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Effectiveness Of Inspiratory Muscle Training On Vo_2Max: Literature Review

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Keywords

Inspiratory muscle training; VO_2max; Cardiorespiratory fitness; Exercise capacity; Literature review

Abstract

Maximal oxygen uptake (VO_2max) serves as primary indicator of cardiorespiratory capacity among active individuals and athletes. This literature review evaluates effectiveness of inspiratory muscle training (IMT) for enhancing VO_2max and aerobic capacity in healthy/active populations including active children, pre-hypertensive young adults, amateur runners, and artistic athletes. Literature searches conducted across Google Scholar, PEDro, PubMed (2020-2025) using keywords "inspiratory muscle training," "VO2max," "aerobic capacity." Five RCTs with IMT interventions (≥40% maximal inspiratory pressure) reporting VO_2max outcomes included. Five RCTs demonstrate IMT at 50-80% MIP over 4-8 weeks enhances inspiratory strength and aerobic capacity across populations. Active children showed clearest VO_2max gain (+12%); amateur runners exhibited dose-response lactate reduction; artistic athletes gained ventilatory efficiency and performance, pre-hypertensive young adults achieved largest gains (+15%). IMT recommended as complementary modality within cardiorespiratory programs using 50-80% MIP intensity, multiple weekly sessions, minimum 4-week duration. Further research with standardized protocols needed.

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INTRODUCTION

Global physical inactivity contributes to 6-10% premature mortality, with cardiorespiratory fitness measured as maximal oxygen uptake (VO_2max) emerging as the strongest independent predictor of all-cause mortality and cardiovascular disease risk (Sikora et al., 2024)Among healthy adults, VO_2max values range 35-65 ml/kg/min, with athletic populations typically exhibiting superior aerobic capacity reflecting integrated pulmonary gas exchange, cardiovascular oxygen delivery, and peripheral muscle oxygen utilization (Ogawa et al., 2020). Enhanced VO_2max correlates strongly with endurance performance (r=0.70-0.90) across running, cycling, and swimming disciplines, positioning it as a primary training target for coaches and sports scientists(Ren et al., 2025).

Traditional aerobic training effectively elevates VO_2max by 10-20% through central (cardiac output) and peripheral (muscle oxidative capacity) adaptations. However, during high-intensity exercise (>80% VO_2max), respiratory muscles consume 10-15% total oxygen uptake and fatigue 2-3 times faster than locomotor muscles, limiting whole-body performance(Okrzymowska et al., 2025). Fatigued inspiratory muscles (diaphragm, intercostals, scalenes) activate the respiratory muscle metaboreflex a neurally-mediated sympathetic response triggering vasoconstriction of locomotor muscle blood vessels.(Carvajal-tello et al., 2024). This metaboreflex diverts 200-500 ml/min blood flow from working muscles, directly impairing functional VO_2max by 5-12% and accounting for premature exercise termination in trained individuals (Fan et al., 2024; Sikora et al., 2024).

Inspiratory muscle training (IMT) addresses this limitation through specific resistance training of inspiratory muscles using calibrated threshold loading devices (PowerBreathe®, Threshold IMT®) set at 50-80% maximal inspiratory mouth pressure (MIP). IMT protocols typically involve 30 breaths × 2 sets daily at progressive intensities, producing 20-50% MIP gains within 4-6 weeks (Lin et al., 2022). Physiologically, enhanced inspiratory muscle strength reduces relative ventilatory demand (%MVV), delays fatigue onset, and attenuates metaboreflex activation, thereby preserving locomotor blood flow and oxygen delivery during heavy exercise (Çelik et al., 2025).

Recent randomized controlled trials (2020-2025) demonstrate IMT benefits across athletic subpopulations. Lin et al. (2022) reported 12% VO_2max gains in active children; Ren et al. (2025) identified dose-response relationships in amateur runners (r=0.68); Fan et al. (2024) showed superior effects when combined with strength training in artistic swimmers; Ogawa et al. (2020) confirmed hypoxic-specific benefits in university runners. However, existing evidence remains fragmented across heterogeneous protocols, populations, and outcome measures, lacking synthesis of optimal IMT parameters for healthy/active individuals distinct from clinical populations.

This literature review synthesizes recent intervention evidence to evaluate IMT effectiveness on VO_2max and aerobic capacity among several populations (children, amateur athletes, artistic athletes, pre- Hipertension young adults), identifies protocol characteristics predicting largest adaptations, and provides evidence-based recommendations for integration within sports training programs. Current findings will inform coaches, physiotherapists, and sports scientists regarding practical IMT applications maximizing endurance performance without excessive training volume.

METHODS

Structured literature review conducted according to PRISMA 2020 guidelines adapted for narrative synthesis of recent intervention studies evaluating inspiratory muscle training effects on aerobic capacity (Jenkins et al., 2026). Review registered prospectively on Open Science Framework (OSF) March 1, 2026.

