Heliyon 9 (2023) e21103

Contents lists available at ScienceDirect

Heliyon

journal homepage: www.cell.com/heliyon

Effects of usual yoga practice on the diaphragmatic contractility: A cross-sectional controlled study

Teresa E. Fernández-Pardo [a,b,c,*], Mercedes Furió-Valverde [b], María García-Arrabé [b], David Valcárcel-Linares [d], Ignacio Mahillo-Fernández [e], Germán Peces-Barba Romero [f]

[a] Escuela de Doctorado UAM. Ciudad Universitaria de Cantoblanco, Madrid, Spain
[b] Faculty of Sport Sciences, Universidad Europea de Madrid, Villaviciosa de Odón, Madrid, Spain
[c] Physiotherapy Department. Ramón y Cajal University Hospital, Madrid, Spain
[d] Unidad Técnica de Apoyo a Programas Europeos. Fundación para la Investigación e Innovación Biomédica en Atención Primaria, Madrid, Spain
[e] Unidad de Bioestadística y Epidemiología. IIS Fundación Jiménez Díaz, Madrid, Spain
[f] Servicio de neumología, IIS Fundación Jiménez Díaz, CIBERES. UAM, Madrid, Spain

ARTICLE INFO

Keywords:
Yoga
Ultrasonography
Diaphragm
Breathing exercise

ABSTRACT

Objectives: The aim of this study is to observe and compare the effects of regular yoga practice on the main inspiratory muscle, the diaphragm, by analyzing its thickness, excursion, velocity and contraction time, using ultrasound.
Design: A Cross-Sectional Controlled Study.
Participants: 80 healthy subjects (40 habitual yoga practitioners and 40 non-practitioners), without previous respiratory pathology participated in this study. During maximum diaphragmatic breathing, the diaphragmatic thickness (at rest and after maximum inspiration), excursion, velocity and contraction time were measured by ultrasound.
Results: in the experimental group, practicing yoga, statistically significant differences ($p < 0.001$) were observed compared to the control group, not practicing, in the thickness of the diaphragm at rest (0.26 ± 0.02 vs 0.22 ± 0.01 cm); the diaphragmatic thickness in maximum inspiration (0.34 ± 0.03 vs 0.28 ± 0.03 cm); contraction velocity (1.54 ± 0.54 vs 2.23 ± 0.86 cm/s), contraction time (3.28 ± 0.45 vs 2.58 ± 0.49 s) and Borg scale of perceived exertion (1.05 ± 1.6 vs 1.70 ± 1.34), $p = 0.05$. However, the diaphragmatic excursion was greater in the control group (5.45 ± 1.42 vs 4.87 ± 1.33 cm) with no statistically significant differences ($p = 0.06$).
Conclusions: the regular practice of yoga improves the parameters of diaphragm thickness, speed and contraction time measured in ultrasound and the sensation of perceived exertion during a maximum inspiration. So it can be considered as another method for training the inspiratory muscles in clinical practice.

* Corresponding author. Teresa E Fernández-Pardo. Escuela de Doctorado UAM. Ciudad Universitaria de Cantoblanco. Faculty of Sports Sciences, Universidad Europea de Madrid. Villaviciosa de Odón, Madrid, Spain.

E-mail addresses: teresaemilia.fernandez@estudiante.uam.es, teresa.fernandez@universidadeuropea.es (T.E. Fernández-Pardo), mercedes.furio@universidadeuropea.es (M. Furió-Valverde), maria.gararrabe@universidadeuropea.es (M. García-Arrabé), david.valcarcel@salud.madrid.org (D. Valcárcel-Linares), Imahillo@fjd.es (I. Mahillo-Fernández), GPeces@quironsalud.es (G. Peces-Barba Romero).

https://doi.org/10.1016/j.heliyon.2023.e21103
Received 6 July 2023; Received in revised form 13 October 2023; Accepted 16 October 2023
Available online 17 October 2023
2405-8440/

1. Introduction

Breathing is an uninterrupted physiological process from birth to death. Most of the time it is automatic (involuntary), but it has the characteristic of being able to be modified and activated voluntarily. One can change the frequency, intensity, direction and the rhythm of breathing thanks to the information provided by the phrenic afferent pathways that contribute to the somatosensation of the diaphragm and the conscious perception of breathing [1].

The practice of yoga differs from any other sports practice, in the form of conscious breathing combined with postures (asanas) and meditation. Originating in India more than 3,000 years ago and increasingly common in Occident, it is considered not only as a physical activity, but also as a philosophy of life [2]. Different studies have observed the benefits that patients with respiratory diseases such as, COPD [3] or asthma [4] present after practicing yoga, reducing the sensation of dyspnea.

