INSPIRATORY MUSCLE TRAINING IN CYCLICAL SPORTS MODALITIES: A SYSTEMATIC REVIEW

ENTRENAMIENTO MUSCULAR INSPIRATORIO EN MODALIDADES DEPORTIVAS CÍCLICAS: UNA REVISIÓN SISTEMÁTICA

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Abstract

Inspiratory muscle training has been shown to positively impact the performance of acyclic sports, however a review has not been carried out that presents these same changes in cyclic sports. This systematic review aimed to determine the effect of Inspiratory muscle training in cyclic sports and identify the impact on aerobic capacity, respiratory muscle strength and pulmonary function. An advanced search was conducted in the databases of Web of Science, PubMed, Scopus, PEDro, ScienceDirect, OXFORD, LILACS, Taylor & Francis Group, Springer, and SciELO, according to the Preferred Reporting Items for Systematic Reviews and Meta-Analyses. Of 15,710 studies identified, twelve of them met eligibility criteria for the final review. Showing significant improvements in expiratory flow during forced expiration from maximum inspiration, Maximum Inspiratory Pressure and in maximum forced expiratory volume in the first second, as they were evaluated before and after training. Additionally, significant changes were evident in those groups that used resistance devices than those that did not use any device or placebo. In conclusion, inspiratory muscle training with a minimum of four weeks of training, at least six days a week and if accompanied by strengthening the core muscles, supports positive effects on pulmonary function, respiratory muscle strength and aerobic capacity endurance in cyclic sports.

Keywords: Inspiratory muscle training, muscle fatigue, physical therapy modalities, cardiorespiratory fitness, athletic performance.

Resumen

Se ha demostrado que el entrenamiento de los músculos inspiratorios impacta positivamente en el rendimiento de los deportes acíclicos, sin embargo, no se ha realizado una revisión que presente estos mismos cambios en los deportes cíclicos. Esta revisión sistemática tuvo como objetivo determinar el efecto del entrenamiento de los músculos inspiratorios en deportes cíclicos e identificar el impacto sobre la capacidad aeróbica, la fuerza de los músculos respiratorios y la función pulmonar. Se realizó una búsqueda avanzada en las bases de datos de Web of Science, PubMed, Scopus, PEDro, ScienceDirect, OXFORD, LILACS, Taylor & Francis Group, Springer y SciELO, según PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses). De 15.710 estudios identificados en las bases de datos, doce de ellos cumplieron con los criterios de elegibilidad para la revisión final. Mostrando mejoras significativas en el flujo espiratorio durante la espiración forzada desde la inspiración máxima, la Presión Inspiratoria Máxima y en el volumen espiratorio forzado máximo en el primer segundo, tal como fueron evaluados antes y después del entrenamiento. Además, se evidenciaron cambios significativos en aquellos grupos que usaron dispositivos de resistencia que en aquellos que no usaron ningún dispositivo o placebo. En conclusión, el entrenamiento de los músculos inspiratorios con un mínimo de cuatro semanas de entrenamiento, al menos seis días a la semana y acompañado de fortalecimiento de los músculos centrales o core, evidencian efectos positivos sobre la función pulmonar, fuerza muscular respiratoria y capacidad aeróbica en los deportes cíclicos.

Palabras clave: Entrenamiento de los músculos inspiratorios, fatiga muscular, modalidades de fisioterapia, aptitud cardiorrespiratoria, desempeño atlético.

Introduction

Cyclical sports are characterized by a specific series of movements repeated in the same sequential order, constituting a succession of cycles. Thus, anaerobic resistance is emphasized depending on the execution time required. The intrinsic characteristics of these types of sports are associated with a recovery time between efforts which, many times, are performed at a very high intensity and for a short period of time (Fernández, 2012). In this type of modality, sports performance depends on variables such as maximum oxygen uptake (VO2max), aerobic capacity, strength, endurance, and motor coordination. VO2max and aerobic capacity, in turn, are influenced by the functioning of the respiratory muscles that participate in the ventilation process, thus affecting physical performance in sports (Lorca-Santiago et al., 2020).

Inspiratory muscle training may prevent muscle fatigue, which leads to "metabolic reflex" or "metaboreflex." This reflex causes vasoconstriction of the blood vessels of the peripheral muscles, leading to deterioration in respiratory performance during sports activity (Chang et al., 2021; Lorca-Santiago et al., 2020; Walter et al., 2010). Thus, IMT is proposed as a strategy for promoting optimal ventilation and perfusion among athletes during training and competition.

Previous investigations suggest that this intervention contributes to sports performance and physical qualities such as aerobic capacity or endurance, respiratory muscle strength (HajGhanbari et al., 2013; Lemaitre et al., 2013; Romer et al., 2006), mainly in cyclical sports. Nonetheless, currently, there are no reviews that identify their association with aerobic capacity, respiratory muscle strength, and pulmonary function in acyclic sports (Tsvetkova-Gaberska et al., 2023). Consequently, effective load intensities or training protocols may be established based on the results to help more precisely understand the functioning of the inspiratory muscles and the effect of training with resistance devices in different modalities.

Methodology

This investigation followed the specifications of the Cochrane collaboration for systematic reviews and the criteria included in the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) checklist (Higgins & Green, 2008; Page et al., 2021). The protocol was registered in the international prospective register of systematic reviews PROSPERO CRD42021287471.

Eligibility Criteria

Randomized clinical trials were included, answering the PICO (population, intervention, control, and outcomes) questions (table 1), considering that the training of respiratory (inspiratory) muscles is performed with a threshold or resistance device. Full-text articles were limited to English, Spanish, and Portuguese from January 1, 2021, to December 15, 2023, and without publication date restrictions.