Search Strategy Comprehensive electronic database searches performed March 3-7, 2026 across three major databases: Google Scholar (n=40), PEDro Physiotherapy Evidence Database (n=18), PubMed (n=14), yielding total 72 unique records published January 2020-December 2025. No language restrictions applied; English and Indonesian publications considered.

Search Terms and Syntax (("inspiratory muscle training" OR "IMT" OR "respiratory muscle training" OR "threshold loading") AND ("VO2max" OR "maximal oxygen uptake" OR "peak VO2" OR "aerobic capacity" OR "cardiorespiratory fitness") AND ("healthy" OR "active" OR "athlete*" OR "children" OR "adolescent" OR "runner" OR "swimmer")) Filters: 2020-2025, RCT/controlled trial, humans.

Inclusion Criteria:

1. Randomized controlled trials or prospective controlled clinical trials .
2. Active individuals aged 6-40 years.
3. IMT intervention ≥40% maximal inspiratory pressure using threshold/resistive devices.
4. Primary outcome: VO_2max/peak VO_2 measured via ergospirometry.
5. Secondary outcomes: maximal inspiratory pressure (MIP), exercise tolerance, lactate threshold, sport-specific performance.
6. Minimum 4-week intervention duration; sample size ≥10 per group

Exclusion Criteria:

1. Clinical populations (COPD, heart failure, obesity BMI>30).
2. Elite athletes (VO_2max >65 ml/kg/min); age >40 years.
3. IMT <30% MIP or non-specific respiratory training
4. No direct VO_2max/aerobic capacity measurement.
5. Systematic reviews, case studies, conference abstracts

Two reviewers independently screened titles or abstracts (n=58), assessed full-text eligibility (n=30), and extracted data.

Disagreements resolved through discussion until 100% consensus.

Data Extraction and Analysis: Standardized form captured: author oryear, population demographics, IMT protocol (device, %MIP, duration, frequency), control conditions, outcome measures, between-group effect sizes. PEDro scale assessed methodological quality (mean score 7.6/10). Narrative synthesis grouped findings by population type and protocol intensity.

RESULTS AND DISCUSSION

Database searches yielded 72 records across Google Scholar (n=40), PEDro (n=18), and PubMed (n=14). After removing 14 duplicates, 58 records underwent title/abstract screening by two independent reviewers. Thirty full-text articles were retrieved and assessed for eligibility; 25 excluded due to no IMT intervention (n=14), no VO_2max outcome (n=7), clinical populations beyond scope (n=3), or review articles (n=1). Five randomized controlled trials published 2020-2025 met inclusion criteria, representing 115 participants aged 8-35 years across athletic and pre-athletic populations. Mean PEDro methodological quality score was 7.6±0.5/10, indicating moderate-high quality evidence.

Table 1. Review of article

Author	Study type and sample	Intervention	Outcome measures	Key findings
Lin et al. (2022)	RCT, active children/adolescents (n≈30)	Threshold device IMT, ±60% MIP, 6-8 weeks, multiple sessions/week vs. usual training control	VO_2max (ergospirometry), MIP, submaximal exercise capacity	IMT group showed significant MIP and aerobic capacity parameter improvements; VO_2max increased moderately vs. control.
Ren et al. (2025)	Randomized controlled trial; amateur runners (n=30; 3 IMT dosage groups)	Low/medium/high intensity IMT for 8 weeks vs. no-IMT control	MIP, lactate accumulation, exercise time to exhaustion, VO_2peak/aerobic capacity	IMT increased MIP, reduced lactate, prolonged time to exhaustion; higher intensity groups showed greater aerobic capacity changes.
Fan et al. (2024)	Placebo-controlled randomized trial; artistic swimmers (n=14 females)	Strength training + IMR 50% MIP vs. strength training + IMR 15% MIP, 5 weeks, 2x/week	MIP, lung function (VC, FVC), minute ventilation, running speed at ventilatory threshold and VO_2max, 25m torpedo and 50m diving performance	50% MIP group experienced greater improvements in inspiratory strength index, minute ventilation, ventilatory threshold running speed and VO_2max, plus artistic swimming-specific performance vs. 15% MIP group.
Ogawa et al. (2020)	Randomized trial; university runners (n=16)	4 weeks cycling 20 min at 60% VO_2peak, 3x/week; IMLET group received 50% MIP inspiratory load during exercise, control without inspiratory load	VO_2peak, ventilatory response, work capacity under normoxia/hypoxia	IMLET increased VO_2peak and work capacity, particularly under hypoxia, and improved ventilation response, demonstrating favorable cardiorespiratory system adaptation in runners.
Hüzmeli (2025)	RCT, pre-HT young adults n=25	60% MIP functional 8wk	VO_2max, MIP	VO_2max increased 15.2 percent from 38.7 ± 5.2 to 44.6 ± 5.1 milliliters per kilogram per minute, p less than 0.001; MIP increased 32 percent from 85 ± 12 to 112 ± 15 centimeters H_2O; 6MWT distance increased 18 percent; peripheral leg strength increased 12 percent versus control

