

The effectiveness of respiratory muscle training in competitive swimmers: a systematic review

A efetividade do treinamento muscular respiratório em nadadores competitivos: uma revisão sistemática

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ABSTRACT

Introduction: Respiratory muscle training can enhance lung function, improving performance of competitive swimmers. However, there is a lack of studies that have comprehensively examined the impact of respiratory muscle training specifically on swimmers. **Objective:** The objective of this study was to verify the effectiveness of respiratory muscle training on respiratory muscle strength, lung function, swimming performance and aerobic capacity among competitive swimmers. **Method:** This is a systematic review of the current literature, conducted according to PRISMA criteria and registered with PROSPERO. A total of 629 articles were identified using the PICO search strategy. Following rigorous eligibility criteria, 13 studies were included in this review. **Results:** The results showed a significant improvement in maximum inspiratory pressure values. No significant changes were observed in lung function parameters. There was an improvement in swimming performance and no significant changes were observed in the aerobic capacity of competitive swimmers. **Conclusion:** Respiratory muscle training was effective in increasing respiratory muscle strength, particularly in the inspiratory muscles, and positively contributed to the sports performance of swimmers. However, this training did not exhibit effectiveness in improving lung function or the aerobic capacity of the athletes.

Keywords: breathing exercises; athletes; swimming

RESUMO

Introdução: O treinamento muscular respiratório pode otimizar a função pulmonar, contribuindo para a melhora do desempenho de nadadores competitivos. No entanto, há uma escassez de estudos que investigaram o impacto do treinamento muscular respiratório especificamente em nadadores. **Objetivo:** O objetivo deste estudo foi verificar a eficácia do treinamento dos músculos respiratórios sobre a força dos músculos respiratórios, função pulmonar, desempenho na natação e capacidade aeróbica em nadadores competitivos. **Método:** Trata-se de uma revisão sistemática da literatura, conduzida de acordo com os critérios PRISMA e registrada no PROSPERO. Um total de 629 artigos foi encontrado como resultado da estratégia de busca baseada no modelo PICO. Após a rigorosa aplicação dos critérios de elegibilidade, 13 artigos foram incluídos nesta revisão. **Resultados:** Os resultados indicaram uma melhora significativa nos valores de pressão inspiratória máxima; não foram observadas alterações significativas nos parâmetros gerais de função pulmonar; houve melhora no desempenho na natação e não foram observadas mudanças relevantes na capacidade aeróbica dos nadadores competitivos. **Conclusão:** O treinamento dos músculos respiratórios foi eficaz em aumentar a força dos músculos respiratórios, especialmente dos músculos inspiratórios, e contribuiu positivamente para o desempenho esportivo dos nadadores. No entanto, esse treinamento não demonstrou eficácia na melhora da função pulmonar geral nem da capacidade aeróbica dos atletas.

Palavras-chave: exercícios respiratórios; atletas; natação

Introduction

Respiratory muscle training (RMT) is an intervention designed to improve the endurance of the inspiratory and/or expiratory muscles and optimize respiratory function [1]. These interventions utilize incentive spirometry devices (e.g., Respirom), pressure threshold (e.g., Threshold and PowerBreathe), or resistance devices [2]. Pressure threshold devices have calibrated valves that require a target pressure for airflow, while resistance devices provide constant resistance adjustable by the size of the air openings. Incentive spirometry devices promote deep, slow breaths to improve lung volumes based on predefined airflow feedback [2]. RMT is a cost-effective, easy-to-apply, and safe non-pharmacological intervention, considered essential in the management of certain cardiopulmonary diseases [3] and an adjunct for optimizing physical fitness and athletic performance [3,4].

The essential role of RMT is evident when examining the effect of respiratory muscle fatigue on sports performance [5], in healthy individuals [6] and individuals with cardiorespiratory diseases such as pulmonary hypertension [7] and chronic heart failure [8]. In athletes, limitations in physical performance may result from reduced blood flow to skeletal muscles due to vasoconstriction and redirection of blood flow to the respiratory muscles. This physiological response leads to an increase in metabolites, such as lactate, in the respiratory muscles, intensifying local fatigue and ultimately reducing athletic performance [5,9].

Athletes from various sports modalities have used RMT techniques to overcome these limitations, to enhance physiological responses and improve exercise tolerance [10]. Research has shown that improving respiratory mechanical efficiency, fatigue resistance, and reducing oxygen consumption leads to increased oxygen availability for skeletal muscles, resulting in enhanced exercise endurance, reduced respiratory fatigue, decreased sensation of dyspnea, and effort during exercise in both normoxia and hypoxia [3,5,11]. Studies support these findings, showing significant improvements in the performance of athletes across various sports, such as football [12,13], skating [14], rugby [15], kickboxing [16], basketball [17,18], running [19,20] and increased load endurance in triathletes [5].

However, swimming, unlike other sports, requires both strength and endurance and demands a balance between aerobic and anaerobic energy production. Inspiratory muscle fatigue can negatively affect athlete performance, particularly due to the respiratory demands associated with the prone position, resulting in a 16% decrease in the ability to generate force, restricted breathing frequency, and increased respiratory resistance due to water immersion and hydrostatic pressure surrounding the thoracic cavity [11,21,22]. The use of RMT in training can enhance respiratory strength and performance, as well as extends periods of apnea, hence improving immersion time and swimming endurance [23].

Although other systematic reviews have addressed RMT in athletes [3,24,25] and more targeted reviews relating RMT to sports such as football [26]. While the

conclusion of these reviews highlights improvements in maximal inspiratory pressure (MIP) [26], maximal oxygen consumption [26], sports performance [3,10,24,25], lung function [3,10] and respiratory muscle strength [25], the specificities of swimming make the context for athletes in this sport limited due to the lack of studies that have investigated the effects of RMT on swimmers. Therefore, the objective of this study was to assess the effectiveness of respiratory muscle training on respiratory muscle strength, lung function, swimming performance, and aerobic capacity among competitive swimmers.

Methods

This is a systematic review conducted in accordance with the recommendations of the Preferred Reporting Items for Systematic Reviews and Meta-Analysis (PRISMA) and it was registered in the public database PROSPERO under the number CRD42024518455.

Eligibility criteria

The inclusion criteria were studies with humans, swimming athletes, interventional studies, observational studies (prospective, retrospective, and cross-sectional), or experimental studies (randomized clinical trials), with no restrictions on race, sex, or country.