Table 1
Components of the PICO Question

P (Population)	I (Intervention)	C (Comparison)	O (Outcomes)
Subjects who practice cyclical sports modalities	Use of RMT and/or IMT	Same conditions with placebo and/or control groups	Pulmonary function Respiratory or inspiratory muscle strength and aerobic capacity

Note. RMT: Respiratory Muscle Training. IMT: Inspiratory Muscle Training.

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In this systematic review, the term lung function is attributed to the physiological properties of the lungs, including airflow mechanics, volumes, and gas transport, which can be reflected by means of some tests, such as spirometry, plethysmography, and single-breath lung carbon monoxide uptake (DLCO) (Stanojevic, et al. 2022).

Another outcome measure is the Respiratory or inspiratory muscle strength, which is the result of the maximum contraction generated against a maximum resistance to inspiration and/or expiration (maximal inspiratory pressure and maximum expiratory pressure); and the inspiratory muscle resistance, represented as the ability to breathe against increasing inspiratory loads, or the ability to breathe with a fixed load for a predetermined amount of time (Fabero-Garrido et al, 2022).

And finally, Aerobic capacity, a concept taken from the American Physical Therapy Association (APTA) guide in which it is defined as the ability to perform work or participate in an activity over time using the body's mechanisms of oxygen uptake, supply and release of energy and thus determine the suitability of an individual's responses to a greater demand for oxygen, which includes VO2 max tests, blood lactate, peripheral tissue saturation, among other tests (APTA, 2023).

Exclusion Criteria

Articles where the measurement did not specifically correspond to the results or outcomes of interest and studies where the population did not include cyclical athletes were excluded.

Information Sources and Search Strategy

The search was conducted in the electronic bibliographic databases of Web of Science, PubMed, Scopus, The Physiotherapy Evidence Database (PEDro), ScienceDirect, OXFORD, Literatura Latinoamericana y del Caribe en Ciencias de la Salud (LILACS), Taylor & Francis Group, Springer, and SciELO. The following Medical Subjects Heading (MeSH) terms were used: respiratory muscle training, sports, breathing exercises, physical therapy modalities, cardiorespiratory fitness, athletic performance; other terms such as swimming, cycling, rowing, triathlon, canoeing, running, athletics, inline skating, and cross-country skateboarding were also used. All terms used were combined with "AND" and "OR" booleans. The searches were repeated just before the final analyses.

Study Selection

A subgroup analysis was conducted for the primary outcomes according to the following outcomes: aerobic capacity, pulmonary function, and maximal inspiratory pressure.

Data Collection

Four researchers (MIS, SOG, CS, APM and DP) started the filtering process blindly and independently after searching the databases. Each investigator listed studies analyzing their title and abstract. Articles in which there was agreement between the reviewers were included and, if the answer was different, other evaluators (JDA or MA) decided regarding the inclusion of the article, blind to the answers given by the others. The eligibility criteria (inclusion and exclusion) were applied to the full-text analysis during final selection. Any disagreements between authors regarding eligibility, quality, and data retrieved from the studies were resolved by consensus with the other authors. Data were extracted independently using a form generated in Excel, which includes first author and year, type of study, country, sample size, age, objective of the study, description of the evaluation, instrument, IMT protocol, and the results of the intervention with quantitative values (averages, means, standard deviations, and confidence interval).

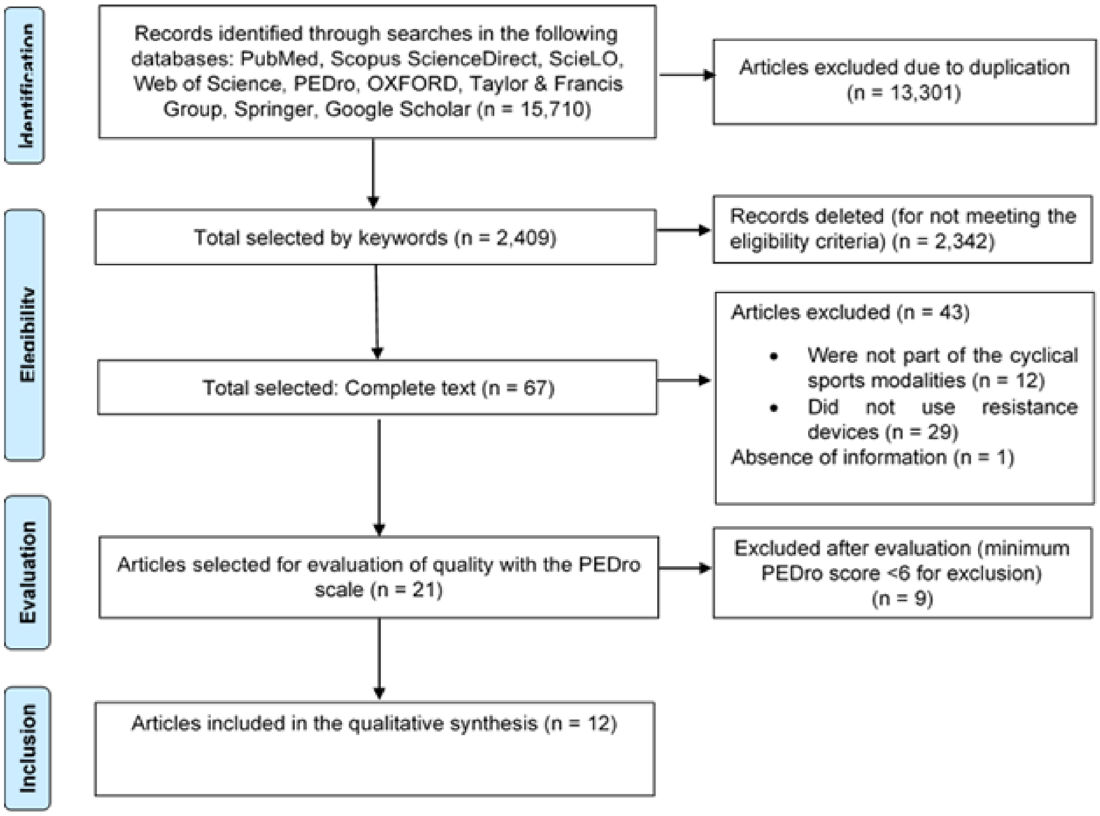
Methodological Quality and Risk of Bias Assessment

