

Original Research

Effects of a Brief Inspiratory Muscle Training Protocol on Cardiorespiratory Performance and Autonomic Modulation in Amateur Runners

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Abstract : Inspiratory muscle training (IMT) is widely recognized as an effective strategy to improve cardiorespiratory efficiency, increase functional capacity, and modulate the autonomic nervous system in both healthy individuals and those with chronic conditions. In the field of sports, IMT has gained growing interest in its potential to optimize physical performance and enhance recovery following intense physical efforts. Therefore, this study aimed to evaluate the effects of a short IMT protocol on relevant physiological parameters in amateur runners. Forty recreational runners (20 men and 20 women; 35.33 ± 6.13 years; 69.77 ± 11.02 kg; 168.70 ± 8.86 cm; 24.43 ± 2.55 kg/m²) were randomly assigned to an intervention group ($n = 20$) or a control group ($n = 20$). The intervention consisted of 5 minutes of daily training at 50% maximal inspiratory pressure (MIP) for 10 consecutive days. Maximal Oxygen Consumption (VO₂max), Second Ventilatory Threshold (VT₂), MIP, and heart rate variability (HRV), specifically the root mean square of successive differences (RMSSD), were assessed. Baseline characteristics did not differ significantly between groups, except for age ($p = 0.012$). Significant time group interactions were found for VO₂max, VT₂, RMSSD, and MIP (all $p < 0.001$). Compared with the control group, the IMT group showed greater improvements in VO₂max ($+2.87$ ml/kg/min ; $d = 0.59$), VT₂ ($+2.61$ ml/kg/min; $d = 0.68$), RMSSD ($+5.69$ ms; $d = 0.58$), and MIP ($+15.48$ cmH₂O; $d = 1.71$). Increases in MIP correlated positively with changes in VO₂max ($\rho = 0.74$), VT₂ ($\rho = 0.77$), and RMSSD ($\rho = 0.71$; all $p < 0.001$). These findings support the efficacy of short-duration IMT as a complementary tool to improve cardiorespiratory performance and autonomic modulation in recreational athletes, without requiring long periods of intervention.

Keywords : Inspiratory training; Heart rate variability; Aerobic exercise; Ventilatory threshold; Oxygen consumption.



1. Introduction

In recent years, respiratory muscle training has gained relevance as an effective method to improve the strength and endurance of the respiratory muscles across various populations, including professional and recreational athletes, as well as patient with health conditions (Ferraro et al., 2025; HajGhanbari et al., 2013). The inspiratory muscles, particularly the diaphragm, play crucial role in the respiratory system and are susceptible to fatigue during intense physical exercise, which can activate metaboreflex and lead to vasoconstriction, thereby reducing blood flow to the working locomotor muscles (Romer & Polkey, 2008). This redirection of blood flow between respiratory and locomotor muscles has been identified as a limiting factor for exercise capacity and aerobic performance (Lima et al., 2025 ; Ogoh, 2025).

During sustained exercise, ventilatory demand rises significantly in response to increased metabolic activity, helping to maintain arterial blood gas levels and acid base balance (Phillips et al., 2020). If the respiratory muscles are not adequately conditioned, this increased demand can lead to diaphragmatic fatigue, which in turn may compromise oxygen delivery to the peripheral muscles (Archiza et al., 2018). However, strengthening these muscle groups through specific training can reduce fatigue and improve ventilatory efficiency (Illi et al., 2012 ; Shei, 2018). Recent studies have shown that inspiratory muscle training (IMT) can elevate ventilatory thresholds and increase maximal oxygen uptake ($\text{VO}_{2\text{max}}$) in both elite and recreational athletes (Kowalski et al., 2023 ; Ren et al., 2025).

In parallel, heart rate variability (HRV) has emerged as a non-invasive biomarker of autonomic nervous system function, reflecting the balance between the sympathetic-parasympathetic activity (Ishaque et al., 2021). Time domain parameters, such as the standard deviation of normal R-R intervals (SDNN) and the root mean square of successive differences

(RMSSD), are indicators associated with vagal autonomic activity (Michael et al., 2017). In this context, previous studies have also indicated that IMT can positively influence HRV, promoting beneficial adaptations in autonomic nervous system regulation (Cipriano et al., 2019 ; Ladrián-Maestro et al., 2024; Legg Ditterline et al., 2018; Rodrigues et al., 2021).