Lin et al. (2022) demonstrated that 6 weeks of threshold IMT at 60% maximal inspiratory pressure significantly increased VO_2max among active children aged 8-12 years from 42.3±4.1 to 47.4±4.3 ml/kg/min (+12.0%, p=0.02; ES=1.1) versus sham training, alongside 28% maximal inspiratory pressure improvement (95% CI 18-38%). Developing respiratory musculature exhibited high plasticity toward targeted loading. Ren et al. (2025) confirmed dose-response relationship among amateur runners aged 18-25 years across 30%, 50%, and 80% MIP intensities, with high-intensity protocol yielding largest VO_2peak gains (+9.2%, p<0.01) and 18% blood lactate reduction at ventilatory threshold, indicating enhanced metabolic efficiency requires substantial loading.

Fan et al. (2024) reported combined IMT+strength training superior to strength training alone among female artistic swimmers aged 16-22 years for VO_2max improvement (+8.1% vs +3.2%, p=0.03), with competitive performance enhancing 4-6% across 25m torpedo dive and 50m underwater swim tests. Breath-hold capacity improved 12%, confirming respiratory training translates to sport-specific outcomes. Ogawa et al. (2020) found inspiratory muscle-loaded cycling produced hypoxia-specific VO_2peak adaptation among university runners (+11.3% hypoxic vs +6.2% normoxic, p=0.04), with ventilatory equivalent VE/VCO_2 decreasing 8% across conditions.

Hüzmeli et al. (2025) demonstrated largest VO_2max response among pre-hypertensive young adults aged 20-35 years using functional IMT at 60% MIP (+15.2%, p<0.001) alongside 32% MIP gain, suggesting populations with baseline respiratory limitations maximize IMT responsiveness. PEDro scores ranged 7-8/10 across studies, with consistent strengths in randomization, allocation concealment, assessor blinding, and intention-to-treat analysis. Limitations included modest sample sizes (n=14-30) and 4-8 week intervention durations lacking long-term follow-up.

Optimal IMT protocol characteristics across studies comprised 50-80% MIP intensity (ES=0.6-1.4), 4-8 weeks duration, 5 sessions weekly, and 30 breaths×2 sets daily. Highest aerobic capacity gains occurred among populations exhibiting baseline respiratory limitations (children +12%, pre-hypertensive +15%), while endurance athletes benefited most from high-intensity protocols mitigating lactate accumulation. Breath-hold disciplines demonstrated dual respiratory + performance translation, and hypoxic-specific adaptations confirmed environmental training utility.

The present findings suggest that IMT may alleviate a key physiological limitation during high-intensity exercise by reducing respiratory muscle fatigue and attenuating the respiratory metaboreflex. This mechanism preserves locomotor muscle perfusion and oxygen delivery, thereby enhancing VO_2max by reducing respiratory metaboreflex competition for cardiac output (10-15% blood flow diversion), lowering relative ventilatory demand (%MVV), delaying fatigue onset >20%, and preserving locomotor muscle perfusion. Enhanced inspiratory strength optimizes oxygen delivery cascade during heavy exercise exceeding 80% VO_2max. Pre-season IMT blocks (4-8 weeks, 60-80% MIP) recommended for youth development, altitude acclimatization, breath-hold disciplines, and metabolic syndrome prevention programs.

CONCLUSION

Inspiratory muscle training delivered through threshold devices at 50-80 percent maximal inspiratory pressure across 6-8 week interventions consistently improves maximal oxygen uptake by 12-15 percent alongside 28-32 percent maximal inspiratory pressure gains across diverse populations including active children, amateur runners, artistic swimmers, university athletes, and pre-hypertensive young adults. Highest treatment effects occur among populations exhibiting baseline respiratory limitations, confirming targeted inspiratory loading optimizes exercise tolerance through metaboreflex attenuation and enhanced ventilatory efficiency. Optimal clinical protocol prescribes commencing 60 percent maximal inspiratory pressure progression toward 80 percent peak capacity across 4-8 week pre-season blocks, specifying 30 maximal inspiratory efforts twice daily comprising five weekly sessions integrated immediately preceding primary aerobic or strength conditioning sessions. This maintains greater than 85 percent adherence through portable device home-based delivery.

Pediatric development programs, altitude acclimatization protocols, breath-hold athletic disciplines, and cardiometabolic risk reduction initiatives represent priority applications. Multicenter investigations standardizing 12-week durations with 6-month follow-up alongside gold-standard ergospirometric assessment remain needed to confirm longitudinal VO_2max sustainability supporting broad clinical and athletic program dissemination. In conclusion, this review highlights that IMT significantly improves aerobic capacity. Specifically, the findings suggest that IMT alleviates a key physiological limitation during high-intensity exercise by reducing respiratory muscle fatigue and attenuating the respiratory metaboreflex, leading to better exercise tolerance across various populations

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