Breathing or pranayama is an essential pillar in the practice of yoga. It includes different exercises such as alternating the nostrils between right and left, with which one inhales or exhales (nadi shodhan), including quick and short exhalations (kapalabhati), inhaling and exhaling with the same intensity (bhastrika), exhaling imitating the buzz of a bee (brahmari) and/or combine phases of maximum inspiration with phases of post-inspiratory or post-expiratory apnea (kumbaka or air retention) [5].

All these techniques are the result of the contraction and coordination of the respiratory muscles, including the diaphragm. Considered the main inspiratory muscle, it only achieves 75% of the increase in lung volume in inspiration, while 25% is carried out by the accessory muscles: intercostals, scalenes, and sternocleidomastoid [6]. It is a very active muscle, with a high work cycle compared to other muscles, contracting between 25 and 30% of the time [7]. Like any other muscle, training and performing specific exercises will improve its strength and resistance, both in athletes [8] and in patients with lung disease [9].

The reference method for evaluating the diaphragm is undoubtedly the measurement of transdiaphragmatic pressure, but as it is an invasive method, lung ultrasound is emerging as a useful tool for evaluating the diaphragm. It is fast, cost-effective, and does not use ionizing radiation [10]. Real-time ultrasound exploration allows movement to be seen and quantified and has been validated in clinical practice, as an evaluative method of the functionality and strength of the diaphragm [11].

The main objective of this study was to observe the effect of regular yoga practice on the diaphragm contractility expressed in diaphragm thickness at rest and at maximum inspiration; and the excursion, velocity, and time of contraction at maximum diaphragmatic inspiration.

2. Methods

2.1. Study population

Non-randomized cross sectional controlled study, assessor blind, carried out in the laboratories of the Department of Physiotherapy of the European University of Madrid between the months of February and June 2022.80 subjects who met the inclusion/exclusion requirements participated in this study. They were recruited at two yoga centers in Madrid (El gong and Mysore House) and at the European University of Madrid through social networks.

2.2. Ethical approval of the study protocol

The study was approved by the Ethics Committee of the European University of Madrid (CIPI/213006.62) and registered in Clinical Trials number NCT05330026. Throughout the study the Declaration of Helsinki was complied with, and all the participants signed the consent to participate voluntarily. Any patients whose data or images are included in your publication have consented for all images and clinical data and other data included in the manuscript to be published.

2.3. Inclusion and exclusion criteria

40 ashtanga yoga practitioners(who practice yoga at least for the last two years, a minimum of 2 times a week) and 40 non-practitioners, both groups between 18 and 65 years of age and who did not fit any of the exclusion criteria (previous respiratory pathology, thoracic deformities, neuromuscular diseases, treatment with corticosteroids, muscle relaxants and/or barbiturates, episode of allergy or thoracic/abdominal surgery in the last three weeks or practice another sports activity regularly) [10,12]. Ashtanga yoga is a vigorous type of yoga, with a sequence of asanas that follows the same order in each practice, it follows a standardized sequence.

2.4. Methods

The participants were told to fast for the previous 2–3 h and rest for 10–30 min before the measurements. The variables of height, weight, age were taken, and they answered the GPAQ questionnaire on physical activity. This questionnaire assesses the physical activity performed by each subject, divided into intense or moderate, based on the METs consumed. The RUSI protocol for taking measurements with ultrasound for physiotherapists was followed, taking three measurements and calculating the average of the three, pausing 30 s between each repetition [12].

The measurements were taken by a single evaluator who was unaware to which group each subject belonged to and was trained in the ultrasound technique, with two years of experience. The ultrasound machine was always the same, the Logiq S7 model from the

Enraf Nonius commercial house. The participants were in a supine position, with the head of the stretcher flat and the legs flexed at 30-45° [13].

2.4.1. Ultrasonic variables

Ultrasound measurement of the thickness of the diaphragm. The assessment was made in the right hemidiaphragm since it is more accessible than the left through its hepatic window. To assess the thickness, a linear probe at 10–12 MHz was used, placing it perpendicular to the intercostal space between the 9th and 10th rib [11,14], in the anterior part of the axillary line (Fig. 1).

At this level, three parallel layers with different echogenicity are observed, corresponding to the pleura, the diaphragm and the peritoneum. The measurement was made with the M mode, where the image was frozen on a non-forced expiration (representing the functional residual capacity) and on a maximum inspiration. The distance between the inner edge of the pleural line and the inner edge of the peritoneal line was measured [14].

