The misuse of respiratory resistive loading during aerobic exercises: revisiting mechanisms of "standalone" inspiratory muscle training

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Introduction

The application of "standalone" respiratory muscle training (RMT) to clinical and athletic populations is now supported by a plethora of systematic reviews and meta-analyses supporting its benefits (1). The most commonly applied method of RMT adopts the principles of strength training, whereby brief bouts of moderate intensity respiratory loading (40 to 60% of maximal strength) are applied, resulting variously in improvements in respiratory muscle strength, power, shortening velocity and endurance (2). Among RMT modalities, inspiratory muscle training (IMT) is the most commonly employed method for healthy (1,3) and clinical (4,5) populations. A typical IMT intervention consists in breathing against an inspiratory load (IRL), twice daily, for five to seven days per week, for four to twelve weeks (3,4,5). Recently, a high-intensity inspiratory muscle strength training (IMST) protocol that required 30 breaths (~5 minutes) per session, for 5 to 7 days (25–35 total minutes) per week for 6 weeks, reduced resting blood pressure in young healthy adults (6), in midlife/older adults (7), and older adults with obstructive sleep apnoea (OSA) (8). Behind its mechanisms, IMST improved endothelial function, NO bioavailability, and oxidative stress (7), and reduced muscle sympathetic nerve activity (8).

IMT has been included as a component of exercise-based cardiopulmonary rehabilitation programmes. Indeed, randomized controlled trials (RCTs) suggested an additive effect of inspiratory muscle training (IMT) and aerobic exercise (AE) training in chronic heart failure (CHF) and chronic obstructive pulmonary diseases (COPD) if conducted in independent sessions (9,10). IMT plus AE training improved cardiorespiratory responses to exercise in CHF (9) while providing additional gains in endurance time and reduced dyspnoea in COPD (10).

However, no study supports the inspiratory loading use during AE in either sporting or clinical populations. In this research letter, we revisit putative mechanisms underlying the established benefits of "standalone" IMT in order to support our contention that IMT need not and should not be used during AE sessions.

Mechanism 1: The respiratory muscle metaboreflex

During heavy-intensity exercise, respiratory muscle work requires an average of 14–21% of the cardiac output, potentially "competing" for blood flow (e.g., oxygen and nutrients) with locomotor muscles. The mechanism by which blood flow competition arises is suggested to occur via the so-called "respiratory muscle metaboreflex" (11), whereby fatiguing activity of the inspiratory muscles leads to accumulation of metabolites, which stimulate unmyelinated afferents. This stimulation induces a sympathetically-mediated vasoconstriction within limb locomotor muscles (12), which hastens locomotor muscle fatigue and exercise limitation (12) and intensifying effort perceptions. IMT has been shown to increases the threshold for respiratory metaboreflex activation in healthy (13) and patients with heart failure (5), thereby improving exercise tolerance.

Mechanism 2: *Reduced respiratory and locomotor effort perceptions*

The hypothesis that IMT improves exercise performance may be explained, in part, by the reduced respiratory and whole body effort perceptions in athletes (14) and clinical populations (4) after IMT. The reduced dyspnoea seems to be associated with improvements in the force-generating capacity of inspiratory muscles after IMT, which decreases the relative tension for a given level of ventilation (4). During conditions where elevated ventilation is needed, such as exercise, this adaptation from inspiratory muscles most likely underpins the diminished respiratory effort (4). IMT also reduces peripheral effort sensations (14) probably via a reduction in respiratory muscle blood flow needs and a boosting of oxygen delivery and metabolite removal from to the limbs.

Mechanism 3: Reduced oxygen cost of breathing

The oxygen cost of breathing is related directly to the energy requirement of the respiratory muscles. IMT reduces the oxygen cost of breathing for a given ventilatory requirement during voluntary hyperpnoea post-IMT (15). Specifically, in highly trained cyclists, IMT reduced the oxygen cost of breathing at ventilations above 50% of the maximal oxygen uptake (15). It suggests that IMT, at least in this population, reduces the energy demand from respiratory muscles during hyperpnoea.

Thus, in trained individuals, a reduced oxygen cost of breathing most likely contributes to exercise performance improvements following IMT by reducing their demand for oxygen, thereby liberating oxygen for use by locomotor muscles. To our knowledge, this mechanism has yet to be evaluated in clinical populations.

