), external oblique (EO) and *transversus abdominis*/ internal oblique (TrA/IO) during inspiration and expiration, according posture factor: standing (UStand + StandAS) *versus* sitting (USit + SitAS) postures. Data are presented as mean and standard deviation. *P* values for significant differences between postures are also presented.

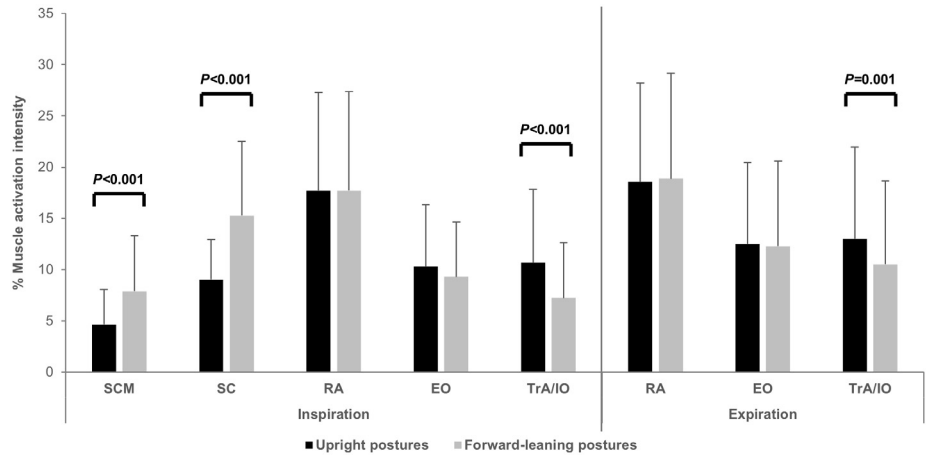

Fig. 4. Muscle activation intensity (expressed as %) of upper *trapezius* (UT), *sternocleidomastoideus* (SCM) and *scalenus* (Sc) during inspiration, and *rectus abdominis* (RA), external oblique (EO) and *transversus abdominis/* internal oblique (TrA/IO) during inspiration and expiration, according leaning the trunk forward with arm support factor: upright (UStand + USit) *versus* forward-leaning (StandAS + SitAS) postures. Data are presented as mean and standard deviation. *P* values for significant differences between postures are also presented.

3.2. Thoraco-abdominal movement

No significant interaction between posture and leaning the trunk forward with arm support appeared in the magnitude of any thoracoabdominal movement, either. With a large effect, the magnitude of the anterior-to-posterior movement of the upper ribcage ($P < 0.001$ and $\eta_p^2 = 0.546$) and the abdomen ($P < 0.001$ and $\eta_p^2 = 0.662$) was significantly greater in forward-leaning postures (StandAS and SitAS) than in upright ones (UStand and USit). However, the magnitude of the medial-to-lateral movement of the lower ribcage and abdomen was significantly lower in forward-leaning postures (StandAS and SitAS) than in upright ones (UStand and USit), also with a large effect ($P = 0.039$ and $\eta_p^2 = 0.149$) (Table 2; Figs. 5 and 6).

4. Discussion

Results revealed that forward-leaning postures (StandAs and SitAS) promoted significantly low UT activation intensity in relation