Running has become increasingly popular worldwide, with a growing number of recreational participants training and competing across various distances (Boullosa et al., 2020). At higher intensities and over longer durations, running imposes substantial physiological demands on the body, with the respiratory system playing a crucial role in meeting these requirements (Tiller, 2019). HRV has been shown to be a useful parameter for monitoring the training load in amateur runners, as it reflects the body's adaptations and responses to these stresses (Boullosa et al., 2020). Early research has suggested that the use of IMT, when performed for more than four weeks, can lead to improvements in respiratory muscle function and running performance (Inbar et al., 2000 ; Mickleborough et al., 2010; Ogawa et al., 2020 ; Ren et al., 2025). Although there are limited studies that include shorter training protocols, limiting their applicability in time-constrained programs, an approach that could be particularly beneficial for amateur runners (Ogawa et al., 2020). Such shorter approaches may have implications for the development of accessible, efficient, and low-cost interventions. Therefore, the study aimed to determine whether a 10-day IMT protocol, performed alongside regular aerobic training, can generate significant physiological changes in amateur runners, specifically in $\text{VO}_{2\text{max}}$, second ventilatory threshold (VT_2), maximal inspiratory pressure (MIP), and HRV.

2. Materials and Methods

Participants— Forty amateur runners (20 men and 20 women; age: 35.33 ± 6.13 years; weight: 69.77 ± 11.02 kg ; height: 168.70 ± 8.86 cm ; body mass index

[BMI]: $24.43 \pm 2.55 \text{ kg/m}^2$) all aged between 25 and 40 years and with at least 12 months of experience in continuous aerobic training experience, participated in the study. Inclusion criteria required participants to have no history of cardiovascular, respiratory, or musculoskeletal health conditions that could limit their running performance. Using a convenience sampling approach, as they were readily accessible to the research team through their affiliation with a local running club. The participants were selected and randomly divided into two groups: IMT group ($n = 20$) and control group ($n = 20$). Prior to participation, all participants were informed both with a written and oral explanation about the potential risks and benefits of participation in the study. Each participant then provided a written informed consent form, following the Declaration of Helsinki (2013). The study was conducted in accordance with the ethical standards outlined in the Declaration of Helsinki for research involving human subjects.

Procedure— Initial and post-intervention physiological assessments included the evaluation of autonomic function through HRV, recorded using a chest-strap heart rate monitor (Polar H10, Kempele, Finland). Upon awakening, participants were instructed to maintain the supine position and breathe normally for 5 minutes while their heart rate was recorded (Nakamura et al., 2016). HRV data were analyzed using the validated Kubios software (Kuopio, Finland; see <http://www.kubios.com/>) (Tarvainen et al., 2014). The RMSSD parameter was analyzed and used as an index of parasympathetic modulation (Ishaque et al., 2021). An assessment of MIP was performed using a Power Breathe KH2 respiratory training device (Powerbreathe®, IMT Technologies Ltd., Birmingham, England). Participants were instructed to perform three maximal inspiratory efforts from a residual volume against an occluded airway, sustaining each maneuver for at least 1 second. The highest pressure value recorded in cmH_2O

was recorded for analysis (Laveneziana et al., 2019). Finally, a cardiopulmonary exercise test was implemented using an incremental treadmill protocol (Riboli et al., 2022). The variables VO_2max and the VT_2 were determined using a breath-by-breath Cortex Metalyzer 3B gas analyzer system (Leipzig, Germany). VO_2max was determined as the average of maximum oxygen consumption 157 during the last 30 seconds of the test 158 (Midgley et al., 2007), and VT_2 was identified 159 using the method of ventilatory equivalents 160 and end-expiratory partial pressures of oxygen (PetO_2) and carbon dioxide (PetCO_2) (Glaab & Taube, 2022). Both groups continued their regular aerobic training regimen, consisting of three weekly sessions comprising 8–10 kilometers of volume-based exercise at moderate intensity, corresponding to approximately 60% of the theoretical maximum heart rate. The IMT group performed an inspiratory strength protocol using a respiratory training device set at 50% of MIP for 5 minutes daily over 10 consecutive days. The protocol was conducted in a seated position, with participants maintaining continuous, controlled breathing throughout the 5-minutes period. All sessions were supervised by a member of the research team to ensure correct execution of the protocol, and adherence was monitored through daily attendance records. Only participants who completed all sessions were included in the final analysis. The control group did not perform additional respiratory training and only maintained their usual running training protocol.