Mechanism 4: Attenuation of central fatigue

Lastly, we proffer an as yet untested mechanism underpinning the ergogenic effect of IMT. Exercise intolerance is elicited by a number of interrelated peripheral factors, but is also affected by so-called "central fatigue", which is driven by feedback from muscle afferents (16). To date, the focus of attention has been upon feedback originating from locomotor muscles; however, feedback from the respiratory muscles almost certainly contributes to the ensemble of inputs influencing central motor drive. Accordingly, we suggest that attenuation of respiratory muscle afferent feedback following IMT might delay, or attenuate, central fatigue, thereby improving exercise tolerance. To our knowledge, this has yet to be evaluated directly.

[insert figure here]

Figure 1. Putative mechanisms underlying improved respiratory muscle function and exercise performance following "standalone" inspiratory muscles training (IMT). (?) indicates that this mechanism is yet to be investigation.

Does inspiratory loading during exercise have an ergogenic effect?

Finally, we close by considering how knowledge of putative mechanisms described above should influence the way in which IMT is implemented in practice; specifically, is there any rationale for loading to be applied during exercise?

A recent systematic review (17) of nineteen studies concluded that inspiratory loading during AE impairs exercise tolerance due to an inadequate ventilatory (V_E) response. Amongst the twelve studies that reported peripheral oxygen saturation (SpO_2), seven showed a decrease in SpO_2. On the other hand, when inspiratory loading was applied during recovery from high-intensity interval training, a positive effect was found upon clearance of lactate. The psychophysiological effects of imposing respiratory loads during exercise are negative and well-established (17), including increased breathing discomfort, anxiety and intensification of effort during AE.

Accordingly, we argue that imposing an ergogenic intervention, such as inspiratory loading, *during* exercise has the same pitfalls as training at high altitude; specifically, it impairs the quality of the training that can be accomplished, whilst not providing any additional benefits to sea-level performance (18). Altitude researchers realised quickly that the benefits of altitude training could be optimised by adopting the so-called 'live-high-train-low' paradigm, whereby the erythropoietic benefits of altitude exposure were achieved without compromising athletes' training quality (18).

Our understanding of the mechanisms that underpin the ergogenic effects of RMT (see figure 1), as well as the conclusions of the systematic review by López-Pérez (17), lead to the inevitable conclusion that implementing RMT via respiratory loading *during* AE sessions is a mistake. Moreover, this combination may lead to harmful psychophysiological effects, whilst also being ineffective (17). In contrast, there is ample evidence that the implementation of "standalone" IMT using resistance-training principles is well-tolerated and highly effective for a wide range of individuals (19).

The results of RCTs suggest that IMT is a key part of exercise-based cardiac and pulmonary rehabilitation programs. However, in these studies, IMT protocols were conducted in separate sessions, and they provided benefits in cardiorespiratory responses to exercise and reduced dyspnoea in CHF (9) and COPD patients (10), respectively. Based on the current literature, it is recommended to combine IMT with AE in separate sessions. In summary, using inspiratory loading during AE may have a negative impact, whereas performing IMT and AE in separate sessions allows for sufficient recovery and may lead to additional physiological enhancements compared to just doing IMT or AE training alone.