The quality of the studies was assessed independently and blindly using the PEDro scale (Moseley et al., 2020). This process was carried out by four evaluators and if at any time consensus is required, the tree evaluators are consulted for the inclusion decision. This scale evaluates random assignment, blinding of random assignment, similarity of participants' baseline characteristics, masking of participants, masking of therapists, masking of evaluators, outcome data in at least 85% of participants for at least one primary outcome, intention-to-treat analysis, statistical comparisons between groups, and point estimates and variability measurements. Studies that obtained a score of ≥ 6 points were included. Study bias was evaluated using the criteria described by the Joanna Briggs Institute (Barker, 2023) used in systematic reviews of experimental studies.

Results

After generating and applying the search strategies in the different databases chosen for this purpose, 15,710 articles were found, of which 12 were included in the quality synthesis, after excluding duplicates or articles that did not meet the inclusion or quality criteria (Figure 1).

Figure 1
Flowchart for Item Selection



Study Characteristics

A total of 240 cyclical athletes who were between 16-36 years of age were pooled from the studies analyzed. The studies presented here included relevant data on pulmonary function, maximum inspiratory pressure and aerobic capacity. Given the nature of the search, most studies evaluated up to four of the concepts stated above, while others evaluated only one. Another aspect to be selected from the study was respiratory muscle training with resistance and threshold devices that showed evident changes and benefits after training. Of the 12 articles reviewed, 11 reported the intensity and exact dosage of the treatment, but one of them did not exactly report the amount of resistance and dosage applied because it varied (Table 2).

Table 2
Study Characteristics

Author	Year/ Country	Population: number of participants per group	Age by group (years)	Sport	Intervention 1	Intervention 2 (Comparison)	Intervention 3	Outcome measures
Williams et al. [12]	2002 USA	G1: 7	20.9 ± 1.2	Running	G1: Powerlung devices, 30 inhalation and exhalation cycles two times a day for 4 weeks. Intensity began at 50%-60% MIP and was progressed by 5% each week. 5–7 sets (4–5 min of loaded breathing) with a 1- to 2-min rest period between each set.	.		- Pulmonary function - MIP - Aerobic capacity

Amonette and Dupler. [13]	2002 Houston, USA	G1: 8 G2: 4	G1: 36.75 ± 8.83 G2: 34.75 ± 7.05	Triathlon	G1: Powerlung device (threshold); 30 cycles, inhalations, twice a day for 4 weeks. (Maximum effort, trial and error)	G2: (CON). Device (false), resistance 15%; 30 inhalations two times a day for 4 weeks. (Sham machine, same instructions)		- Pulmonary function - Aerobic capacity
Holm et al.[14]	2004 Arizona	G1: 10 G2: 4 G3: 6	28 ± 7	Cycling	G1: Device (isocapnic hyperpnea). Experimental group 20 sessions of 45 min	G2: Placebo group (SHAM training (20 sessions of 5 min)	G3: Control group, did not do any training	- Pulmonary function - Aerobic capacity
Wells et al.[15]	2005 Canada	G1: 17 G2: 17	15.6 ± 1.3	Swimming	G1: RMT: + ST. Powerlung device Aprox. 50% MIP. Intensities increase every 3 weeks. 10 breaths min. (3 s/ inspiration: 3 s/ espiration. Total training 12 week	G2: Placebo group SHAM powerlung-RMT+ST		- Pulmonary function - MIP and MEP -Aerobic capacity (Modified rebreathing test)
Griffiths and McConnell [16]	2007 UK	G1: 10 G2: 7	24.9 ± 5.6 28.7 ± 9.1	Rowing	G1: Phase 1: Powerbreathe and Powerlung device pressure threshold loading for IMT. 30 repetitions 2 times a day, for 4 weeks; 50% MIP Phase 2: 6 weeks later, combined IMT/MT 2 times a day, 50% MIP/ MEP	G2: Phase 1: Powerlung device pressure threshold loading only EMT 30 repetitions two times a day, for 4 weeks; 50% MEP Phase 2: Same protocol as the intervention group		- Pulmonary function - MIP and MEP - Aerobic capacity
Mickleborough et al. [17]	2008 USA	G1: 10 G2: 10 G3: 10	18,2 ± 1.6	Swimming	G1: RMT+ST. (RT2 training device) device- Load 80% MIP, 3 times per week, for 12 weeks	G2: SHAM – IMT+ST. Load 30%, 3 times per week, for 12 weeks	G3: Only control (ST), 3 times per week, without IMT for 12 weeks	- Pulmonary function, lung volume measures and DLCO
Forbes et al. [18]	2011 Canada	G1: 9 G2: 12	G1: 23 ± 11 G2: 22 ± 9	Rowing	G1: RMT: 10%, 15% MIP, MEP, of 8–10 repetitions. 10 weeks	G2: SHAM: 10%, 15% PIM, PEM of 8–10 repetitions. 10 weeks		- Pulmonary function - Aerobic capacity
Tong et al. [19]	2016 China	G1: 8 G2: 8	G1:22.8 ± 3.2 G2:22.4 ± 3.9	Running	G1: RU (interval training) + (Power breathe device), 30 inspiratory efforts, two times a day, 6 days a week, for 4 weeks. Endurance 50%, and core muscle training	G2: only interval training		- Pulmonary function - MIP and MEP - Aerobic capacity