The exclusion criteria were studies that did not include respiratory muscle training, athletes with pathologies (e.g., asthma and spinal cord injury), para-athletes or athletes with disabilities, comparative studies between normoxia and hypoxia situations or in hypothermia, athletes from other sports (e.g., football, basketball, rugby, tennis), duplicate studies, case studies and case series, comments, conference abstracts, recommendations, letters to the editor, editorials, studies containing protocols for randomized clinical trials, guidelines, consensus, reviews, and incomplete studies.

Information sources

The search was conducted in the following databases: PubMed, Web of Science, Scopus and Embase.

Search strategy

The “PICO” strategy was outlined according to the objectives of the study (Table I). A search was conducted for DeCS and MeSH descriptors related to the terms for the population (‘athlete’) and the intervention (‘respiratory muscle training’, i.e., a non-DeCS-MeSH term).

Table I - PICO Strategy

Group	Variable
Population	Athlete
Intervention	Respiratory muscle training
Comparison	Not applicable
Outcome	Lung function; Swimming performance; Respiratory muscle strength; Aerobic capacity

The Group column refers to the acronym “PICO”; Table developed by the authors based on data from the study

The search strategy used was (“respiratory muscle training” OR “inspiratory muscle training” OR “expiratory muscle training” OR “breathing exercises” OR “respiratory training” OR “breathing devices”) AND (“Athlete*” OR “Athletic performance”). For the Embase database, the strategy used was (“respiratory muscle training” OR “inspiratory muscle training” OR “expiratory muscle training” OR “breathing exercises” OR “respiratory training” OR “breathing devices”) AND (“Athletes” OR “Athletic performance”) to maximize the retrieval of relevant articles.

Filter: Studies published in the last ten years (2014 to 2024) in Portuguese, English, and Spanish, with full texts available for free or accessible via institutional subscription, were selected according to the study’s inclusion criteria.

Selection process

The study selection was conducted in pairs: two reviewers (C.N. and L.MD.) independently selected the studies according to the inclusion criteria. In case of disagreement between the two reviewers, a third reviewer (G.K.) served as mediator to assess and decide on study inclusion or exclusion. Individual studies included in the systematic reviews from the search strategy were consulted separately as an additional selection (outside the search strategy). The title and abstract of potentially eligible studies were read in full for the selection of studies according to the pre-established inclusion and exclusion criteria. Full-text studies were consulted when the information in the abstract was insufficient. The ZOTERO® software was used to manage data screening. Finally, a flowchart following the PRISMA recommendation (<http://www.prisma-statement.org/>) was used to present a summary of the study selection process.

Data collection process

All selected studies were read in full, and the data collection process was conducted similarly to the selection process, including two independent reviewers (in blind) and a third reviewer to mediate disagreements. The data collection was conducted without any automation using only the full reading of the report.

Data items

The following information was extracted from each study: author identification, publication year, country of origin, study design, sample size, sex, participants' mean age, type of respiratory training, and key outcomes.

Study risk of bias assessment

The National Heart, Lung, and Blood Institute (NIHLBI) instrument "Quality Assessment of Controlled Intervention Studies" was used to assess the methodological quality of the studies. This instrument was selected due to its structured and reliable assessment of the methodological quality of intervention studies, assessing potential biases and internal validity. It consists of 14 items, with possible responses of "yes," "no," or "not reported." A score of 1 is assigned for a "yes" response, while a score of 0 is assigned for the other responses. Therefore, the overall score represents the number of affirmative responses. For qualitative evaluation of the final scores, studies with a score above 12 were considered "good," those scoring between 9 and 12 were considered "moderate," and studies scoring below 9 were considered "weak." The evaluation and quality assessment were conducted independently by two authors.

Synthesis methods

A narrative synthesis of the included studies was conducted, structured around study design, participants, type of respiratory muscle training, and outcomes assessed.

Reporting bias assessment

The risk of bias was assessed qualitatively using the Zotero platform, in addition to the The National Heart, Lung, and Blood Institute (NIHLBI) instrument "Quality Assessment of Controlled Intervention Studies".

Certainty assessment

A formal assessment of the certainty of the body of evidence was interpreted qualitatively based on study design, methodological quality, sample size, and consistency of results across the included studies.

Results

The initial search yielded 629 studies: 111 from the PubMed platform, 200 from Embase, 205 from Scopus, and 113 from Web of Science. Of these, 351 were excluded due to duplication, for not meeting the inclusion criteria, and 60 for not including swimmers (Figure 1).