Conclusions and future directions

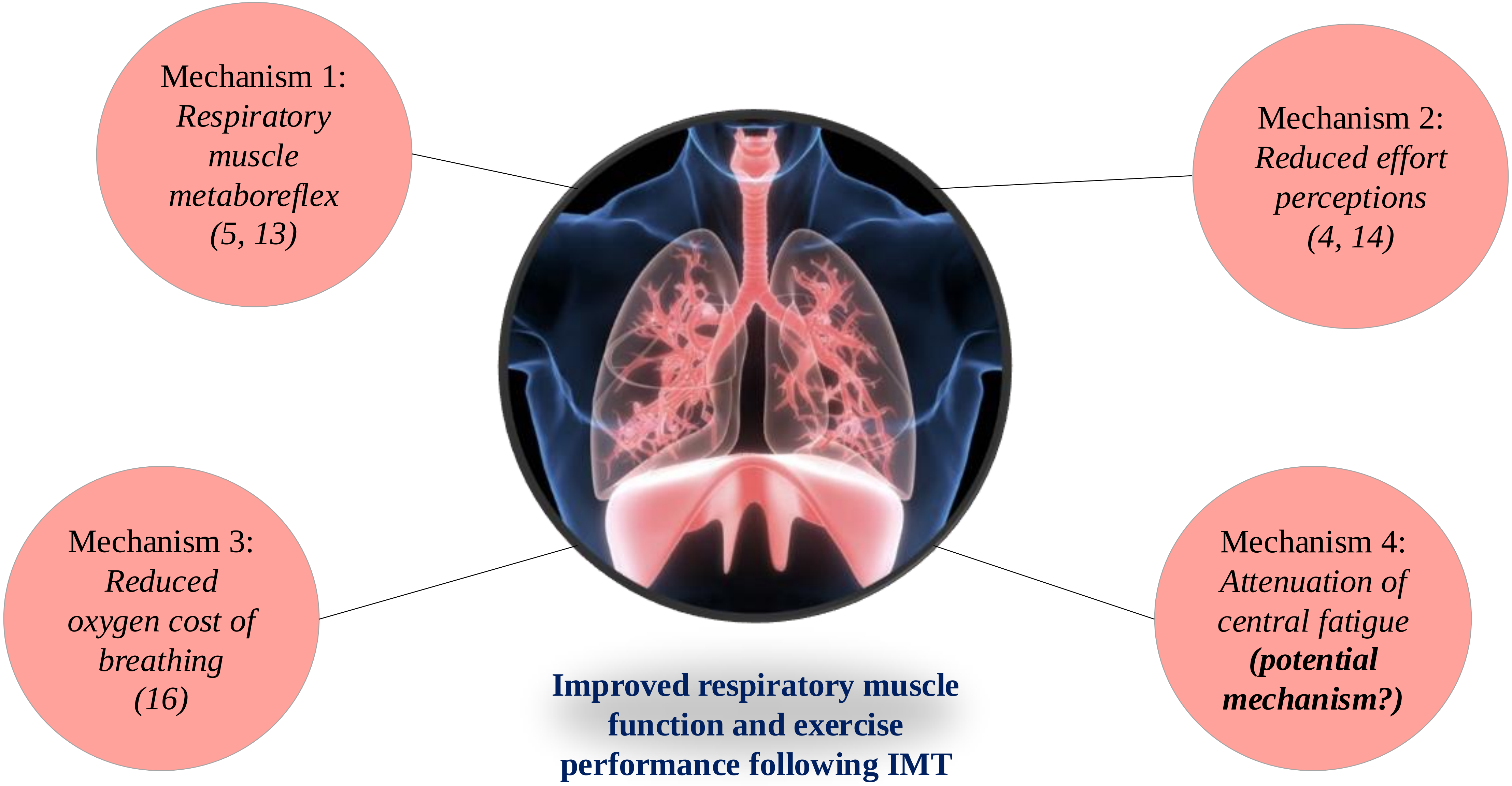
Finally, there is one context in which we recommend further research into the effects of combining RMT with other forms exercise. A single study has investigated the combination of IMT with whole body, "functional" strength training (19). The data suggested that a standalone IMT provided a foundation of improved inspiratory muscle strength and core muscle functions. Furthermore, a follow-on programme of IMT, combined with simultaneous core muscle training exercises, enhanced core muscle function further, as well as and providing cumulative benefits to running performance. The mechanistic rationale for this approach is the role of the respiratory musculature in trunk stabilisation (2), as well as in balance (20). To underscore, a strong foundation of standalone IMT was the first step of the aforementioned study and, in our opinion, is crucial to support the combination of IMT with other forms of strength training.

References

1. Illi SK, Held U, Frank I, Spengler CM. Effect of respiratory muscle training on exercise performance in healthy individuals: a systematic review and meta-analysis. *Sports Med* 2012: 42(8), 707-24.