Diaphragm thickening fraction (TF): Indirect measurement was obtained by subtracting the thickness of the diaphragm after a maximum inspiration (TLC) minus the thickness after an unforced expiration between the thickness at unforced expiration (FRC). The result is measured as a percentage [11].

Ultrasonographic measurement of the excursion of the diaphragm: A 2.5–3.5 MHz convex probe [13] was used below the right costal arch and in the line drawn corresponding to the middle of the clavicle, orienting it cranially. The dome of the right hemi-diaphragm is visualized, which appears as a thick hyperechogenic line. We look for the highest diaphragmatic position, which is the part of the diaphragm that produces the greatest craniocaudal excursion [14] (Fig. 2).

Activating the M mode, it is measured from the highest point of the diaphragmatic dome (end-expiration, in functional residual capacity) to the lowest point, which is achieved with the end of each inspiration. This distance is the diaphragmatic excursion [14].

Diaphragm contraction time: Inspiratory time in seconds: from the point at which inspiration begins to the point of maximum inspiration [13].

Diaphragm contraction speed: It is an indirect measurement that is calculated by dividing the diaphragmatic amplitude in cm by the inspiratory time in seconds [13]. To do this, the first gauge is placed at the foot of the slope of the diaphragmatic echoic line and the second at the vertex [14].

2.4.2. Borg scale of perceived exertion

Measured at the end of each breath, scoring from 0 (no dyspnea) to 10 (maximum dyspnea) [15].

The ImageJ program was used to calculate all measurements and analyse the images.

2.4.3. Statistical analysis

The study by Trevisan et al. [12] was used as a reference to calculate the sample size. Categorical variables (sex and smoker) are described with frequencies (percentages) and all the others as mean and standard deviation. Continuous variables were tested for normality using the Kolmogorov-Smirvov test. Most of the variables are not normally distributed, however skewness coefficients are not very biased, and histograms do not show distributions with high asymmetry. Furthermore, the compared groups have more than 30 observations, so the central limit theorem can be applied. This means that means and medians are similar and parametric and non-parametric methods yield similar results. A statistical comparison was made between the experimental and control groups, for the variables of sex and smoker the chi-square test or Fisher's exact test was used and for all the others, the T-student test. An alpha value of <0.05 was considered statistical. The IBM® SPSS® version 29 program was used (SPSS Inc., Chicago, IL, USA).

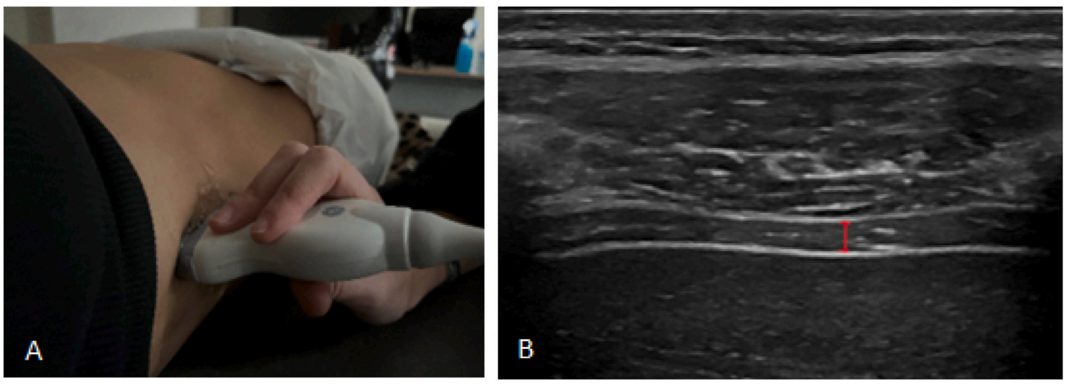

Fig. 1. Ultrasound measurement of the right diaphragmatic thickness (A). A linear probe at 10–12 MHz was used, placing it perpendicular to the intercostal space between the 9th and 10th rib in the anterior part of the axillary line. The ultrasound image observed (B). The distance between the inner edge of the pleural line and the inner edge of the peritoneal line was measured.