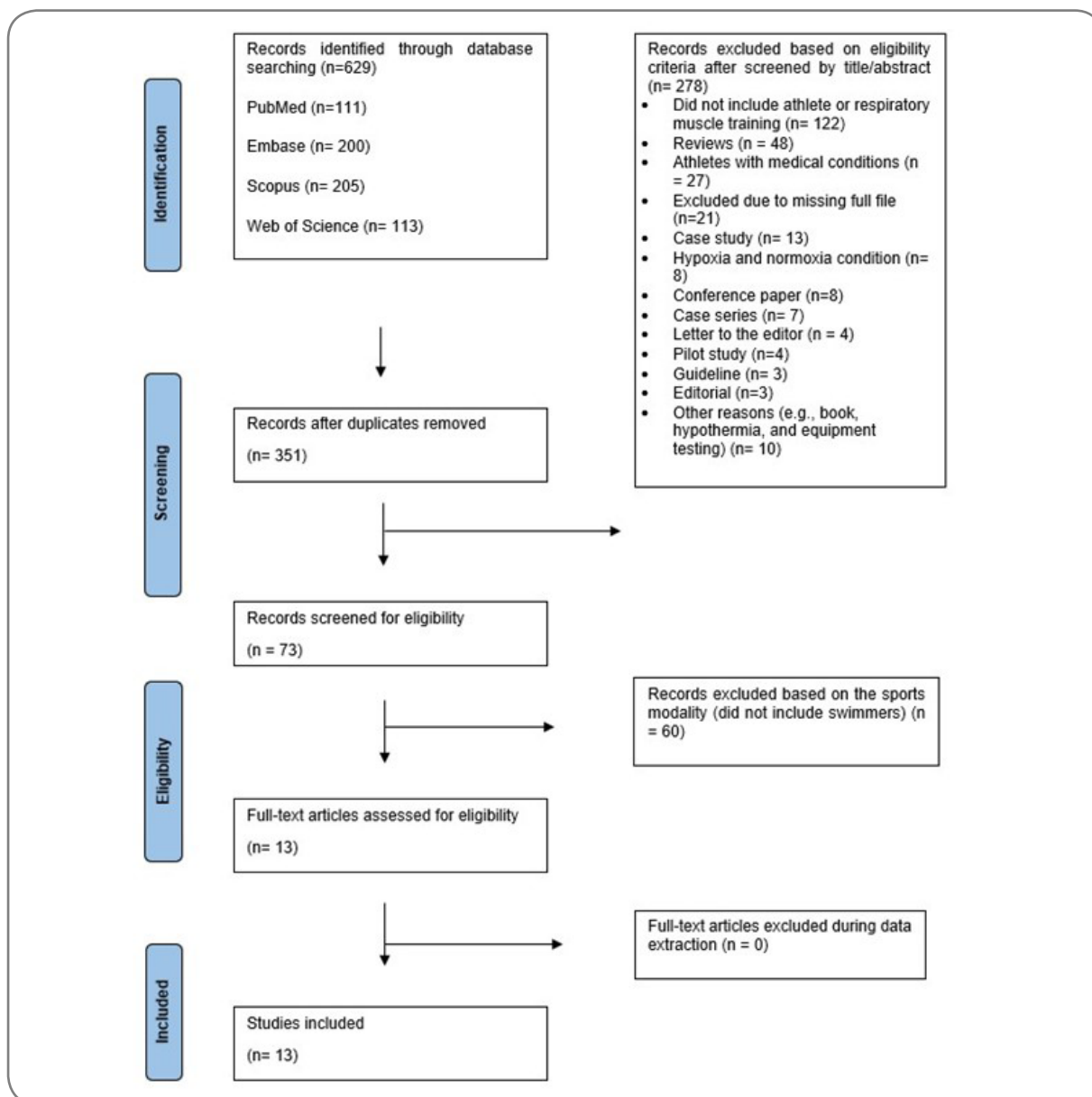


Figure 1 - PRISMA flowchart of study selection

Of the 13 selected articles, 11 were randomized clinical trials, one was an exploratory study, and one was a non-randomized trial. Regarding methodological quality, only one study had good quality, seven studies had moderate quality, and five studies were rated as having poor quality.

The studies were conducted in the United States (2 studies) [22,27], the United Kingdom (2 studies) [28,29], Chile (2 studies) [30,31], India [32], the Czech Republic [23], Mexico [21], Portugal [33], Latvia [34], China [11] and Japan [35] with one study each. Most studies included both sexes. One study did not specify the number of male and female participants [23] while three studies had exclusively male subjects [4,11,35]. The minimum sample size was 11 participants [21] and the maximum was 43 [11], with a minimum average age of 11 years [23] and a maximum average age of 21 years [11,29]. Twelve studies were published in English [4,11,21-23,27-29,32-35] and one in Spanish [31] (Table II - Appendix I).

Among the respiratory muscle training methods, nine studies used “flow-resistive inspiratory muscle training,” with seven of these utilizing POWERbreathe devices [11,28-31,33,35], one study using the Threshold device [23] and one study not stating the device type [22]. The remaining studies used the Yogic Breathing Practices (YBP) [32], controlled frequency breathing (CFB) [27], MRfit protocol [21] and modified breathing exercise [34].

The outcome “respiratory muscle strength” was examined in ten studies [11,22,23,27-31,33,35]. Eight studies reported significant improvements in Maximum Inspiratory Pressure (MIP) [22,23,27,28,30,31,33,35] in the Experimental Group (EG) compared to the Control Group (CG). However, results regarding Maximum Expiratory Pressure (MEP) were inconsistent. Vasickova *et al.* [23] reported an improvement in MEP between the EG and CG, while [28] did not find a statistically significant improvement between the groups. In addition to the improvement in respiratory muscle strength, Yañez-Sepulveda [30] also identified a significant improvement in maximum inspiratory flow between the EG and CG. In contrast, two studies [29,33] did not find any difference in MIP values between the groups after Respiratory Muscle Training (RMT). In the intragroup analysis, Tan *et al.* [11] identified improvements in MIP parameters in the EG when comparing pre- and post-RMT results.

Of the ten studies that examined the outcome “lung function” [11,22,23,27,29-34] seven of them [22,23,27,29-31,33] did not find statistically significant improvements in pulmonary function parameters when comparing the EG with the CG. Only the study by Hakked *et al.* [32] reported improvements in lung function parameters, including Maximum Voluntary Ventilation (MVV) and Forced Vital Capacity (FVC) in the EG compared to the CG. However, no improvements were observed in Slow Vital Capacity (SVC), Inspiratory Reserve Volume (IRV), Minute Ventilation (MV), and Peak Expiratory Flow (PEF) [32]. In intragroup comparisons, Tan *et al.* reported improvements in vital capacity (VC) [11] and Jakubovskis *et al.* [34] reported improvements in FVC and Peak Inspiratory Flow (PIF), both in the EG compared to the pre-training situation.

The outcome “Swimming performance” was examined in ten studies [11,23,27-34]. Among these, six studies [23,28-30,32,34] found improvements in performance in the EG compared to the CG. Hakked *et al.* [32] showed improvements through the reduction in the number of strokes; Jakubovskis *et al.* [34] reported the improvement in the world aquatic (WA) points; Wilson *et al.* [29] found improved performance in the 100 m exclusively when respiratory muscle training (RMT) was combined with the warm-up and Yañez-Sepulveda [30] found significant improvements in swimming times for 50 m, 100 m, and 200 m. Lomax *et al.* [28] also found improvements in 100 m and 200 m performance following RMT, but these improvements were limited to athletes with higher training loads (above 31 km/week). Vasickova *et al.* [23] reported improvements in apnea time, with effects sustained for 1-month post-RMT in the EG compared to the CG due to the cross-over design. Intragroup analyses showed improvements in 50 m and 100 m performance times, reduced number of breaths during

performance, and increased distance covered before the first inspiration in the EG [11]. Nevertheless, two studies did not find significant improvements in swimming performance. Burtch *et al.* [27] and Cunha *et al.* [33] did not observe improvements in the 200m performance.

Finally, the outcome, “aerobic capacity,” was examined in only three studies [21,27,31]. None of the studies reported significant changes in aerobic capacity parameters in the EG compared to the CG [21,27,31].

Discussion

The objective of this study was to examine the effectiveness of respiratory muscle training on respiratory muscle strength, lung function, swimming performance, and aerobic capacity among competitive swimmers. The results showed that most of the studies included in this systematic review reported improvements in MIP [22,23,27,28,30,31,33,35] but not in lung function parameters. The studies reported improvements in swimming performance but did not identify changes in the aerobic capacity of competitive swimmers.