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Okrzymowska et al. [20]	2019 Poland	G1: 10 G2: 6	G1:18,20 ± 4,64 G1:18,50 ± 4,97	Swimming	G1: RMT: threshold device, 30-60% MIP, the load increased every week, 5 days per week, 2 times a day, for 8 Weeks. Additionally, ST	G2: Only ST.		- Pulmonary function - MIP and MEP
Gómez-Albareda et al. [21]	2023 Spain	G1: 4 G2: 4	G1: 21.0 ± 2.6 G2: 18.3 ± 1.3	Swimmers	G1: Powerbreathe plus, starts load at 60% MIP increases every 2 weeks, two times a day for 6 weeks. Morning Session in a seated position three sets of 10 repetitions, rest for 30 s. In the afternoon, stimulating core muscles (prone and lateral), 3 sets four repetitions, with 15 inspirations	G2: Powerbreathe Maintained load at 60% of MIP for 6 weeks once daily. Session of three series of 10 repetitions, rest for 30 s in a sitting position. Additional exercises are performed in prone and lateral position without the Powerbreathe		- Previous-Subsequent MIP Measurement - Lactate (aerobic capacity) - T3000 Swimming Performance Test (exercise performance test)
Tan et al. [22]	2023 China	G1:20 G2: 23	G1: 21.21 ± 0.61 G2: 21.26 ± 0.74	Swimmers	G1: Powerbreathe Plus device, session 15–20 min, three series of 30 inhalations, before swimming training, 6 weeks	G2: Regular swimming training regimen on Mondays, Wednesdays, and Fridays		- Swimming performance metrics (exercise performance test) - Function of the inspiratory muscles - Biochemical parameters
Kowalski et al.[23]	2023 USA	G1: 9 G2: 7	G1: 30.2 ± 6.4 G2: 32.5 ± 4.3	Triathletes	G1: (VIH) Intentional vigorous ventilation for up to 30 or 40 min, at intensity of 60%–90% of MVV, little external resistance, every other day with a gradual progression based on session duration and RR. They start with 3 min of exercise with a RR 20, during the first session and 1 min is added with each consecutive session, 6 weeks	G2: (IPTL) Device with a spring-loaded inspiratory valve and an unloaded expiratory flap valve, resistance corresponding to 30%–50% of the MIP, 5 days/week, two times/day, 6 weeks		-Blood markers, subjective measurements, cardiac indices, near-infrared spectroscopy indices - Fatigue of the inspiratory muscles and training load induced by RMT before, during, and after the sessions

Note. Values are expressed as mean ± SE.

Abbreviations: RMT, Respiratory muscle training; IMT, Inspiratory muscle training; EMT, Expiratory muscle training; SHAM, False Respiratory muscle training device; ST, Swimming training week program; MIP: Maximum inspiratory pressure; MEP: Maximum expiratory pressure; DLCO: Diffusion capacity of the Lung; RT2: Device, pressure manometer with infrared. RU: running; VIH, Voluntary isocapnic hyperpnea; IPTL, Inspiratory pressure threshold load; MVV, maximum voluntary ventilation. RR: respiratory rate.

Quality Assessment

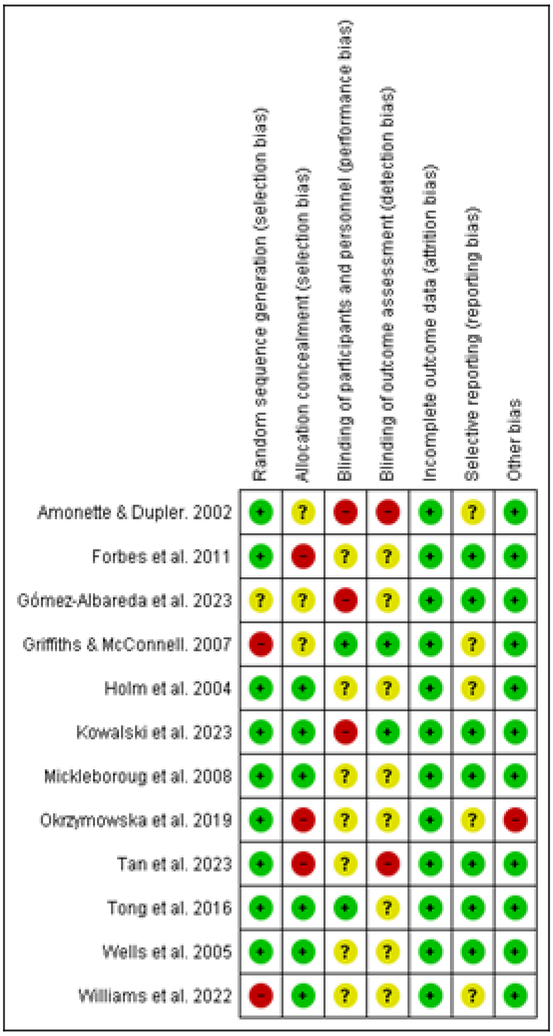
According to the methodological quality evaluated using the PEDro scale, we observed that most of the studies exceeded the minimum limit to be accepted as a study with good methodological quality. Furthermore, the sections where the most shortcomings were evident were associated with blinding of participants, blinding of therapists, blinding of evaluators, and statistical comparisons (Table 3).