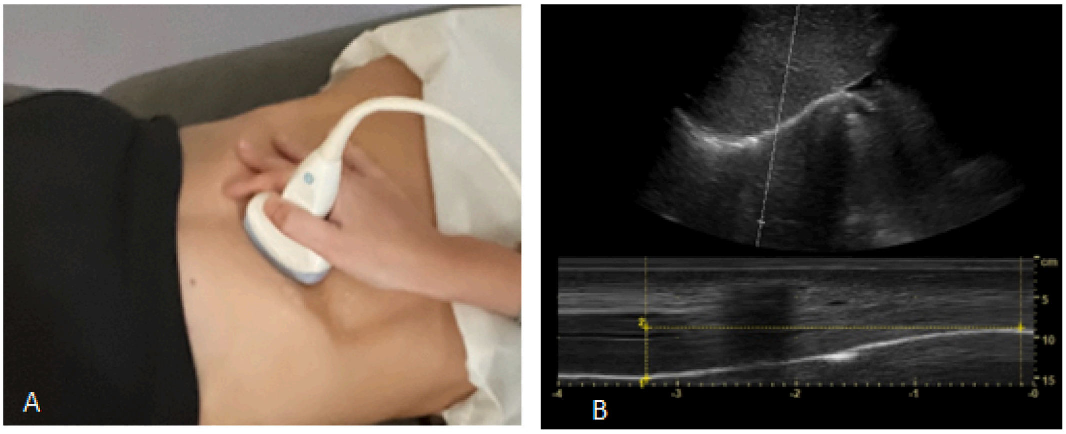

Fig. 2. Ultrasound measurement of the diaphragmatic excursion (A). The convex probe was used below the right costal arch and in the line drawn corresponding to the middle of the clavicle, orienting it cranially. Ultrasound image (B), where the values of diaphragmatic excursion and contraction time are measured.

3. Results

Study population: 80 subjects participated in the study with no significant differences in the demographic variables (Table 1). Half of them (40 subjects) were regular yoga practitioners (7.58 ± 3.35 years practicing) and the other half (40 subjects) had never practiced, but all of them with a similar level of physical activity.

When analyzing the variables studied (Table 2), it was observed that the group practicing yoga obtained better results ($p < 0.001$) in the diaphragmatic thickness at rest measured in cm (0.26 ± 0.02 vs 0.22 ± 0.01). Likewise, at the end of a maximum diaphragmatic inspiration, the diaphragmatic thickness was also greater in the yoga group (0.34 ± 0.03 vs 0.28 ± 0.03), as was the duration of diaphragm contraction measured in seconds (3.28 ± 0.45 vs 2.58 ± 0.49).

On the other hand, the group that did not practice yoga obtained higher values in the diaphragm contraction speed measured in cm/s (2.23 ± 0.86 vs 1.54 ± 0.54), in the perceived exertion measured with the Borg scale (1.70 ± 1.34 vs 1.05 ± 1.60) and in the diaphragmatic excursion measured in cm without this difference being statistically significant (5.45 ± 1.42 vs 4.87 ± 1.33, with a value of $p = 0.063$).

Three groups according to the number of the years practicing yoga (0–5 years, 6–10 years, >10 years) were defined and compared with control group (Table 3). A limitation of this analysis is that when separating by groups the number of subjects is diminished, and the statistical power will be less. According to this we have made the comparisons with parametric and non-parametric methods with similar results.

4. Discussion

This study demonstrates that regular yoga practice improves diaphragmatic activity, expressed in diaphragm thickness, contraction

Table 1
Baseline characteristics of study participants.

	All (n = 80)	Yoga practitioners (n = 40)	Non yoga practitioners (n = 40)	P value
Sex				1.000
Men	17 (21.2%)	9 (22.5%)	8 (20.0%)	
Women	63 (78.8%)	31 (77.5%)	32 (80.0%)	
Smoker				1.000
Non	69 (86.2%)	35 (87.5%)	34 (85.0%)	
Yes	11 (13.8%)	5 (12.5%)	6 (15.0%)	
Age (years)	34.6 ± 9.84	35.1 ± 9.52	34.1 ± 10.2	0.636
Weight (kg)	61.7 ± 10.2	61.9 ± 10.7	61.6 ± 9.90	0.905
Height (m)	1.67 ± 0.08	1.68 ± 0.08	1.66 ± 0.08	0.398
BMI	22.0 ± 2.81	21.8 ± 2.88	22.2 ± 2.76	0.597
Years of yoga practice		7.58 ± 3.35		
Physical activity				
Totally (METS)	4077 ± 2948	3997.5 ± 2841	4156.5 ± 3059.1	0.810
Intensive (METS)	1237.5 ± 1536	901.5 ± 1132	1565 ± 2107.2	0.08
Moderate (METS)	2855 ± 2102	3118.5 ± 2368.9	2591.5 ± 1768.2	0.263

BMI: body mass index; METS (metabolic equivalent, is the amount of oxygen consumed while sitting at rest and is equal to 3.5 ml O2 per kg body weight x min).

Table 2
Outcome diaphragmatic variables measured with ultrasound.