Regarding respiratory muscle strength, 8 of the 10 studies included showed improvement in MIP. MIP primarily assesses diaphragmatic strength [10]. This finding is supported by other studies examining this parameter in different sports, with increased MIP attributed to improvements in diaphragmatic oxidative capacity and an increase in strength that contributes to greater fatigue resistance [10], leading to better athletic performance. Studies with soccer players have shown that an increase in MIP resulted in reduced sprint times [12,36] improving exercise tolerance and enhancing the players' endurance [36]. Similarly, RMT in both elite and non-elite swimmers significantly increased MIP, regardless of participants' age, intervention duration, or baseline MIP [37].

In contrast, MEP was not largely examined in the studies, and only a few utilized this instrument as a measure of respiratory muscle strength. MEP assesses the strength of the respiratory muscles, particularly the internal intercostals and abdominal muscles [10]. Perhaps the well-established capacity of MIP to predict diaphragm weakness [38] aligned with enhancements in anaerobic performance are factors that may have favored the utilization of MIP over MEP in these studies [39].

The findings of this systematic review showed that there was no improvement in lung function among competitive swimmers following RMT, similar to what has been described by Carvajal-Tello *et al.* [37]. These findings may be related to supra-physiological limits of lung function in athletes. A meta-analysis has shown that, before RMT, the values of key lung function parameters were already approaching $\geq 100\%$ of physiological levels in athletes [3]. Swimming is a sport that imposes a significant demand on lung function due to increased hydrostatic pressure and high inspiratory flow during breathing [40], factors that promote inspiratory muscle training [40]. Therefore, since lung function is already close to a maximum plateau, the

possibility of additional gains is reduced [3,36]. Additionally, the use of insufficient RMT loads may have contributed to the lack of significant improvements, considering the already elevated pulmonary function of the athletes [3], particularly in the study by Hakked *et al.* [32], which incorporated Yogic Breathing practices without additional RMT load.

The lack of improvement in lung function, or improvement in only a few parameters, with RMT was also observed in other studies examining different sports, such as running [41], soccer [26], hockey [42], and martial arts [16]. Therefore, it is possible that lung function was already optimized prior to RMT in these athletes or that the resistance used in RMT was insufficient.

This systematic review showed an improvement in athletic performance among swimmers following RMT, despite the significant variability in performance measurement parameters. Improvement in athletic performance was observed not only in studies that also included swimmers [34,40], but also in other sports such as running [19], cycling [43], and soccer [36]. RMT enhances the oxidative capacity of inspiratory muscles, reduces the oxygen demand of the respiratory muscles, and promotes tissue remodelling of the respiratory muscles, such as diaphragm hypertrophy and an increase in type II fibres [44]. These adaptations increase the strength and functionality of the respiratory muscles, delay the respiratory metabolic reflex [40,45,46], facilitate the availability of oxygen to peripheral muscles [45], and reduce the perception of shortness of breath and discomfort in the limb muscles [45,47]. Therefore, these physiological improvements may explain the enhancement in athletic performance [3,45].

Finally, no improvements in aerobic capacity were observed; however, only three studies addressed this topic in our review. $\text{VO}_{2\text{max}}$ is related to the amount of oxygen diffused and utilized by the body during physical activity [10]. Two meta-analyses examined this topic: Hajghanbari *et al.* [48], examining 13 studies, reported no improvements in $\text{VO}_{2\text{max}}$, while Fernández-Lázaro *et al.* observed that RMT produced improvements in aerobic capacity, although not significant [10]. Espinosa-Mendez *et al.* [21] found an improvement in $\text{VO}_{2\text{max}}$ in their study, although they acknowledged the scarcity of studies corroborating such findings. This may occur due to $\text{VO}_{2\text{max}}$ being more reliant on cardiac output than on the respiratory system [21]. It is estimated that, during intense exercise, the respiratory muscles can utilize up to 16% of cardiac output, reducing the availability of oxygen for the skeletal muscles responsible for mobility. This phenomenon occurs due to the sympathetic vasoconstrictor response, which decreases blood flow to the skeletal muscles, reducing their energy production and consumption. As a result, skeletal muscle may fatigue increase and blood flow is redistributed to preserve respiratory function without compromising the energy demands of the respiratory muscles [10].

This systematic review has limitations. The small number of studies reduces the robustness of the conclusions. Additionally, the variability in outcome measurement, particularly regarding swimming performance, limits comparisons among

studies. The greatest variations were related to the RMT method, training load, and weekly frequency. Due to the lack of alignment in these key training variables, conducting a meta-analysis was not feasible. Regarding the assessment of methodological quality, among the 13 included studies, only one study was rated as good quality, seven as moderate quality, and five as poor quality. The findings show that the majority of the available evidence has important methodological limitations, which must be taken into account when interpreting the results of this review. However, given the lack of prior systematic reviews in this specific area, we decided to conduct the present study to synthesize the available evidence and highlight gaps to be addressed in future studies.

Nevertheless, the strength of this study lies in its status as, to our knowledge, this is the first systematic review to examine the effectiveness of respiratory muscle training in athlete swimmers. This confers the study an innovative approach, establishing a framework for future investigations and filling a gap in this research area.

Recommendation for future research

Future studies should aim to improve methodological quality (e.g., randomization and blinding) and prioritize the standardization of RMT protocols, particularly regarding the type of device used, as well as key training variables such as load, frequency, and intervention duration, which showed considerable variability across studies. It is also recommended to include subgroup analyses based on athletes' competitive level, as this may help to distinguish performance responses according to different levels of competition, even among professional swimmers. In addition, studies should explore the physiological mechanisms underlying performance gains and examine the effects of higher resistance parameters in RMT, especially in swimmers with greater baseline respiratory conditioning.

Conclusion

Respiratory muscle training was effective in increasing respiratory muscle strength, particularly inspiratory strength, in swimmers. Additionally, respiratory muscle training was effective in improving the athletic performance of these athletes. However, no effectiveness of this training was observed in improving pulmonary function and aerobic capacity among the swimmers.

Academic affiliation

This article is derived from a postgraduate thesis in Physical Education, conducted under the supervision of Dr. Lucélia Luna Melo-Díaz at the Hospital de Clínicas Complex of the Federal University of Paraná.

Conflict of interest

The authors declare that they have no competing interests.

Funding sources

There were no external funding sources for this study.

Authors' contributions

Conception and design of the research: Neves CNN, Kielling GA, Melo-Diaz LL; Data acquisition: Neves CNN, Kielling GA, Melo-Diaz LL; Data analysis and interpretation: Neves CNN; Kielling GA, Melo-Diaz LL; Statistical analysis: Neves CNN; Kielling GA; Melo-Diaz LL; Funding acquisition: Neves CNN, Kielling GA, Melo-Diaz LL; Manuscript writing: Neves CNN, Kielling GA, Melo-Diaz LL; Critical revision of the manuscript for important intellectual content: Neves CNN, Kielling GA, Melo-Diaz LL.