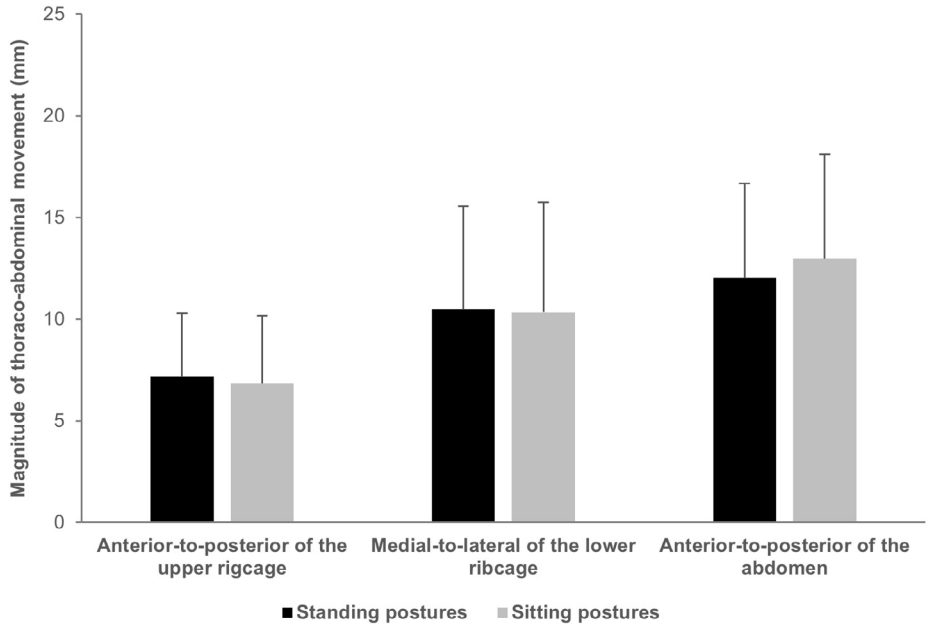

Fig. 5. Magnitude of thoraco-abdominal movements (expressed as millimetres) – anterior-to-posterior of the upper ribcage, medial-to-lateral of the lower ribcage and anterior-to-posterior of the abdomen – during breathing, according posture factor: standing (UStand + StandAS) *versus* sitting (USit + SitAS) postures. Data are presented as mean and standard deviation. *P* values for significant differences between postures are also presented.

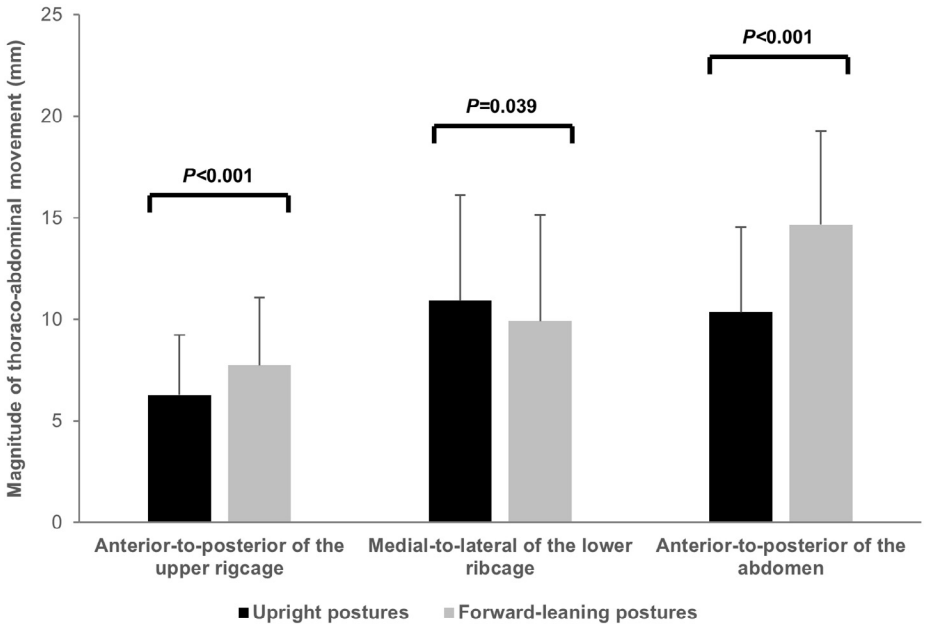

Fig. 6. Magnitude of thoraco-abdominal movements (expressed as millimetres) – anterior-to-posterior of the upper ribcage, medial-to-lateral of the lower ribcage and anterior-to-posterior of the abdomen – during breathing, according leaning the trunk forward with arm support factor: upright (UStand + USit) *versus* forward-leaning (StandAS + SitAS) postures. Data are presented as mean and standard deviation. *P* values for significant differences between postures are also presented.

to upright postures (UStand and USit), although the significantly greater activation intensity of the SCM and Sc, as well as anterior-to-posterior movement of the upper ribcage, was also observed. Furthermore, the activation intensity of the EO and TrA/IO was significantly lower in StandAS and SitAS than in the upright postures, and in particular, TrA/IO activation intensity was significantly lower in forward-leaning postures than in the UStand and USit positions. Nevertheless, a significantly greater magnitude of the anterior-to-posterior movement of the abdomen was additionally observed.