	All (n = 80)	Yoga practitioners (n = 40)	Non yoga practitioners (n = 40)	P value (parametric analyse)	P value (non parametric analyse)
Thickness at rest (cm)	0.24 ± 0.03	0.26 ± 0.02	0.22 ± 0.01	<0.001	<0.001
Thickness end expiration (cm)	0.31 ± 0.04	0.34 ± 0.03	0.28 ± 0.03	<0.001	<0.001
TF (%)	29.8 ± 8.22	29.2 ± 6.03	30.4 ± 9.99	0.504	0.851
Excursion (cm)	5.16 ± 1.40	4.87 ± 1.33	5.45 ± 1.42	0.063	0.057
Contraction speed (cm/sg)	1.88 ± 0.80	1.54 ± 0.54	2.23 ± 0.86	<0.001	<0.001
Contraction time(sg)	2.93 ± 0.58	3.28 ± 0.45	2.58 ± 0.49	<0.001	<0.001
Borg	1.38 ± 1.50	1.05 ± 1.60	1.70 ± 1.34	0.05	0.008

TF: diaphragm thickening fraction.

Table 3
Outcome diaphragmatic variables measured with ultrasound, divided into subgroups according to the number of the years practicing yoga (0–5 years, 6–10 years, >10 years).

	Non yoga practitioners (n = 40)	0–5 years (n = 13) Subgroup 1	6–10 years (n = 19) Subgroup 2	>10 years (n = 8) Subgroup 3	P value Controls vs Subgroup 1	P value Controls vs Subgroup 2	P value Controls vs Subgroup 3
Thickness at rest (cm)	0.22 + 0.01	0.26 + 0.02	0.26 + 0.02	0.26 + 0.02	<0.001	<0.001	<0.001
Thickness end expiration (cm)	0.28 + 0.03	0.34 + 0.04	0.33 + 0.03	0.35 + 0.02	<0.001	<0.001	<0.001
Excursion (cm)	5.45 + 1.42	4.54 + 1.43	5.15 + 1.24	4.76 + 1.41	0.050	0.423	0.212
Contraction speed (cm/sg)	2.23 + 0.86	1.51 + 0.67	1.60 + 0.50	1.42 + 0.42	0.008	0.004	0.013
Contraction time (sg)	2.58 + 0.49	3.17 + 0.55	3.31 + 0.41	3.39 + 0.40	0.001	<0.001	<0.001
TF	30.4 + 9.99	28.3 + 6.81	27.9 + 5.42	33.6 + 4.36	0.477	0.311	0.377
Borg	1.70 + 1.34	1.38 + 2.02	0.89 + 1.56	0.88 + 0.83	0.522	0.046	0.103

speed and time, and perceived effort in contraction.

One of the first visible adaptations that occurs in the body after the regular practice of a physical activity, such as yoga, is hypertrophy or the increase in muscle volume [16]. Striated muscles such as the diaphragm present the characteristic of increasing in volume during contraction, due to the creation of actin and myosin bridges [17]. Faced with a constant stimulus, such as strength training, the muscle undergoes an adaptation, called hypertrophy or increased thickness [16] that can be observed and quantified with ultrasound [18].

In the case of the diaphragm, there is an association between diaphragmatic thickness and anthropometric values such as height, weight or gender, but it is also related to muscle strength [18]. Scarlata et al. [19] already included physical activity as a value to take into account in diaphragmatic thickness. In their study, they compared two groups (one sedentary and the other physically active) and saw that when normalizing the anthropometric and demographic variables, there was still a difference in thickness (greater in the active group), as the result of greater physical activity. As in our study, in which the diaphragmatic thickness at rest is greater in the group that practices yoga regularly, since muscle hypertrophy is the result of exercise, both strength and resistance [20]. This difference is statistically significant even when considering that all participants, being healthy subjects, were within the considered normal limits (>0.2 cm) [14].

Several studies relate diaphragmatic thickness and excursion: the greater the thickness, the greater the excursion [21]. Despite not having spirometry data from our participants, it has been demonstrated that there is a relationship between an increase in excursion and a higher lung capacity [11]. It is logical to think that a strong diaphragm is capable of moving more and therefore, of mobilizing more air. This is true if we think of diaphragmatic thickness as an indicator of strength [18], but it has already been seen that this muscular hypertrophy is also a response of the organism to training [20]. Therefore, it would be more logical to think of the thickening fraction as a reference value, since it is the real value that indicates the contraction capacity of the diaphragm [14]. The fact that this thickness at the end of inspiration is greater in the yoga-group, as it was found in our study, is mainly explained because it starts from a greater diaphragm thickness at rest. Since if we look at the diaphragm thickening fraction data, it is the same in both groups (around 30%), values that are considered normal for a functional diaphragm (greater than 20%) [14], that would explain it, as all participants are healthy individuals with functional diaphragms. This idea was already considered by Schultz et al. [22], when in their study, the diaphragmatic excursion had a positive correlation with the thickening fraction and not with the thickness. If the TF is similar, as is the case in present study between yoga practitioners and non-practitioners (around 30%), there are no significant differences in diaphragmatic excursion. It can be seen that this distance is slightly greater in the non-yoga group, but it may be due to differences in height, sex, age, posture [14] of the subjects, without being related to greater activation or strength of the diaphragm.