Table 3
PEDro Score

Autor / Año	Evaluator 1	Evaluator 2	Evaluator 3	Accord
(Williams et al., 2002)	8	7	7	7
(Amonette & Dupler, 2002)	9	9	9	9
(Holm et al., 2004)	10	10	10	10
(Wells et al., 2005)	10	10	10	10
Griffiths y Mc.Connell. / 2007	7	7	7	7
(Mickleboroug et al., 2008)	7	7	7	7
(Forbes et al., 2011)	8	8	8	8
(Tong et al., 2016)	10	10	10	10
(Okrzymowska et al., 2019)	9	9	9	9
(Gómez-Albareda et al., 2023)	8	8	8	8
(Tan et al., 2023)	10	10	10	10
(Kowalski et al., 2023)	9	9	9	9

Bias Risk Assessment

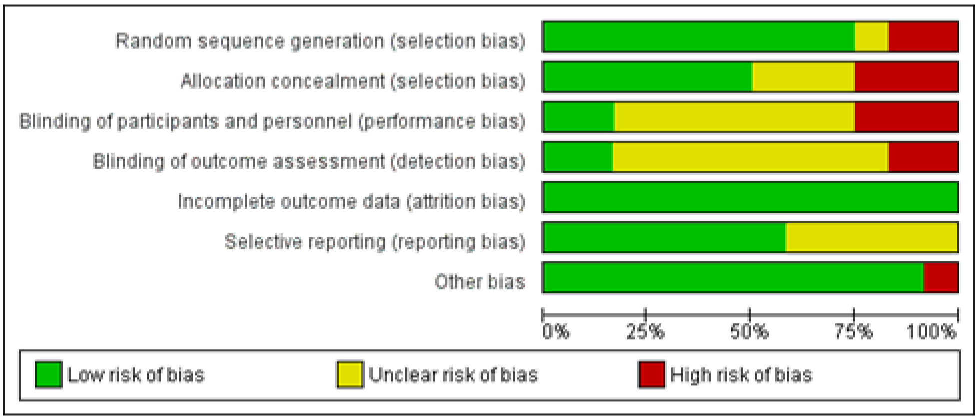
Figure 2
Flowchart Assessmet of Risk of Bias in the Studies Included



The evaluation was performed using the Review Manager software version 5.4 (figures 2 and 3), which shows the risk of bias found in the studies. The analysis showed that most of the studies presented an "unclear" risk of bias in the blinding of participants and personnel and the evaluators in terms of the intervention conducted in the population (athletes), making the application of blinding difficult.

The other guidelines regarding incomplete outcome data, including baseline comparison between experimental groups, treatments, and measurements of the entire event, were performed reliably and comparably, showing a low risk of bias in all the studies. Only one study presented little detail regarding the measurement method that can alter the quality of the data, which showed a high risk in the "other biases" item.

Figure 3
Risk of Bias Summary



Effects on Pulmonary Function

Most of the studies that evaluated lung function did so using the spirometry test to measure air flow. Taking peak expiratory flow (PEF) and forced expiratory volume in 1 s (FEV1) as results, as they were reported by most of the studies it was evident that they presented significant improvements in terms of maximum expiratory flow during forced expiration from maximum inspiration (PEF) and in maximum FEV1, as they were evaluated before and after training. Significant changes were evident in those groups that used resistance devices than those that did not use any device and did not perform IMT.

Effects on Maximum Inspiratory Pressure

Of the 12 studies that were included, 10 evaluated the maximum inspiratory pressure using the maximal inspiratory pressure (MIP) test to mainly evaluate diaphragmatic strength. However, other derived measurements were also used, such as Breathing endurance time (BET), sport- specific endurance plank test, (SEPT), static maximum inspiratory mouth pressure (P0). These tests articulate the measurement of strength and resistance of the respiratory muscles useful to understand respiratory muscle performance.

The majority presented perceptible improvements after training, and the MIP increased significantly in those sports that required more training of the inspiratory muscles after the first intake such as swimming, rowing, and athletics.

Effects on Aerobic Capacity

Of the 12 studies evaluated, four evaluated aerobic capacity and reported significant improvements in Maximal oxygen uptake (VO2max) only three of them, showing as a common characteristic that training and the different interventions focused on EMR that include a minimum of four weeks of training at least six days a week and additionally add strengthening the core muscles, present important effects on cardiorespiratory performance, thus also improving performance in sports such as cycling, swimming and running. The results of the three effects studied in this systematic review are presented in table 4.

Table 4
Effects on Pulmonary Function, Maximum Inspiratory Pressure and Aerobic Capacity

Author/ Sport	Effects on pulmonary function			Effects on maximum inspiratory and expiratory pressure		Effects on aerobic capacity		
	G1	***G2***	***G3***	***G1***	***G2***	***Test***	**G1**	**G2**
Williams et al., (2002). Running				MIP: (cmH2O) respiratory muscle strength and endurance were significantly improved) after IMT in this study. BET: Increased significantly (*P* ≤ .05) (31% & 128) compared with pretraining values		Resistance exercise test	Peak VO2 Before: 53.1 ± 9.6 After: 53.3 ± 11.9 No significant differences between pre and post values were detected in during the endurance run as measured at steady state and end of the test after IMT.	
Amonette and Dupler (2002). Triathlon	FEV1: Mean before: 3.77 ± 0.16 Mean after: 3.77 ± 0.15 Change: 0.00%	FEV1: Mean before: 3.68 ± 0.28 Mean after: 3.71 ± 0.30 Change: 0.82%		NR		CPET on cycle ergometer	Peak VO2: Not changes	Peak VO2 Not changes
Holm et al., (2004). Cycling	Sustainable ventilatory capacity(L/min) Increased significantly after training in the RMET group. VE(L)group showed a significant increase in VE after training	Not changes Not changes		Not changes Not changes		CPET on cycle ergometer Time trial time (min)	Peak VO2 (L·min−1) pre-training: 54.0 ± 4.7 RMET-post training: 55.5 ± 4.9 Before: 47.1 ± 5.5 After: 44.9 ± 5.5	Peak VO2 (L·min−1) Control/ Placebo-pre-training: 56.8 ± 3.9 Control/ Placebo-post training: 55.9 ± 7 Before: 42.9 ± 3.2 After: 43.0 ± 3.9