Statistical Analysis— The statistical analysis was performed using the JASP software, v0.19.3 (University of Amsterdam, Amsterdam, Netherlands), while graphs were elaborated with GraphPad Prism v8.0.1 (San Diego, CA, USA). Descriptive analyses (mean, standard deviation) were performed for all variables. Normality was assessed with the Shapiro Wilk test and homogeneity of variances with the Levene test. An unpaired t-test was used to compare

baseline characteristics between the two participant groups. A two-way (time $\times$ training group) analysis of variance (ANOVA) with repeated measures (pre vs post), with a Bonferroni *post hoc* test, was conducted. Effect size (Cohen's d) and their confidence intervals [95% CI] were determined, according to the following values: “very small” ($d < 0.20$), “small” ($d = 0.20\text{--}0.49$), “medium” ($d = 0.50\text{--}0.79$), or “large” ($d \geq 0.80$) (Cohen, 1988). Correlations between changes in MIP, VO_2max , VT_2 , and HRV were explored using the Spearman test. The level of statistical significance was set at $p < 0.05$.

3. Results

Baseline characteristics of the participants are presented in Table 1. No significant differences were observed between the groups for BMI, previous training time, VO_2max , VT_2 , RMSSD, or MIP ($p > 0.05$). Age was the only variable that showed a statistically significant difference between groups ($p = 0.012$; $d = 0.83$ [0.17, 1.47]).

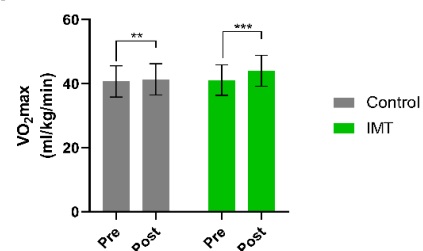
Table 1. Baseline features of the participants.

	Control Group	IMT	p value
Age (years)	32.95 $\pm$ 5.17	37.70 $\pm$ 6.22	0.012
Height (cm)	168.80 $\pm$ 9.20	168.60 $\pm$ 8.75	0.944
Body mass (kg)	69.72 $\pm$ 11.04	69.83 $\pm$ 11.28	0.977
BMI (kg/m ²)	24.44 $\pm$ 2.89	24.41 $\pm$ 2.23	0.970
Training time (months)	39.25 $\pm$ 13.84	34.05 $\pm$ 10.78	0.193
VO_2max (ml/kg/min)	40.67 $\pm$ 4.84	41.14 $\pm$ 4.80	0.757
VT_2 (ml/kg/min)	29.88 $\pm$ 4.45	29.89 $\pm$ 3.28	0.987
RMSSD (ms)	45.47 $\pm$ 9.03	43.87 $\pm$ 10.70	0.611
MIP (cmH ₂ O)	100.44 $\pm$ 10.23	99.76 $\pm$ 6.91	0.806

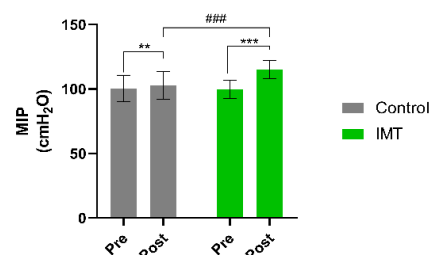
Notes: Body mass index (BMI), maximal oxygen uptake (VO_2max), second ventilatory threshold (VT_2), root mean square standard deviation of the R-R intervals (RMSSD), and maximal inspiratory pressure (MIP).