For their part, Langer et al. [23] observed that by specifically training the inspiratory muscles, not only an increase in their strength (diaphragmatic thickness) was obtained, but also a decrease in diaphragm activation (EMGdi/EMGdimax), that is, a decrease in its contraction speed. This is the calculation of the diaphragmatic excursion between the contraction time [14]. The ability of a muscle to contract at a greater or lesser speed is determined by the type of fibers that compose it. The diaphragm, like any skeletal muscle, is composed of type I, IIa, IIb, and IIx muscle fibers [18]. Type I fibers are smaller in diameter and have a greater density of mitochondria and oxidative capacity, which is why they are more efficient, have a slower rate of contraction, and are resistant to fatigue. Type IIa fibers have a higher contraction speed but are less resistant to fatigue, and IIx and IIb fibers have the largest diameter and generate the greatest force [18]. When performing a basal or maximum breath, as is the case in this study, type I and IIa fibers are mainly activated, slow speed, while for greater efforts, such as the sniff test, the fibers that come into play are IIx or IIb, faster speed [24].

An additional effect of regular yoga practice is a decrease in respiratory rate due not only to slow and conscious breathing used during practice but also to increased parasympathetic activity. Heart rate also decreases, reducing energy expenditure and thus promoting a state of calm and well-being [25].

All these adaptations of the organism to training: decreased activation necessary for diaphragm contraction and increased strength reflected in a greater thickness of the diaphragm are manifested in practice in lower energy expenditure and greater tolerance to exercise [26]. This is explained by the reduction in dyspnea (lower score on the Borg scale) of the trained subjects compared to the untrained [27].

Finally, it should be noted that training a muscle is not only about increasing its strength and resistance, but also about increasing its performance and functionality. The diaphragm is not only the main inspiratory muscle but also participates in trunk stability. A thinner diaphragm is often associated with back pain [28]. Different studies have shown the efficacy of the practice of yoga in the treatment of lower back pain. This is due to not only the breathing exercises but also to the postural work of the rectus abdominis and oblique muscles that are activated during yoga [29,30]. The synergy of work between the diaphragm and stabilizing muscles has been proven [28], which helps to understand the idea that the group practicing yoga presents greater thickness at rest, since during this practice two of its main functions are worked: respiratory muscle and stabilizer of the trunk.

Limits of the study: despite the existence of a protocol to carry out all the measurements and that these were always taken by the same subject, ultrasound is a dependent evaluator tool. Although there are no differences in terms of minutes of physical activity performed by both groups, there may be a population bias, since the experimental group (practicing yoga) could practice other sports in addition to yoga and have better lifestyle habits, that explain better diaphragm performance.

A further limitation to highlight is that, despite the participants being healthy individuals without respiratory pathologies, there is no available spirometry data to corroborate this, especially for smokers among the subjects. Future lines of research: Comparing a group undergoing traditional inspiratory muscle training with a group practicing yoga could provide valuable insights into the effects of different training methods on respiratory function and diaphragmatic contractility, as well as observe the effects that yoga has on subjects with respiratory pathology.

5. Conclusion

Regular yoga practice improves parameters of diaphragm thickness, velocity, and contraction time measured by ultrasound and the sensation of perceived exertion during maximum inspiration, so it can be considered as an alternative method for training inspiratory muscles in clinical practice.

Ethical approval

The study was approved by the Ethics Committee of the European University of Madrid (CIPI/213006.62).

Funding

Non sources of funding are acknowledged.

Data availability statement

The data are not publicly available due to their containing confidential information that could compromise the privacy of research participants.

CRediT authorship contribution statement

Teresa E. Fernández-Pardo: Writing – original draft, Methodology, Investigation, Conceptualization. **Mercedes Furió-Valverde:** Writing – review & editing, Conceptualization. **María García-Arrabé:** Writing – review & editing, Methodology, Investigation. **David Valcárcel-Linares:** Methodology, Investigation. **Ignacio Mahillo-Fernández:** Formal analysis. **Germán Peces-Barba Romero:**

Writing – review & editing, Validation, Supervision.

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.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.heliyon.2023.e21103.