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Wells et al., (2005). Swimming	FEV1: Before: 3.2 ± 0.4 3.7 ± 0.4* After: 4.7 ± 1.0* 4.3 ± 0.8 Experimental group demonstrated a significant 16% increase in FIV1.0 from T1 to T3 (*P* = .050)	FEV1: Before: 3.2 ± 0.2 4.1 ± 0.6* 4.2 ± 0.4* After: 3.7 ± 0.9 5.0 ± 1.1* 4.9 ± 0.3*		MIP: (cmH2O) Female: Before: 105.7 ± 22.2 After: 120.6 ± 12.4 Male: Before: 144.8 ± 28.3 After: 151.1 ± 17.4 MEP: (cmH2O) Female: Before: 137.5 ± 26.2 After: 137.5 ± 26.2 Male: Before: 173.4±16.2 After: 172.0 ± 5.5	MIP: (cmH2O) Female: Before: 115.7 ± 20.7 After: 130.1 ± 15.4 Male: Before: 141.9 ± 21.4 After: 146.4±18.3 MEP: (cmH2O) Female: Before: 133.2 ± 33.8 After: 156.4 ± 18.2 Male: Before: 179.2 ± 12.8 After: 176.5 ± 5.6		Vcrit: (m s-1)	Female: Before: 0.49 ± 0.06 After: 130.1±15.4 1.54 ± 0.10 Males not changes	Not changes
Griffiths and McConnell (2007). Rowing	NR			MIP Before: 129.1 ± 16.5 After: 168.3 ± 31.2	MIP Before: 138.6 ± 27.4 After: 156.7 ± 29.7				
Mickleborough et al., (2008). Swimming	FEV1: Before: 4.87 ± 0.84 After: 5.52 ± 0.97 DLCO (mL min-1 mmHg-1): Before: 35.23 ± 6.4 After: 39.83 ± 7.1	FEV1: Before: 4.96 ±0.88 After: 5.59 ± 0.93 DLCO (mL min-1 mmHg-1): Before: 34.79 ± 7.4 After: 38.69 ± 7.9	FFEV1: Before: 4 .94 ± 0.76 After: 5.49 ± 0.84 DLCO (mL min-1 mmHg-1): Before: 34.76 ± 6.1 After: 37.85 ± 6.5	MIP (cmH2O) Before: 174.4 ± 23.2 After: 255.5 ± 23.8 MEP (cmH2O) Before: 156.7 ± 31.4 After: 219.6 ± 26.4	MIP (cmH2O) Before: 181.6 ± 27.3 After: 245.9 ± 31.8 MEP (cmH2O) Before: 163.4 ± 37.3 After: 227.6 ± 35.4	MIP (cmH2O) Before: 184.6 ± 33.2 After: 242.2 ± 24.2 MEP (cmH2O) Before: 152.7 ± 29.6 After: 221.5 ± 32.4			

Forbes et al., (2011). Rowing	PEF (Lxmin −1) Before: 5.10 ± 144 After: 5.60 ± 1.37 BF (breaths·min−1) Before: 55.8 ± 8 After: 59.2± 8.9 VT (ml·breath−1) Before: 2.06 ± 0.34 After: 2.31± 0.46 VE (L·min−1) Before: 113.7 ± 19.1 After: 135.2 ± 25.5*	PEF (Lxmin −1) Before: 4.60 ± 1.01 After: 5.13 ± 1.20 BF (breaths·min−1) Before: 56.6 ± 5.9 After: 60.9 ± 8.8 VT (ml·breath−1) Before: 2.37± 0.60 After: 2.46± 0.57 VE (L·min−1) Before: 134.1 ± 36.5 After: 148.5 ± 36.6	Increases of 18% in resting MIP and 45.5% in resting MEP with RMT	Not Changes	Rowing performance test Bench press (kg) Leg press (kg) 2000 m race (sec)	Peak VO2 (L·min−1) Before: 3.00 ± 0.59 After: 3.19 ± 0.63 Before: 49.2 ± 22.6 After: 57.5 ± 23.6 Before: 205.4 ± 107.7 After: 268.2 ± 108.8 Before: 505.1 ± 44.3 After :479.0 ± 35.8	Peak VO2 (L·min−1) Before: 3.49±0.88 After: 3.58±0.77 Before: 57.6 ± 22.8 After: :65.7 ± 23.9 Before: 218.8 ± 71.1 After: 263.0 ± 75.3 Before: 472.1 ± 42.0 After :452.2 ± 32.7
Tong et al., (2016). Running			P0 (cmH2O) Before: 156.4 6 15.1 After: 189.5† 6 11.8 SEPT (s) Before: 287.3 6 130.4 After: 317.4† 6 122.2	P0 (cmH2O) Before: 145.5 After: 179.2† 6 14.7 SEPT (s) Before: 305.8 6 135.0 After: 330.0† 6 150.7	OBLA 1-hour treadmill run (kmxh1)	Before: 14.3 ± 6 1.8 after: 15.0 ± 6 2.1 Before: 11.9 6 1.4 after: 13.21 6 1.47	Before: 14.2 6 1.8 after: 14.8† 6 1.5 Before: 12.4 6 1.7 after: 13.10 6 1.52
Okrzymowska et al., (2019). Swimming	PEF (Lxmin −1) Before: 5.19 ± 2.03 After: 5.73 ± 1.87 FEV1 Before: 2.86 ± 0.98 After: 3.12 ± 1.01	PEF (Lxmin −1) Before: 5.51 ± 3.11 After: 7.49 ± 1.34 FEV1 Before: 3.02 ± 1.29 After: 4.05 ± 0.71	MIP (cmH2O) Before: 41.0 ± 2.26 After: 56.6 ± 2.42	MIP (cmH2O) Before: 61.44 ± 19.72 After: 94.38 ± 23.48			