A significant interaction effect between time and training groups was identified for VO_2max ($F = 81.60$; $p < 0.001$; $\eta^2_p = 0.68$), VT_2 ($F = 100.27$; $p < 0.001$; $\eta^2_p = 0.73$), RMSSD ($F = 115.97$; $p < 0.001$; $\eta^2_p = 0.70$), and MIP ($F = 538.88$; $p < 0.001$; $\eta^2_p = 0.93$). As shown in Figure 1, the IMT group exhibited a significant increase in VO_2max of 2.87 ml/kg/min ($p < 0.001$; $d = 0.59$ [0.38, 0.81]) and in MIP of 15.48 cmH₂O ($p < 0.001$; $d = 1.71$ [1.15, 2.31]), both corresponding to medium effect sizes. Although the control group also showed significant differences in these variables, the observed effect sizes were small, with an increase of 0.67 ml/kg/min in VO_2max ($p = 0.002$; $d = 0.14$ [0.03, 0.25]) and 2.24 cmH₂O in MIP ($p = 0.001$; $d = 0.25$ [0.07, 0.44]). Additionally, IMT group resulted in significant changes with medium effect sizes in VT_2 , with an increase of 2.61 ml/kg/min ($p < 0.001$; $d = 0.68$ [0.43, 0.93]), and RMSSD, with an increase of 5.69 ms ($p < 0.001$; $d = 0.58$ [0.37, 0.79]).

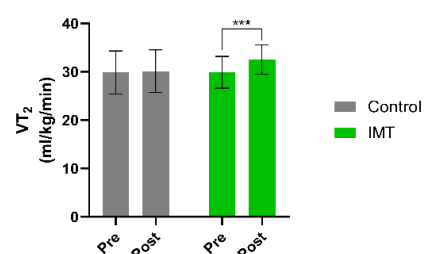
(a)



(b)



(c)



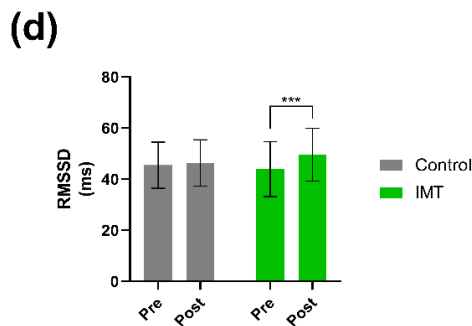


Figure 1. Effect of inspiratory muscle training protocol on physiological parameters, including (a) maximal oxygen uptake ($\text{VO}_{2\text{max}}$); (b) maximal inspiratory pressure (MIP); (c) second ventilatory threshold (VT_2); and (d) root mean standard deviation of the R-R intervals (RMSSD). Grey bars indicate the control group, while green bars represent the IMT group; before (pre) and after (post) intervention. Within-group differences are represented as ** $p < 0.01$; *** $p < 0.001$. Between-group differences are represented as ### $p < 0.001$

The association between the rate of change in MIP and the variations observed in the other variables was analyzed. As is exhibited in Figure 2, positive and significant correlations were identified ($p < 0.001$) between the increase in MIP and changes in $\text{VO}_{2\text{max}}$ ($\rho = 0.74$), VT_2 ($\rho = 0.77$), and RMSSD ($\rho = 0.71$).

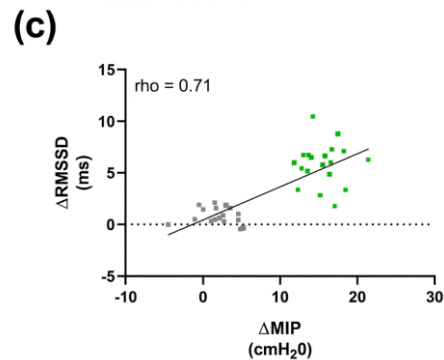
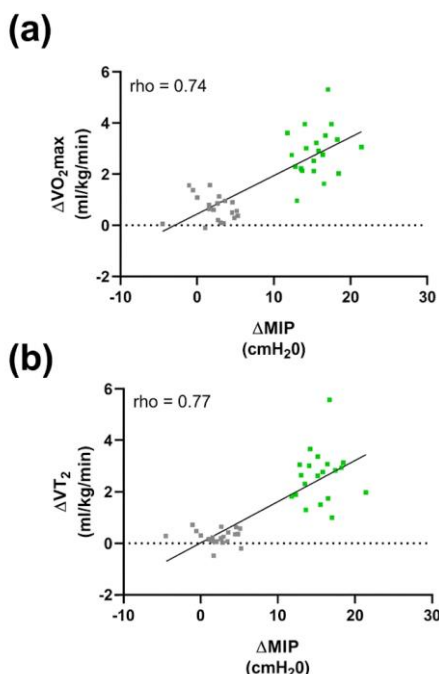


Figure 2. Association between differences (Δ) of maximal inspiratory pressure (MIP) and (a) maximal oxygen uptake ($\text{VO}_{2\text{max}}$); (b) second ventilatory threshold (VT_2); and (c) root mean square standard deviation of the R-R intervals (RMSSD). The correlation index is represented by the rho value