Regarding UT activation intensity, despite its accessory breathing action (i.e., stabilization of the head to aid the respiratory action of cervical muscles attached to the ribcage) (Dalton, 2011), the UT should be more or less stiff or compliant to enable the appropriate active support of the arms (Starr & Dalton, 2011). The results of our study indicated that UT activation intensity was lower in forward-leaning postures than in upright ones. Because the gravitational pull is decreased in postures with the passive support of the arms (StandAS and SitAS), motor-neuron pool excitability also decreases, as does UT recruitment (Meadows & Williams, 2009; Mihailoff & Haines, 2013).

During inspiration, the activation intensity of the SCM and Sc was greater in forward-leaning postures than in upright ones. Normally, the trunk is stabilized, and accessory respiratory muscles move the vertebral column, arm, head, and pelvis on the trunk (Starr & Dalton, 2011). When the shoulder girdle is fixed by arm support, the ribcage becomes the mobile segment (Banzett et al., 1988; Kim et al., 2012). The effect of the muscle's pull is transferred to the ribcage, and the SMC and Sc pull the sternum and the first two ribs, thereby increasing the thoracic diameter by moving the ribcage upward and outward in a pump-handle motion (Starr & Dalton, 2011). Accordingly, the results of the study indicated that the magnitude of the anterior-to-posterior movement of the upper ribcage was greater in forward-leaning postures than in upright ones. The results were moreover consistent with those of Kim et al. (2012). Although patients with chronic obstructive pulmonary disease (COPD) composed their study's sample, both their and our collection protocols allow evaluating the effect of gravity action on the mechanics of breathing.

Regarding the abdominal muscles' dual tasks (i.e., postural control and respiratory mechanics), the change of body orientation in space requires the CNS to appropriately adjust their postural tone to gravity's action and changes in the base of support (Meadows & Williams, 2009; Mihailoff & Haines, 2013). From standing (UStand and StandAS) to sitting (USit and SitAS) postures, the activation intensity of the EO and TrA/IO decreased, which supports the reduction of gravitational pull on muscle loading when the pressure to achieve postural equilibrium and spinal stability decreases (Cholewicki, Juluru, & McGill, 1999). Nevertheless, leaning the trunk forward while standing (StandAS) or sitting (SitAS) with the passive support of the arms also seemed to reduce the postural load, thereby decreasing the recruitment of the TrA/IO compared to in upright postures. Due to its circumferential arrangement, the TrA/IO has the most appropriate mechanical efficiency to modulate intra-abdominal pressure that supports the ribcage and abdominal movements (Hodges & Gandevia, 2000a,b). Thus, as the results of our study revealed, the magnitude of the anterior-to-posterior movement of the abdomen was greater in forward-leaning postures than in upright ones, possibly due to the reduced recruitment of the TrA/IO. The reduced tonic contraction of that abdominal muscle in forward-leaning postures raises abdominal compliance, which increases the abdominal motion (Lee, Chang, Coppieters, & Hodges, 2010; Romei et al., 2010). Earlier research has shown, however, that leaning the trunk forward with arm support while sitting does not affect excursion toward the abdominal cavity (Kim et al.,

2012). That conflicting result could have stemmed from postural differences between postures. According to Kim et al. (2012), in moving from a neutral sitting position (e.g., USit) to sitting with elbows on the knees, the decreased angle between the trunk and hips might increase the resistance of abdominal content to the downward movement of the diaphragm. However, in our study, that angle was maintained between USit and SitAS, which minimized the effect of leaning the trunk forward on the inward movement of the abdominal content against the diaphragm.

Understanding the activity of the diaphragm seems to be crucial to interpreting the effect of both posture and leaning the trunk forward with arm support on the mechanics of breathing. In that sense, the lack of evaluation of the diaphragm could represent a limitation in our study. We opted to not evaluate the diaphragm because we observed crosstalk between the thoracic muscles and diaphragm during a pilot study.

COPD can alter the ability to recruit muscles for respiration and consequently contribute to dyspnea. Although no participant had this chronic respiratory pathology, our results suggested that the specific recruitment pattern of the accessory inspiratory and abdominal muscles in forward-leaning postures with arm support might be important to improving chest wall motion and, in turn, relieving dyspnea. Additional studies conducted among individuals with COPD are therefore strongly recommended.

5. Conclusions

Leaning the trunk forward with arm support while standing or sitting increased the recruitment of accessory inspiratory muscles (i.e., the SCM and Sc), which enhanced the anterior-to-posterior movement of the ribcage. Those postures moreover decreased the recruitment of abdominal muscles (i.e., the TrA/IO), which increased the anterior-to-posterior movement of the abdomen.

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