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Table II - Summary of the characteristics and outcomes of included studies

Study characteristics				Intervention characteristics		Outcome characteristics
Author/ Year/ Country	Type of study/ Context	Sample size/% males /mean age (+SD)	Quality assessment	Intervention x Control	Outcome variables	Main findings (After statistical adjustments where applicable)
Hakked et al. 2017/ India	Randomized matched control clinical study.	27 (EG, N = 14; CG, N = 13) / 52%/ By groups: YBP = 15.23 ± 1.59y; CG =15.08 ± 1.26y.	12 (moderate)	Yogic Breathing Practices (YBP) group: 30 min; 5 d/week for 1 month + regular swimming and physical training. CG: physical training practices only.	Pulmonary function: Spirometry test - SVC, IRV, FVC, MVV and MV, and PEF on day 1 and day 30. Swimming performance: Subjective observation of swimming strokes per breath on day 1 and day 30.	Lung function: Significant improvement in MVV ($F_{(1,22)} = 6.06$, $p = 0.02$) and FVC ($F_{(1,22)} = 5.68$, $p = 0.026$) between the groups following intervention. No significant differences were observed in SVC, IRV, MV and PEF. Swimming performance: Post-intervention measures showed a significant increase in number of strokes per breath in the YBP group compared to CG ($F_{(1,22)} = 13.06$, $p = 0.002$).
Burtch et al. /2017/ USA	Randomized clinical trial	20 (EG, N = 9; CG, N = 11) / 56%/ 20±1y.	7 (weak)	Both groups performed a 1,000-m warm-up of easy mixed swimming. Workout: 4 training sessions/week for 4 weeks, for 35 min. It consisted of 12 repetitions of a 50-m swim. The Controlled frequency breathing (CFB): limited their breathing to 2 breaths per lap, resulting in 24 breaths per workout. CG: breathed on a stroke-matched basis, breathing every 2–3	Swimming performance: 200-yard time in sec. Respiratory muscle strength: MIP and MEP Lung function: Spirometry - FVC, FEV in 1 second, FEF rate over the middle half of expiration (FEF25–75), and PEF rate. Aerobic capacity (measure using treadmill measures): VO2max.	Swimming performance: Four weeks of CFB training did not improve swim performance compared to CG ($p = 0.479$). Respiratory muscle strength: an all-out 200-yard swim led to a 12% decrease in mean MIP scores at 46 sec. post-race (116 cm H ₂ O, $P < 0.001$, 95% CI -7 to -23 cm H ₂ O). After 1.3 minutes post-exercise, mean MIP scores returned to near baseline values. After 4 weeks of CFB training, the drop in mean MIP scores from pre- to 46 sec. post-time trial was eliminated compared to CG. MEP scores did not change post-race at baseline or after race post training. Lung function: No significant difference was found (Fisher's exact test, $p = 0.32$ for both). Aerobic capacity: No effects were found in CFB training group nor in the CG.

strokes, resulting in
10–12 breaths per lap.

Vasicková et al. 2017/ Czech Republic	Randomized, evaluator-blinded, controlled crossover trial.	20 (EG, N = 12; CG, N = 8)/ Not shown / By Groups: EG = 12.0 ± 1.7 y; CG = 11.5 ± 2.4 y.	10 (moderate)	EG: regular swimming training with daily RMT for 1 month. RMT included threshold IMT (inspiratory muscle trainer) and Threshold PEP (positive expiratory pressure) devices daily for 1 month of RMET and RMST. The resistances were adjusted at 30 % of their maximum measured values PImax and PEmax initially and increased weekly by 2 cm H ₂ O until maximal possible resistance was reached, and maintained. Both respiratory devices were used daily. RMST: 10 repetitions of maximal inspiration with the Threshold IMT and 10 repetitions of maximal expiration with the Threshold PEP. RMET: 15	Lung function: VC, FVC, IC, FEV ₁ , and PEF. Respiratory Muscle Strength: PImax and PEmax. Swimming performance: apnea max test - 50 m long indoor pool - 3 to 5 times per week (3 for younger swimmers and 5 for older ones) in a 50 m swimming pool.	Lung function: In the EG, all ventilatory parameters were higher after RMT but the improvement was not significant. FEV ₁ and PEF were higher after RMT in the CG but the difference was not significant. Respiratory muscle strength: EG: after a month of RMT PImax value increased significantly (20.8%). PEmax value increased by 10.6% (i.e., strength of inspiratory and expiratory muscles improved). Significant differences in PImax (13.4%) and PEmax (23.1%) parameters in the CG were found. CG: after a month of regular training, no significant increase in the inspiratory parameters PImax were found. A small negative effect in the expiratory parameters PEmax that decreased. Large effect in all values of PImax and PEmax (pre, post and last) was found between EG and CG after first month (post: $d = 1.28$) and small effect after the second month (last: $d = .49$). There was a medium and large effect in post and last measurements (post: $d = .49$; last: $d = 1.19$) in PEmax parameters. Swimming performance: EG: able to swim for one inspiration increased by 11.36 meters (27.4%). Compared to the preliminary results, there was a significant difference in the follow up measurements, with a large effect size (9.45 meters). CG: there was a significant improvement in the average length, by 3.37 meters in the first month. Compared to the preliminary results, there was a significant difference in the follow up measurements
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				minutes for each device. CG: regular swimming training.		after a month of additional respiratory training, with a large effect size. The length of the distance increased by 9.12 meters (20.7%).
Yañez-Se-pulveda et al. 2021 / Chile	Randomized clinical trial	15 (EG, N = 9; CG, N = 6) / 100% / By Groups: EG = 15.5 ± 1.15y, sham control group (SCG): 14.7 ± 1.09y.	9 (moderate)	Inspiratory muscle training (4weeks). EG conducted two daily IMT training sessions with POWERbreathe Classic Competition® devices, with 30 dynamic inhalations to maximum capacity at an adjusted load/week according to the S-Index. EG load adjustment: 50% of the S-Index with load increased by 5% weekly. SCG load adjustment: 15% of the S-Index and maintained. If the maximum load was reached before four weeks, subjects maintained it until the end of the training period. Warm-up 30 maximum inhalations at 15% of the S-Index was performed by both groups.	Lung function: parameters/ spirometry - FEV1; FVC; PEF; relationship between FEV1 and FVC or Tiffeneau index (VEF1·FVC-1); FEF between 25% and 75% of the maximal flow (FEF25%-75%); and MVV. Respiratory Muscle Strength: (Maximum inspiratory muscle strength): POWER-breathe Kinetic K5® device – for maximum dynamic muscle strength (S-Index) and maximum inspiratory flow (MIF). Swimming performance: three free-style swimming tests of 50-m, 100-m and 200-m, in an Olympic pool, once for three consecutive days	Lung function: Within group comparisons showed that only participants in the EG had a substantial increase of the S-Index (p=0.0003), the inspiratory flow (p=0.0008), VEF1 (p=0.007), FVC (p=0.0004), PEF (p= 0.01), FEF25-75% (p=0.03), and MVV (p=0.0001). Respiratory muscle strength: Between-group comparison showed changes induced by IMT, with significant large effects in respiratory muscle strength (S-Index) (ES: 1.29 CI95%: 0.15 to 2.38; p=0.03) and MIF (ES: 1.31 CI95%: 0.16 to 2.42; p=0.02). Swimming performance: Large reduction in swimming times in all three tests: 50-m (ES: -2.29 CI95%: -3.86 to -0.68; p=0.002), 100-m (ES: -1.75 CI95%: -3.04 to -0.40; p=0.008) and 200-m (ES: -2.12 CI95%: -3.61 to -0.59; large effect; p=0.003). As the absolute improvement of the inspiratory musculature strength was greater, the swimming times in the 50-m tests (r= 0.72; p=0.003) and 100- m (r= 0.65; p=0.008) were also shorter. In addition, a higher maximum inspiratory flow was related to shorter swimming times in 50-m (r= 0.7; p=0.003) and 100-m (r= 0.62; p=0.01). The other respiratory parameters did not show any associations with swimming performance.