Gómez-Albareda et al., **(**2023). Swimmers			MIP: Mean before: 132.75 (27.42) Mean after: 156.75 (21.88)	MIP: mean before 149.25 (22.82) Mean after: 171.50 (23.74)	T3000 swimmer performance time Lactate 1 mmol.L −1 Lactate 5 mmol.L −1 Lactate (mM)	Not changes Not changes Not changes Not changes	Not changes Not changes Not changes Not changes
Tan et al.; **(**2023). Swimmers	PIF: Mean before: ± 5.97 ± 0.84 Mean after: ± 8.52 ± 0.83 VC: Before 4483.42 ± 673.12 After: 5048.48 ± 651.88. (p < .01) MIC: Mean before: 5.97 ± 0.84 Mean after: 8.52 ± 0.83	PIF: Mean before: ± 6.51 ± 0,89 Mean after: 7.54 ± 0.99 VC: Not changes MIC: Mean before: 2.08 ± 0.76 Mean after: 3.34 ± 0.80 (p < .01)	MIP before: 117.70 ± 14.83 MIP after: 162.87 ± 10.77 (*p* < .01)	MIP before: 126.61 ± 20.69 MIP after: 144.19 ± 16.14. (*p* = .05)	Freestyle swimming for 50 m Number of breaths in the 50 m of freestyle swimming Distance before taking the first breath in freestyle swimming 100 m freestyle swimming time	Before: 39.6 s After: 5.4 s (*p* = .0018) Before: 11.45 After: 7.85 (*p* = .006) Before: 27 m After: 30.95 m (*p* = .013) Before: 112.25 s After: 102.3 s (*p* = .004).	Before: 42 s After: 40.4 s (*p* = .28) Before: 15.73 After: 15.75 (*p* = .99) Before: 31.34 m After: 29.25 m (p = .39), Before: 121.47 After: 114.65 s (*p* = .203)
Kowalski et al., (2023). Triathletes	S_INDEX Before: M:1.64 (12.30) *F*: −2.17 (4.50) After: M: 1.57 (5.84) *F*: 4.63 (8.77)	S_INDEX Before: M: 4.15 (7.22) *F*: 2.21 (4.63) After: M: 3.03 (4.06) *F*: 2.97 (4.19)	NR		NIRS: local muscle oxygenation (SmO_2)	SmO_2: vastus lateralis muscle: Before: 8.82 (24.40) After: −5.67 (17.24) SmO_2: internal intercostal muscles: Before: 31.71 (16.48) After: −22.33 (4.62)	SmO_2: vastus lateralis muscle: Before: 10.47 (28.31) After: 7.75 (9.64) SmO2: internal intercostal muscles. Before: 6.65 (27.7) After: 12.75 (12.18)

Note. Values are expressed as mean ± SE

Abbreviations: PEF: Peak Expiratory Flow; FEV1, forced expiratory volume in 1 s, PIM: :Peak inspiratory Flow VC: Vital capacity; MIC :Maximal Inspiratory Capacity; S_INDEX: is a dynamic spirometry assessment used to evaluate inspiratory muscle strength, PCPE: Prueba cardiopulmonar de ejercicio NIRS: Near infrared spectroscopy SmO2: Oxigenación muscular Total, VO2 max; maximum oxygen uptake , Bf = breathing frequency; VT = tidal volume; VE = minute ventilation; VE: pulmonary ventilation rate (VE) as a function of the % endurance time during the constant work-rate exercise test. Vcrit: critical speed; BET: Breathing endurance time; SEPT: sport- specific endurance plank test, OBLA: The onset of blood lactate accumulation, P0 = static maximum inspiratory mouth pressure NR not report.

Discussion

The objective of this systematic review was to identify the effects of IMT in cyclical sports. After a detailed analysis of the 12 articles selected in the review, a total of 240 subjects were addressed. IMT is reported to be useful to improve physical function related to favorable results in pulmonary function, maximum inspiratory pressure, and aerobic capacity, becoming a useful complement for training in high-performance athletes.

The effects of IMT in the field of health and sports performance are supported by extensive scientific literature that shows how this intervention positively influences respiratory muscle fatigue that limits performance through metaboreflex, i.e., the accumulation of metabolites such as lactate which, given the impossibility of sufficient clearance due to the intense muscular demand, promotes peripheral vasoconstriction through the sympathetic nervous system. This vasoconstriction limits the ability of peripheral muscles to maintain physical effort during activity (Nunes Júnior et al., 2018).

Among the measures used in the studies, the majority included evaluation of pulmonary function, followed by the measurement of inspiratory muscle strength with MIP and aerobic capacity through specific exercise tests. The studies selected show the benefits of training in these measures and therefore place IMT as a strategy that can improve sports performance in athletes in general and specifically in the cyclical modalities addressed in this systematic review (Griffiths & McConnell, 2007).

The literature review identified gaps that could guide and solidify future related studies, such as evaluating in more detail the functioning of the inspiratory muscles in cyclical sports modalities while in competition, as well as conducting studies that include the training of the muscles in general in combination with the respiratory muscles and compare whether a joint intervention obtains better results.

The benefits reported in the scientific articles mainly include the contribution of the intervention to the improvement of spirometric variables (Forbes et al., 2011), respiratory muscle strength (Okrzymowska et al., 2019), and cardiopulmonary resistance (Mickleborough et al., 2008) in population groups of various age ranges, with a general average of 28 years (Holm et al., 2004), including > 40-year-old adults (Amonette & Dupler, 2002). Improvement in lung function was seen most frequently in rowing, track racing, marathon, and swimming athletes (Tong et al., 2016). In this sense, studies such as that of Holm et al. (2004) suggest that IMT through pressure threshold loading and voluntary isocapnic hyperactivity may be effective in improving resistance exercise capacity during moderately intense physical activity (60%–75% VO2 max) in athletes. The main methodological problems found in this review are related to the unblinded assignment to groups and the blinding of subjects, researchers, and evaluators. These factors should be considered in future studies to achieve higher quality.