2. McConnell AK. Respiratory Muscle Training: Theory and Practice. 1st ed. 2013, Oxford: Churchill Livingstone. 256.
3. Rodrigues GD, Dal Lago P, da Silva Soares PP. Time-dependent effects of inspiratory muscle training and detraining on cardiac autonomic control in older women. *Exp Gerontol.* 2021: 1150, 111357.
4. Langer D, Ciavaglia C, Faisal A, *et al*. Inspiratory muscle training reduces diaphragm activation and dyspnea during exercise in COPD. *J Appl Physiol (1985*). 2018: 125(2), 381-392.
5. Moreno AM, Toledo-Arruda AC, Lima JS, Duarte CS, Villacorta H, Nóbrega ACL. Inspiratory Muscle Training Improves Intercostal and Forearm Muscle Oxygenation in Patients With Chronic Heart Failure: Evidence of the Origin of the Respiratory Metaboreflex. *J Card Fail*. 2017: 23(9), 672-679.
6. DeLucia CM, De Asis RM, Bailey EF. Daily inspiratory muscle training lowers blood pressure and vascular resistance in healthy men and women. *Exp Physiol*. 2018:103,201–211.
7. Craighead DH, Heinbockel TC, Freeberg KA, et al. Time-Efficient Inspiratory Muscle Strength Training Lowers Blood Pressure and Improves Endothelial Function, NO Bioavailability, and Oxidative Stress in Midlife/Older Adults With Above-Normal Blood Pressure. *J Am Heart Assoc*. 2021: 10(13), e020980.
8. Ramos-Barrera GE, DeLucia CM, Bailey EF. Inspiratory muscle strength training lowers blood pressure and sympathetic activity in older adults with OSA: a randomized controlled pilot trial. *J Appl Physiol*. 2022: 132(6), 1591.
9. Winkelmann ER, Chiappa GR, Lima CO, Viecili PR, Stein R, Ribeiro JP. Addition of inspiratory muscle training to aerobic training improves cardiorespiratory responses to exercise in patients with heart failure and inspiratory muscle weakness. *Am Heart J*. 2009: 158(5):768.e1-768, e7687.
10. Charususin N, Gosselink R, Decramer M, et al. Randomised controlled trial of adjunctive inspiratory muscle training for patients with COPD. *Thorax*. 2018: 73(10), 942-950.
11. Dempsey JA, Romer L, Rodman J, Miller J, Smith C. Consequences of exercise-induced respiratory muscle work. *Respir Physiol Neurobiol.* 2006: 151(2-3), 242-50.
12. McConnell AK and Lomax M. The influence of inspiratory muscle work history and specific inspiratory muscle training upon human limb muscle fatigue. *J Physiol* 2006: 577(1), 445-57.
13. Witt JD, Guenette JA, Rupert JL, McKenzie DC, Sheel AW. Inspiratory muscle training attenuates the human respiratory muscle metaboreflex. *J Physiol* 2007: 584(3),1019-28.
14. Romer LM, McConnell AJ, Jones DA. Effects of inspiratory muscle training upon time trial performance in trained cyclists. J Sports Sci 2002: 20, 547-562.
15. Turner LA, Tecklenburg-Lund SL, Chapman RF, Stager JM, Wilhite DP, Mickleborough TD. Inspiratory muscle training lowers the oxygen cost of voluntary hyperpnea. J Appl Physiol (1985) 2012: 112(1), 127-34.
16. Amann M. Significance of Group III and IV muscle afferents for the endurance exercising human. Clin Exp Pharmacol Physiol 2012: 39(9), 831-5.
17. López-Pérez ME, Romero-Arenas S, Giráldez-García MA, Colomer-Poveda D, Márquez G. Acute psychophysiological responses during exercise while using resistive respiratory devices: A systematic review. *Physiol Behav* 2022: 256, 113968.
18. Bejder J, Nordsborg NB. Specificity of "Live High-Train Low" Altitude Training on Exercise Performance. Exerc Sport Sci Rev. 2018;46(2):129-136. doi:10.1249/JES.0000000000000144.

19. Tong TK, McConnell AK, Lin H, Nie J, Zhang H, Wang J. "Functional" Inspiratory and Core Muscle Training Enhances Running Performance and Economy. *J Strength Cond Res* 2016: 30(10), 2942-51.
20. Ferraro FV, Gavin JP, Wainwright TW, McConnell AK. Association Between Inspiratory Muscle Function and Balance Ability in Older People: A Pooled Data Analysis Before and After Inspiratory Muscle Training. *J Aging Phys Act* 2022: 30(3), 421-433.
20. López-Pérez ME, Romero-Arenas S, Giráldez-García MA, Colomer-Poveda D, Márquez G. Acute psychophysiological responses during exercise while using resistive respiratory devices: A systematic review. *Physiol Behav* 2022: 256, 113968.
21. Bejder J, Nordsborg NB. Specificity of "Live High-Train Low" Altitude Training on Exercise Performance. Exerc Sport Sci Rev. 2018;46(2):129-136. doi:10.1249/JES.0000000000000144.
22. Tong TK, McConnell AK, Lin H, Nie J, Zhang H, Wang J. "Functional" Inspiratory and Core Muscle Training Enhances Running Performance and Economy. *J Strength Cond Res* 2016: 30(10), 2942-51.
23. Ferraro FV, Gavin JP, Wainwright TW, McConnell AK. Association Between Inspiratory Muscle Function and Balance Ability in Older People: A Pooled Data Analysis Before and After Inspiratory Muscle Training. *J Aging Phys Act* 2022: 30(3), 421-433.


Mechanism 1:
Respiratory muscle metaboreflex (5, 13)
Mechanism 2:
Reduced effort perceptions (4, 14)
Mechanism 3:
Reduced oxygen cost of breathing (16)
Mechanism 4:
Attenuation of central fatigue (potential mechanism?)
Improved respiratory muscle function and exercise performance following IMT