Espinosa-Mendez et al. 2020 / México	Randomized clinical trial	11 (EG, N = 6; CG, N = 5) / 36,36 / 14.3±1.2y.	8 (weak)	EG: RMT (MRFit) 20 minutes, two times a week for eight weeks incorporated into their usual training. CG: usual training without MRFit. MRfit protocol: 20-min 16 training sessions, for eight weeks, with a weighted load device for respiratory muscles made with tubes of four different calibers (own elaboration and previously validated).	Aerobic capacity: VO2max - treadmill ergospirometry.	Aerobic capacity: There were no significant differences in the VO2max a $p > 0.05$ for the two groups. The VO2max decreased in both groups, for the EG there was an average of 47.35ml/min, decreasing by 2.03ml/min, while in the CG the average in the second VO2max was 49.12ml min, a difference of 4.9 ml/min, with respect to its first sample (not statistically significant).
Lomax et al. 2017 / United Kingdom	Experimental non-randomized trial	33 (LOW, N = 18; HIGH, N = 15) / 54,54% / By Groups: LOW = 16±3y HIGH = 16±1y.	7 (weak)	Two groups based on their weekly training distance: low training distance group (LOW) or high training distance group (HIGH). Throughout the 6-week period, the coaches of the LOW and HIGH groups ensured the overall swimming training program was the same for both IMT and control swimmers. Intervention: Inspiratory muscle training was performed (POWERbreathe) twice daily, 7 d/wk for 6	Respiratory muscle strength: PImax and PEmax (pre (before the warm-up) and post each performance test). Swimming performance: maximum effort 100- and 200-m front crawl swim from a dive start in a counterbalanced order and on separate occasions within 1 week of each other. Swimming time was recorded per swim using a stopwatch, and in the case of the 200-m swim, per	Respiratory muscle strength: PImax and PEmax were similar between groups. PEmax was unaffected by IMT, but PImax did increase ($F = 105.142$, $p < 0.001$) after IMT. The largest improvement in PImax was seen in the LOW _{IMT} ($98 \pm 4\%$ IMT compliance) and HIGH _{IMT} ($91 \pm 3\%$ IMT compliance) groups ($F = 16.355$, $p < 0.001$, $d = 0.97-1.29$). Swimming performance: Pre-IMT 100- and 200-m swimming times were on average 14% faster (9.1 and 20.8 seconds, respectively) ($p < 0.001$) in the HIGH (pooled HIGH _{con} and HIGH _{IMT}) compared with LOW (pooled LOW _{con} and LOW _{IMT}) group swimmers. IMT improved 100-m ($F = 14.455$, $p < 0.001$, power = 0.954) and 200-m ($F = 21.108$, $p < 0.001$, power = 0.993) swimming times (and hence velocity) in the LOW _{IMT} group (100 m: $d = 0.32$; 200 m: $d = 0.64$) but not the HIGH _{IMT} , LOW _{con} , or HIGH _{con} groups. One hundred and 200-m swimming times were slower after IMT in HIGH _{IMT} and

				weeks. Each session consisted of 30 breaths at an intensity equivalent to 50% PImax. Participants were instructed to periodically increase the load on the inspiratory muscle trainer so that 30 breaths could only just be completed.	100-m partial also. Clean swimming velocity and SR were recorded per 100- and 200-m swim (Finis stopwatch with base count 3 function) using a 12.5-m central pool zone and expressed per 100-m partial of the 200-m swim.	HIGHcon, respectively ($p \leq 0.05$; 100 m: $d = 0.65$; 200 m: $d = 0.59$). The first and second 100-m partials of the 200 m differed between the HIGH and LOW groups ($F = 10.844$, $p = 0.003$, power = 0.889). The first 100-m ($d = 0.39$) and second 100-m ($d = 0.24$) partials were faster after IMT in the LOW_{IMT} group ($p \leq 0.05$). The first 100-m ($d = -0.58$) and second 100-m ($d = -0.58$) partials were slower ($p \leq 0.05$) after the intervention in the HIGH_{con} group. The improvement in PImax post-IMT in the LOW_{IMT} group was not correlated with the change in 100- or 200-m swimming times pre- and post-IMT ($p > 0.05$).
Shei R et al. 2016 / USA	Double-blind, parallel-group experimental design	24 (EG 1, N = 8; EG 2, N = 8; CG, N = 8) / 50% / 19.9 ± 2.6y.	7 (weak)	EG: Group 1: combined swim training (ST) with flow-resistive IMT set at 80% sustained MIP with progressively increased work-rest ratios until task failure for 3 days/week (ST+IMT, n.=8) EG: Group 2: ST with sham-iMT (ST+Sham-IMT, n.=8), or CG: Group 3: (ST only, n.=8).	Lung function (Spirometry): RLV and TLC. Respiratory muscle strength: MIP, sustained maximal inspiratory pressure (SMIP).	Lung function: No significant differences ($P > 0.05$) were observed between the ST+Sham-iMT and ST only groups at baseline and at the end of the 12-week study period, in: FVC, FEV1, RLV and TLC. No significant changes ($P > 0.05$) were observed within groups following the training period: - except FEV1 within the ST+iMT group increased significantly ($P = 0.001$, 95% CI 0.19-0.68 L/s) at the end of the 12-week study period compared to baseline (%Δ, +14.5%). Respiratory muscle strength: Significant increases ($P < 0.05$) in several measures were observed in the ST+IMT group (at the end of the 12-week study period compared to baseline) in MIP (%Δ, +90.0%) and SMIP (%Δ, +49.2%).
Cunha et al. 2019 / Portugal	Randomized controlled trial	29 (EG, N=17; CG, N=12) / 31,25% / MD: EG = 15y; CG=14y.	13 (good)	EG: additional IMT program described as "RMT" at high intensity (50% of MIP). Participants periodically increased the load which allowed only 30	Swimming performance: time taken to complete 200m time trial (TT).	Swimming performance: EG and CG had an increase in FINA points, with mean difference changes of 30 (confidence interval: -0,60) and 19 (confidence interval: 12, 27), respectively. However, the training protocol failed to show significant differences between groups ($P = .271$) on swimming performance.