References

[1] D. Adler, J.P. Janssens, The pathophysiology of respiratory failure: control of breathing, respiratory load, and muscle capacity, Respiration 97 (2) (2019) 93–104, https://doi.org/10.1159/000494063.

[2] M. Tobe, S. Saito, Analogy between classical Yoga/Zen breathing and modern clinical respiratory therapy, J. Anesth. 34 (6) (2020) 944–949, https://doi.org/10.1007/s00540-020-02840-5.

[3] D.A. Kaminsky, K.K. Guntupalli, J. Lippmann, et al., Effect of yoga breathing (pranayama) on exercise tolerance in patients with chronic obstructive pulmonary disease: a randomized, controlled trial, J. Alternative Compl. Med. 23 (9) (2017) 696–704, https://doi.org/10.1089/acm.2017.0102.

[4] P. Raghavendra, P. Shetty, S. Shetty, N.K. Manjunath, A.A. Saoji, Effect of high-frequency yoga breathing on pulmonary functions in patients with asthma: a randomized clinical trial, Ann. Allergy Asthma Immunol. 117 (5) (2016) 550–551, https://doi.org/10.1016/j.anai.2016.08.009.

[5] A.A. Saoji, B.R. Raghavendra, K. Madle, N.K. Manjunath, Additional practice of yoga breathing with intermittent breath holding enhances psychological functions in yoga practitioners: a randomized controlled trial, Explore 14 (5) (2018) 379–384, https://doi.org/10.1016/j.explore.2018.02.005.

[6] C.M. Acosta, M.S. Urbano, G. Tusman, Estudio sonográfico del diafragma. Una nueva herramienta diagnóstica para el anestesiólogo, Rev. Chil. Anest. 47 (2) (2018) 110–124, https://doi.org/10.25237/revchilanestv47n02.08.

[7] T. Schepens, J. Dianti, Diaphragm protection: what should we target? Curr. Opin. Crit. Care 26 (1) (2020) 35–40, https://doi.org/10.1097/MCC.0000000000000683.

[8] M. Karsten, G.S. Ribeiro, M.S. Esquivel, D.L. Matte, The effects of inspiratory muscle training with linear workload devices on the sports performance and cardiopulmonary function of athletes: a systematic review and meta-analysis, Phys. Ther. Sport 34 (2018) 92–104, https://doi.org/10.1016/j.ptsp.2018.09.004.

[9] E. Vázquez-Gandullo, A. Hidalgo-Molina, F. Montoro-Ballesteros, M. Morales-González, I. Muñoz-Ramírez, A. Arnedillo-Muñoz, Inspiratory muscle training in patients with chronic obstructive pulmonary disease (COPD) as part of a respiratory rehabilitation program implementation of mechanical devices: a systematic review, Int. J. Environ. Res. Publ. Health 19 (9) (2022) 5564, https://doi.org/10.3390/ijerph19095564.

[10] A. Fayssoil, A. Behin, A. Ogna, et al., Diaphragm: pathophysiology and ultrasound imaging in neuromuscular disorders, J. Neuromuscul. Dis. 5 (1) (2018) 1–10, https://doi.org/10.3233/JND-170276.

[11] C.B. Laursen, A. Clive, R. Hallifax, et al., European Respiratory Society statement on thoracic ultrasound, Eur. Respir. J. 57 (3) (2021), 2001519, https://doi.org/10.1183/13993003.01519-2020.

[12] M.E. Trevisan, J. Boufleur, J.C. Soares, C.J.P. Haygert, L.G.K. Ries, E.C.R. Corrêa, Diaphragmatic amplitude and accessory inspiratory muscle activity in nasal and mouth-breathing adults: a cross-sectional study, J. Electromyogr. Kinesiol. 25 (3) (2015) 463–468, https://doi.org/10.1016/j.jelekin.2015.03.006.

[13] P. Richard, [Exploring the diaphragm: ultrasound is essential], Rev. Mal. Respir. 34 (6) (2017) 645–660, https://doi.org/10.1016/j.rmr.2017.02.005.

[14] A. Boussuges, J. Finance, G. Chaumet, F. Brégeon, Diaphragmatic motion recorded by M-mode ultrasonography: limits of normality, ERJ Open Res 7 (1) (2021) 714–2020, https://doi.org/10.1183/23120541.00714-2020.

[15] S. Nopp, F. Moik, F.A. Klok, et al., Outpatient pulmonary rehabilitation in patients with long COVID improves exercise capacity, functional status, Dyspnea, Fatigue, and Quality of Life. Respiration 101 (6) (2022) 593–601, https://doi.org/10.1159/000522118.