Comparison With Literature and Practical Implications

Forbes et al. (2011) examined the inspiratory and expiratory resistive load and combined it with strength and resistance training performance in rowing athletes, where they were divided into two groups: one group using an inspiratory and expiratory resistance device and a second group using a sham device (threshold device, Pflex type) or control, with a training duration of 10 weeks, six times or days each week, divided into training of strength and endurance, 3 days each. Both groups had considerable results in improving respiratory capacity, but it was inconclusive in relation to the improvement of the sporting capabilities of rowing athletes (Griffiths & McConnell, 2007).

On the other hand, IMT has also provided favorable effects in acyclic sports, characterized by very specific movement patterns that require changes in direction in speed and specific skills such as the ability to repeat accelerations (Antonelli et al., 2020; Barker et al., 2023; De Sousa et al., 2021). The particularity of this type of sports is based on the recovery time between efforts, which could be one of the causes that justify these significant increases in performance with IMT. Perception of a lower work rate and a lower sensation of lack of air by the athletes allows them to either recover after the previous effort and perform again or increase performance in subsequent actions. Two studies observed these effects, that of Archiza et al. (2018), which evaluated performance between different sprints, improving performance by approximately 30%, and that of Tong et al. (2010), who found that athletes who underwent IMT could perform each sprint at a faster speed than the control group. Furthermore, some studies show that a reduction in dyspnea related to IMT is directly related to improved performance in badminton players (Chuanye & Hua, 2010). In short, if athletes perceive a lower sensation of dyspnea, they will be able to perform efforts with a shorter recovery margin or, on the contrary, perform continuous efforts at a higher speed. Either case represents a competitive advantage.

Other studies have found positive impacts of IMT on sports performance or skills specific to sports, especially on respiratory capacity during training, in sports such as swimming (Mickleborough et al., 2008; Okrzymowska et al., 2019; Wells et al., 2005), cycling (Holm et al., 2004), and athletics (Brown & Kilding, 2011; Tong et al., 2016; Williams et al., 2002). In studies, it is common for training to last between 10 and 13 weeks, interspersed with muscle strength and resistance training in each of the sports. In particular, in sports such as athletics, disciplines such as long-distance running or race running, sporting skills were improved in terms of both resistance and economy of effort, indicating that there was a reduction in reported fatigue. Studies also support that exercising the muscles at low loads as a warm-up protocol is sufficient to show improvements in the performance of active subjects who perform activities such as running (Manchado-Gobatto et al., 2022). Additionally, innovative studies have shown that local oxygenation through near-infrared spectroscopy tends to increase during the IMT session after 6 weeks. However, inspiratory pressure threshold load was associated with an imbalance in blood gas, increased lactate levels, and reports of headaches and dizziness. Therefore, further investigation of its effects is suggested (Kowalski et al., 2023).

As previously stated in the quality and risk of bias criteria analyzed in the scientific evidence collected, it can be deduced that the results can be extrapolated to other high-performance athletes, since the technique is highly reproducible and safe, concluding that this tool has demonstrated not only improvements in outcomes such as lung function and muscle strength, but also in sports performance, justified in different time trials. It is important to note that experimental studies with this intervention present some limitations in blinding and random selection, although in a low proportion of the investigations, a condition that can be explained in some contexts by the difficulty attributable to the sample size and the intervention methodology.

It is worth highlighting that elite athlete who generate high income for clubs could weigh up the investments in these devices and the specialized personnel required for their prescription, which implies that it is a cost-effective intervention. However, this type of muscle training is not routinely performed and we believe that systematic reviews such as this one demonstrates the "research gap" that motivates us to continue researching the type of training adjusted to the requirements of each sport modality. In addition, it is necessary to develop research related to the economic evaluation of this intervention.

Based on the above, it is important to include this intervention focused on strengthening the inspiratory muscles in the microcycle training of cyclic sport athletes. This intervention has an evident influence on sports performance given the reduction of fatigue during physical effort, which implies new practical perspectives for physiotherapy at the service of body movement related to health.

Contextual factors are related to aspects of sports competition, training, and the family and social environment, which directly and indirectly influence the athlete's practice and motivation (Cahill & MacNamara, 2024). In this sense, the studies included in our systematic review were carried out in developed countries that are considered world powers in sport, which could imply differential opportunities for access to this intervention.

Conclusions

The prescription of IMT is an effective method for improving the performance and cardiopulmonary function of cyclical athletes. IMT has effects on increasing pulmonary function, maximum inspiratory pressure, and aerobic capacity, becoming a complementary intervention to enhance sports performance in cyclical sports. It is necessary to continue increasing scientific evidence on this topic, including other sports or physical activities.

The field of action studied in this systematic review has been scarcely explored from the respiratory physiotherapy perspective, and it could be implemented together with conventional physiotherapy in cyclical sports to generate a positive impact on sports performance, framing the importance of the study in the field of this profession.

Ethics Committee Statement

Ethical considerations are associated with research with human beings or animals generally, where the researcher must respect ethical and legal principles, therefore it does not apply to this systematic review.

Conflict of Interest Statement

The authors certify that there is no conflict of interest with any financial organization regarding the material discussed in the manuscript.

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Authors' Contribution

Conceptualization M.I.S., S.L.O.G. & J.E.D.A.; Methodology J.E.D.A. & M.A.R.S.; Software J.E.D.A. & M.A.R.S.; Validation D.P.G. & A.P.M.M.; Formal Analysis M.I.S. & S.L.O.G.; Investigation J.E.D.A., M.A.R.S. & C.S.E.; Resources M.A.R.S; Data Curation D.P.G., A.P.M.M. & C.S.E.; Writing – Original Draft M.I.S. & S.L.O.G.; Writing – Review & Editing J.E.D.A. & M.A.R.S.; Visualization M.A.R.S; Supervision J.E.D.A.; Project Administration J.E.D.A.; Funding Acquisition M.A.R.S. All authors have read and agreed to the published version of the manuscript.

Data Availability Statement

The data that support the findings of this study are available on request from the corresponding author (maria.rodriguez10@usc.edu.co).

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