				inspiratory maneuvers to be completed. CG: IMT intervention at a low training intensity (15% of MIP), and maintained the initial inspiratory load for the whole intervention. IMT: POWERbreathe Plus PB-2002 pressure threshold device, 2 cycles of 30 inspiratory efforts each, 5days/wk, for 12 weeks before swimming training.	Respiratory muscle strength (Inspiratory): MIP Lung function: Spirometry.	Respiratory muscle strength: No significant differences ($P=.914$) were found between groups after intervention. Within groups, IMT showed an improvement in MIP values with mean difference changes of 19.6 ($P<.001$) and 17.9 ($P=.036$) in EG and CG, respectively. Lung function: No significant differences were found between groups after the 12 weeks of IMT for FVC ($P=.262$), FEV1 ($P=.265$) and PEF ($P=.270$). A modest increase in FVC and FEV1 for the EG was found, with mean difference changes of 0.1 L, reaching significance ($P=.011$) for FVC but not for FEV1 ($P=.061$).
Tan et al. 2023 / China	Randomized controlled trial	43 (EG, N=20; CG, N=23) / 100% / By Groups: EG = 21.21±0.61y; CG = 21.26±0.74y.	8 (weak)	EG: standard training with IMT leveraging the capabilities of the Power Breather Plus device - for six weeks. IMT program: 15–20 min of training per session with three sets of 30 inhalations each. 2) CG: followed regular swimming training.	Swimming performance: time of 50 m freestyle, number of breaths in 50 m freestyle, distance before first breath in freestyle, time of 100 m freestyle; Respiratory muscle strength: MIP, MIF, and MIC. Lung function: spirometry - VC	Swimming performance: 50 m freestyle swim time: CG had a slight decrease from an average of 42 s to 40.4 s ($p = 0.28$); 0 EG showed a significantly greater decrease from an average of 39.6 s to 35.4 s ($p = 0.0018$). The number of breaths taken in the 50 m freestyle was not significant in the CG (15.73 vs. 15.75; $p = 0.99$), but significantly reduced in EG (11.45 to 7.85; $p = 0.006$). The distance before taking the first breath in the freestyle swim decreased slightly for the CG (31.34 m vs. 29.25 m; $p = 0.39$), whereas it increased significantly for the EG (27 m to 30.95 m; $p = 0.013$). 100 m freestyle swim time: CG had a small decrease (from 121.47s to 114.65s; $p = 0.203$), while the EG had a considerable decrease (from 112.25s to 102.3s; $p = 0.004$). Respiratory muscle strength: MIP: significant improvements were found in the EG starting on the second week ($p<0.01$), with an additional

significant increase between the second and fourth week ($p < 0.01$). CG showed modest progress ($p = 0.05$ at the sixth week versus pre-training levels). At the end of six weeks, MIP for the EG went from 117.70 ± 14.83 to 162.87 ± 10.77, while the CG went from 126.61 ± 20.69 to 144.19 ± 16.14. MIF: EG had significant improvements beginning the second week ($p < 0.01$) while CG only had it beginning the fourth week ($p = 0.03$). After six weeks, MIF rose from 5.97 ± 0.84 to 8.52 ± 0.83 in the EG and from 6.51 ± 0.89 to 7.54 ± 0.99 in the CG. MIC: Both groups had an upward trajectory every two weeks, but EG had significant increases from the second week ($p < 0.01$), while CG only had them by the sixth week. Post training, MIC increased in EG from 5.97 ± 0.84 to 8.52 ± 0.83, and from 2.08 ± 0.76 to 3.34 ± 0.80 in CG. Lung function: No significant change was found in VC in CG compared to pre-training levels. EG had a substantial increase by the sixth week of training ($p = 0.01$), raising their VC from a baseline of 4483.42 ± 673.12 to 5048.48 ± 651.88.					
Ando et al. 2020/ Japan	Randomized controlled trial	19 (EG, N=10; CG, N=9) / 100% / By Groups: EG = $19.3 \pm 0.1y$; CG = $19.3 \pm 0.1y$.	10 (moderate)	EG: 6-week inspiratory resistive training program + their usual swimming and strength training. CG: continued their usual swimming and strength training only. Protocol: Inspiratory muscle training device (POWERbreathe) was used for inspiratory	Respiratory muscle strength (P_Imax): was measured using a computerized spirometer system with a handheld mouth pressure meter. Respiratory Muscle Strength: P_Imax increased significantly in both groups after 6 weeks. However, the relative change in P_Imax from baseline to 6 weeks later was significantly greater in the EG than in the CG. Baseline P_Imax at 15%, 45% and 75% of the P_Imax were 20.8 ± 2.9 cmH₂O, 62.4 ± 8.7 cmH₂O and 104.0 ± 14.5 cmH₂O, respectively, in the CG, and 19.3 ± 2.7 cmH₂O, 58.0 ± 8.1 and 96.6 ± 13.5 cmH₂O, respectively, in the EG. The inspiratory mouth pressures at 15%, 45% and 75% of the P_Imax after the 6-week training program were 23.3 ± 3.3 cmH₂O, 69.8 ± 10.0 cmH₂O, and 116.3 ± 16.7 cmH₂O, respectively, in the CG, and 24.4 ± 3.4 cmH₂O, 73.2 ± 10.1 cmH₂O, and 122.0 ± 16.8 cmH₂O, respectively, in the EG.