4. Discussion

This study examined whether a short 10-day IMT program, combined with regular aerobic training, improves $\text{VO}_{2\text{max}}$, VT_2 , MIP, and HRV in amateur runners. The results of this study indicate that even a brief IMT protocol can induce meaningful physiological adaptations in amateur runners. In particular, the observed increase in $\text{VO}_{2\text{max}}$ and VT_2 suggests an improvement in cardiorespiratory efficiency, coinciding with previous findings that used longer IMT interventions and similar devices in distance runners (Kowalski et al., 2023 ; Rożek-Piechura et al., 2020). Strengthening inspiratory muscles such as the diaphragm and internal intercostals is thought to reduce respiratory muscle fatigue, thereby improving redistribution of blood flow to the locomotor muscles (Dempsey et al., 2006 ; Torres-Castro et al., 2025). This mechanism is particularly relevant during prolonged exercise, where competition for blood flow between systems can limit performance. The improvement of MIP by more than 15 cmH_2O in the intervention group aligns with previous studies reporting comparable gains with longer training duration protocols (Illi et al., 2012).

Regarding the autonomic modulation, the observed increase in RMSSD reflects an enhancement of parasympathetic activity, which is associated with improved

recovery capacity and reduced cardiovascular strain (Cipriano et al., 2019). These changes in HRV parameters are likely mediated by modulation of the respiratory muscle metaboreflex, leading to increased parasympathetic tone and concurrent reduction in sympathetic activity (de Abreu et al., 2017 ; Witt et al., 2007). Such favorable autonomic adaptation may be particularly beneficial for recreational athletes who lack access to advanced monitoring technologies but seek to improve performance through simple and cost-effective strategies. Previous studies have shown that IMT using high-intensity breathing devices can significantly enhance respiratory muscle strength and overall physical performance in endurance athletes. Rozek-Piechura et al. (2020) reported notable improvements in long-distance runners, while protocols using training devices have also been shown to improve spirometric parameters, respiratory muscle strength, and overall physical performance in long-distance runners (Okrzymowska et al., 2025). Similarly, Ogawa et al. (2020) examined a shorter IMT protocol (i.e., 4 weeks) and observed increased inspiratory muscle strength and reduced work capacity under hypoxic conditions in university-level runners. The findings of the present study extend this evidence, demonstrating that even a brief 10- day IMT intervention can elicit significant physiological adaptations. While traditional IMT protocols are implemented over at least four weeks; however, our results suggest that meaningful improvements can be achieved in a much shorter timeframe. This short-term approach offers a practical alternative

for use during pre-competitive phases or as a complementary strategy within rehabilitation and functional training programs (Chang et al., 2025 ; Ren et al., 2025). Although the control group exhibited statistically significant changes in VO_2max and MIP, the associated effect sizes were small, indicating that the magnitude of these changes was limited. These results may be partially explained by the continuation of their habitual endurance training could have elicited slight improvements, consistent with previous findings reporting increases in MIP and aerobic capacity following conventional endurance protocols (Dunham & Harms, 2012 ; Ogawa et al., 2020).

A key limitation of this study is the relatively small sample size ($n = 40$), which may limit the generalizability of the findings and reduce the statistical power to detect smaller effects. In addition, the use of convenience sampling from an accessible population may further restrict the broader applicability of the findings. In addition, the absence of long term follow-up prevents assessment of whether the observed adaptations are maintained over time. In complement, the protocol did not include progressive load adjustments, which may have influenced the outcome, although this decision was made to preserve the ecological validity of the intervention. Finally, the lack of standardization of participants' baseline training characteristics, together with the significant age differences observed between groups, may have introduced potential confounding effects and therefore require cautious interpretation of

the findings. Despite these constraints, the immediate effects observed provide a basis for future research to evaluate the duration of the effects and their applicability in other populations such as older adults, individuals with chronic diseases, and elite athletes. Future studies should address these limitations by incorporating longitudinal follow-up, controlling training background, and exploring whether higher training intensities could produce similar or greater benefits over short timeframes, as suggested by the present findings.