[16] H. Wackerhage, B.J. Schoenfeld, D.L. Hamilton, M. Lehti, J.J. Hulmi, Stimuli and sensors that initiate skeletal muscle hypertrophy following resistance exercise, J. Appl. Physiol. 126 (1) (2019) 30–43, https://doi.org/10.1152/japplphysiol.00685.2018.

[17] Brendan Egan, y Adam P. Sharples, Molecular responses to acute exercise and their relevance for adaptations in skeletal muscle to exercise training, Physiol. Rev. 103 (3) (2023) 2057–2170, https://doi.org/10.1152/physrev.00054.2021.

[18] M.J. Fogarty, C.B. Mantilla, G.C. Sieck, Breathing: motor control of diaphragm muscle, Physiology 33 (2) (2018) 113–126, https://doi.org/10.1152/physiol.00002.2018.

[19] S. Scarlata, D. Mancini, A. Laudisio, A.I. Raffaele, Reproducibility of diaphragmatic thickness measured by M-mode ultrasonography in healthy volunteers, Respir. Physiol. Neurobiol. 260 (2019) 58–62, https://doi.org/10.1016/j.resp.2018.12.004.

[20] E. Baz-Valle, C. Balsalobre-Fernández, C. Alix-Fages, J. Santos-Concejero, A systematic review of the effects of different resistance training volumes on muscle hypertrophy, J. Hum. Kinet. 81 (2022) 199–210, https://doi.org/10.2478/hukin-2022-0017.

[21] J.H. Jung, N.S. Kim, The correlation between diaphragm thickness, diaphragmatic excursion, and pulmonary function in patients with chronic stroke, J. Phys. Ther. Sci. 29 (12) (2017) 2176–2179, https://doi.org/10.1589/jpts.29.2176.

[22] Schulz A, Erbuth A, Boyko M, et al. Comparison of ultrasound measurements for diaphragmatic mobility, diaphragmatic thickness, and diaphragm thickening fraction with each other and with lung function in patients with chronic obstructive pulmonary disease. Int. J. Chronic Obstr. Pulm. Dis..: Sep. 12;17:2217-2227. doi: 10.2147/COPD.S375956.

[23] D. Langer, C. Ciavaglia, A. Faisal, et al., Inspiratory muscle training reduces diaphragm activation and dyspnea during exercise in COPD, J. Appl. Physiol. 125 (2) (2018) 381–392, https://doi.org/10.1152/japplphysiol.01078.2017.

[24] A.D. Brown, M.J. Fogarty, G.C. Sieck, Mitochondrial morphology and function varies across diaphragm muscle fiber types, Respir. Physiol. Neurobiol. 295 (2022), 103780, https://doi.org/10.1016/j.resp.2021.103780.

[25] A. Zaccaro, A. Piarulli, M. Laurino, et al., How breath-control can change your life: a systematic review on psycho-physiological correlates of slow breathing, Front. Hum. Neurosci. 12 (2018) 353, https://doi.org/10.3389/fnhum.2018.00353.

[26] R. Fabero-Garrido, T. Del Corral, S. Angulo-Díaz-Parreño, et al., Respiratory muscle training improves exercise tolerance and respiratory muscle function/structure post-stroke at short term: a systematic review and meta-analysis, Ann Phys Rehabil Med 65 (5) (2022), 101596, https://doi.org/10.1016/j.rehab.2021.101596.

[27] F. Zhang, Y. Zhong, Z. Qin, X. Li, W. Wang, Effect of muscle training on dyspnea in patients with chronic obstructive pulmonary disease: a meta-analysis of randomized controlled trials, Medicine (Baltim.) 100 (9) (2021), e24930, https://doi.org/10.1097/MD.0000000000024930.

[28] C. Calvo-Lobo, J. Almazán-Polo, R. Becerro-de-Bengoa-Vallejo, et al., Ultrasonography comparison of diaphragm thickness and excursion between athletes with and without lumbopelvic pain, Phys. Ther. Sport 37 (2019) 128–137, https://doi.org/10.1016/j.ptsp.2019.03.015.
[29] E.J. Roseen, H. Gerlovin, D.T. Felson, A. Delitto, K.J. Sherman, R.B. Saper, Which chronic low back pain patients respond favorably to yoga, physical therapy, and a self-care book? Responder analyses from a randomized controlled trial, Pain Med. 22 (1) (2021) 165–180, https://doi.org/10.1093/pm/pnaa153.
[30] C. Quentin, R. Bagheri, U.C. Ugbolue, et al., Effect of home exercise training in patients with nonspecific low-back pain: a systematic review and meta-analysis, Int. J. Environ. Res. Publ. Health 18 (16) (2021) 8430, https://doi.org/10.3390/ijerph18168430.