				resistive training, with maximum inspirations at a load resistance of 50% of their P _I max value. Sessions included 30 maximum inspirations, twice a day, six days/week.		
Wilson et al. 2013 / United Kingdom	Randomized controlled cross over trial	15 / 60% / 21.2±1.6	10 (moderate)	Randomly allocated weekly to one of four warm-up protocols for four consecutive weeks. Protocol 1: Standard swimming warm-up of 2500 m (100×25 m lengths), with a mix of all four strokes, leg-only work, arm-only work, and under-water work. Protocol 2: Respiratory muscle-specific warm-up (Power-breathe): 2 sets of 30 inspirations at 40% of maximal inspiratory muscle pressure at 40% load to prevent fatigue. Protocol 3: protocol 1, followed by sham IME warm-up with a	Swimming performance: 100 m freestyle sprint time-trial time following warm-up in a 25 m (short-course) pool. Respiratory muscle strength: MIP and MEP Lung function: Spirometry: FVC, FVC per cent predicted, FEV₁/FVC ratio, ratio percent predicted, peak flow (PEF), PEF percent predicted.	Swimming performance: There were significant differences between the four different warm-up protocols and the resulting 100 m freestyle times. The fastest protocol was swimming plus IME warm-up with a 100 m time of 57.05 s. Protocol 4 was significantly faster than both protocol 2 (Mean difference=1.18s, 95% CI 0.44 to 1.92, p<0.01) and protocol 1 (Mean difference=0.62s, 95% CI 0.001 to 1.23, p=0.05). Protocol 4 was faster than protocol 3, but the difference was not statistically significant (mean difference=0.33 s, 95% CI -0.44 to 1.11, p=1.00). Protocol 2 was significantly faster than protocol 3 (Mean difference=0.85 s, 95% CI 0.05 to 1.65, p=0.035). Respiratory muscle strength: There were no significant differences in this variable or in physiological parameters between any of the warm-up protocols. Lung function: There were no significant differences in this variable or in physiological parameters between any of the warm-up protocols.

				resistance load equal to 15% maximal inspiratory muscle pressure.		
				Protocol 4: protocol 1, followed by IME warm-up (protocol 2).		
Jakubovskis et al. 2024 / Latvia	Exploratory study	31 (EG=15; CG= 16)/ both male and female / By Groups: EG=16.15 ±2.4y; CG =16.5 ±2.0y.	9 (moderate)	Participants were reassessed after four weeks. CG (n=16): Regular training without changes to breathing techniques. EG (n=15): Regular training but added modified breathing exercises: reducing inhalation frequency and gradually increasing breath-holding during swimming.	Lung function (Spirometry): FVC, PIF and PEF. Swimming performance: world aquatic (WA) points - 100-m competition	Lung function: After four weeks, EG showed significant improvements in FVC (↑ 4%–6%, $p = 0.02$) and PIF (↑ 24%–34%, $p = 0.001$). PEF increased slightly (↑ 6%) but without statistical significance ($p = 0.46$). The CG showed no significant changes in any of the respiratory measures. Swimming performance: The EG improved their WA points by 6%–8% ($p = 0.001$), indicating enhanced performance after the intervention. The CG showed no change.
Troncoso-Galleguillos et al. 2024 /Chile.	Randomized Controlled Trial	14 (EG=7; CG=7) / 71,43% (n=10) / By groups: EG: 17.1 ± 2.2y; CG= 16.0 ± 1.4y.	9 (moderate)	Both groups maintained usual swimming training. However, EG completed 36 sessions of respiratory muscle training over three weeks—two daily sessions of 30 breaths at 70% of MIP using the Powerbreathe® device.	Respiratory muscle strength: PImax. Lung function (Spirometry): FVC, FEV1, FEV1/FVC ratio, PIF, and PEF. Aerobic capacity: VO2max. Swimming performance: 200-meter freestyle test in a 25-meter heated pool	Respiratory muscle strength: A significant interaction effect was found for PImax ($p = 0.0115$) with a large effect size ($\eta^2 = 0.4254$). Post hoc analysis showed a significant increase in PImax after the intervention in the EG group ($p = 0.0010$). No differences were observed in CG. Lung function: No significant effects of the intervention were found for FVC, FEV1, FEV1/FVC ratio, PEF, or PIF. Aerobic capacity: No effects of the intervention were observed in the ergospirometric (cardiopulmonary exercise) variables.

(time, number of strokes, and number of breaths).

Swimming performance: No significant differences were found in split time ($p = 0.3347$, $\eta^2 = 0.0734$), number of strokes ($p = 0.8747$, $\eta^2 = 0.0169$), or number of breaths ($p = 0.7980$, $\eta^2 = 0.0247$) during the swimming test.

95% CI = 95% Confidence Interval; CG = Control Group; EG = Experimental Group; EMF = Expiratory Muscle Fatigue; EMT = Expiratory Muscle Training; FEF = Forced Expiratory Flow; FEV = Forced Expiratory Volume; FEV1 = Forced Expiratory Volume in 1 second; FVC = Forced Vital Capacity; HR = Heart Rate; HR – Hazard Ratio; IC = Inspiratory Capacity; IMF = Inspiratory Muscle Fatigue; IMR = Inspiratory Muscle Training; IRV = Inspiratory Reserve Volume; MD – Median; MEP = Maximal Expiratory Pressure; MIC = Maximum Inspiratory Capacity.; MIF = Maximum Inspiratory Flow; MIP = Maximal Inspiratory Pressure; MV = Minute Ventilation; MVV = Maximum Voluntary Ventilation; N/A – Not Applicable; OR = Odds Ratio; p = p value; PaO_2 / FiO_2 – Partial Pressure Of Oxygen/Fraction Of Inspired Oxygen; PEF = Peak Expiratory Flow; PEmax – Maximal Expiratory Pressure; PHR = Peak Heart Rate; PImax = Maximal Inspiratory Pressure; RCT – Randomized Controlled Trial; RERmax = Respiratory Exchange Ratio at Maximal Exercise; RLV = Residual Lung Volume; RMET = Respiratory Muscle Endurance Training; RMST = Respiratory Muscle Strength Training; SR = Stroke Rate; SVC = Slow Vital Capacity; TLC = Total Lung Capacity; VC = Vital Capacity; VE_{max} = Maximal Expired Ventilation Rate; $\text{VO}_{2\text{max}}$