5. Practical Applications.

The findings of this study indicate that a short-duration IMT protocol—consisting of 5 minutes per day at 50% of MIP for 10 consecutive days—can lead to significant improvements in key physiological variables, including VO_2max , VT_2 , MIP, and HRV, specifically the RMSSD index, in recreational runners. These results support the use of brief IMT as an effective, low-cost, and easily implementable strategy to enhance cardiorespiratory performance and autonomic modulation without requiring prolonged training interventions. Such a protocol can be integrated into regular training schedules, particularly during general preparation periods, recovery phases, or weeks with reduced training load, providing physiological benefits without increasing overall workload. Consequently, coaches, trainers and healthcare professionals may consider incorporating short-duration IMT as a complementary approach to improve endurance performance and post-exercise recovery in recreational runners.

6. Conclusions

Brief IMT (5 minutes daily at 50% of MIP for 10 days) proved effective in improving VO_2max , VT_2 , MIP, and RMSSD in amateur runners. This type of intervention represents a simple, low-cost complement to traditional aerobic training, capable of enhancing performance and autonomic recovery with minimal time and resources.

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Conflicts of Interest: The authors declare that there is no conflict of interest in this research.

Statements: During the preparation of this paper, the authors used ChatGPT to improve the writing and understanding of this paper. After using this tool, the authors reviewed and edited the content as needed, assuming full responsibility for the content of the publication.

References

- Archiza, B., Welch, J. F., Geary, C. M., Allen, G. P., Borghi-Silva, A., & Sheel, A. W. (2018). Temporal characteristics of exercise-induced diaphragmatic fatigue. *Journal of Applied Physiology*, 124(4), 906–919. <https://doi.org/10.1152/jappphysiol.00942.2017>
- Boullosa, D., Esteve-Lanao, J., Casado, A., Peyré-Tartaruga, L. A., Gomes da Rosa, R., & Del Coso, J. (2020). Factors affecting training and physical performance in recreational endurance runners. *Sports*, 8(3), 35. <https://doi.org/10.3390/sports8030035>
- Chang, C.-L., Fang, T.-P., Tsai, H.-M., Chen, H.-C., Liu, S.-F., Lin, H.-L., & Liu, J.-F. (2025). Inspiratory muscle training and aerobic

- exercise for respiratory muscle strength in myasthenia gravis post hospitalization- a randomized controlled trial. *BMC Pulmonary Medicine*, 25(1), 266. <https://doi.org/10.1186/s12890-025- 03733-7>
- Cipriano, G. F. B., Cipriano Jr., G., Santos, F. V., Güntzel Chiappa, A. M., Pires, L., Cahalin, L. P., & Chiappa, G. R. (2019). Current insights of inspiratory muscle training on the cardiovascular system : a systematic review with meta-analysis. *Integrated Blood Pressure Control, Volume 12*, 1–11. <https://doi.org/10.2147/IBPC.S159386>
- Cohen, J. (1988). *Statistical power analysis for the behavioral sciences*. L. Erlbaum Associates.
- De Abreu, R. M., Rehder-Santos, P., Minatel, V., dos Santos, G. L., & Catai, A. M. (2017). Effects of inspiratory muscle training on cardiovascular autonomic control: A systematic review. *Autonomic Neuroscience*, 208, 29–35. <https://doi.org/10.1016/j.autneu.2017.09.002>
- Dempsey, J. A., Romer, L., Rodman, J., Miller, J., & Smith, C. (2006). Consequences of exercise-induced respiratory muscle work. *Respiratory Physiology & Neurobiology*, 151(2–3), 242–250. <https://doi.org/10.1016/j.resp.2005.12.015>
- Dunham, C., & Harms, C. A. (2012). Effects of high-intensity interval training on pulmonary function. *European Journal of Applied Physiology*, 112(8), 3061–3068. <https://doi.org/10.1007/s00421-011- 2285-5>
- Ferraro, F. V., Edris, R., & Wainwright, T. W. (2025). Inspiratory muscle training: A theoretical framework for its selected application in orthopaedic enhancing recovery pathways. *International Journal of Orthopaedic and Trauma Nursing*, 58, 101193. <https://doi.org/10.1016/j.ijotn.2025.101193>
- Glaab, T., & Taube, C. (2022). Practical guide to cardiopulmonary exercise testing in adults. *Respiratory Research*, 23(1), 9. <https://doi.org/10.1186/s12931-021-01895-6>
- HajGhanbari, B., Yamabayashi, C., Buna, T.R., Coelho, J. D., Freedman, K. D., Morton, T. A., Palmer, S. A., Toy, M. A., Walsh, C., Sheel, A. W., & Reid, W. D. (2013). Effects of respiratory muscle training on performance in athletes. *Journal of Strength and Conditioning Research*, 27(6), 1643–1663. <https://doi.org/10.1519/JSC.0b013e318269f73f>
- Illi, S. K., Held, U., Frank, I., & Spengler, C. M. (2012). Effect of Respiratory Muscle Training on Exercise Performance in Healthy Individuals. *Sports Medicine*, 42(8), 707–724. <https://doi.org/10.1007/BF03262290>
- Weiner, P., Azgad, Y., Rotstein, A., & Weinstein, Y. (2000). Specific inspiratory muscle training in well trained endurance athletes. *Medicine & Science in Sports & Exercise*, 32(7), 1233–1237. <https://doi.org/10.1097/00005768-200007000-00008>
- Ishaque, S., Khan, N., & Krishnan, S. (2021). Trends in heart-rate variability signal analysis. *Frontiers in Digital Health*, 3. <https://doi.org/10.3389/fdgth.2021.639444>
- Kowalski, T., Kasiak, P. S., Rebis, K., Klusiewicz, A., Granda, D., & Wiecha, S. (2023). Respiratory muscle training induces additional stress and training load in well-trained triathletes — randomized controlled trial. *Frontiers in Physiology*, 14. <https://doi.org/10.3389/fphys.2023.1264265>
- Ladrián-Maestro, A., Sánchez-Infante, J., Martín-Vera, D., & Sánchez-Sierra, A. (2024). Influence of an inspiratory muscle fatigue protocol on healthy youths on respiratory muscle strength and heart rate variability. A randomized controlled trial. *Frontiers in Physiology*, 15. <https://doi.org/10.3389/fphys.2024.1457019>
- Laveneziana, P., Albuquerque, A., Aliverti, A., Babb, T., Barreiro, E., Dres, M., Dubé, B.-P., Fauroux, B., Gea, J., Guenette, J. A., Hudson, A. L., Kabitz, H.-J., Laghi, F., Langer, D., Luo, Y.-M., Neder, J. A., O'Donnell, D., Polkey, M. I., Rabinovich, R. A., ... Verges, S. (2019). ERS statement on respiratory muscle testing at rest and during exercise. *European Respiratory Journal*, 53(6), 1801214. <https://doi.org/10.1183/13993003.01214- 2018>
- Legg Ditterline, B. E., Aslan, S. C., Randall, D. C., Harkema, S. J., Castillo, C., & Ovechkin, A.

- V. (2018). Effects of respiratory training on heart rate variability and baroreflex sensitivity in individuals with chronic spinal cord injury. *Archives of Physical Medicine and Rehabilitation*, 99(3), 423-432. <https://doi.org/10.1016/j.apmr.2017.06.033>
- Lima, T. B. W. e, Silva, B. B. dos S., Souza, A. P. S. de, Aires, D. M. F., & Fagundes, M. G. (2025). The effect of inspiratory muscle training on the inspiratory muscle metaboreflex: A systematic review. *Canadian Journal of Respiratory Therapy*, 61. <https://doi.org/10.29390/001c.132324>
- Michael, S., Graham, K. S., & Davis, G. M. (2017). Cardiac autonomic responses during exercise and post-exercise recovery using heart rate variability and systolic time intervals—A review. *Frontiers in Physiology*, 8. <https://doi.org/10.3389/fphys.2017.00301>
- Mickleborough, T. D., Nichols, T., Lindley, M. R., Chatham, K., & Ionescu, A. A. (2010). Inspiratory flow resistive loading improves respiratory muscle function and endurance capacity in recreational runners. *Scandinavian Journal of Medicine & Science in Sports*, 20(3), 458–468. <https://doi.org/10.1111/j.16000838.2009.00951.x>
- Midgley, A. W., McNaughton, L. R., Polman, R., & Marchant, D. (2007). Criteria for determination of maximal oxygen uptake. *Sports Medicine*, 37(12), 1019–1028. <https://doi.org/10.2165/00007256-200737120-00002>
- Nakamura, F., Flatt, A., Pereira, L., Ramirez Campillo, R., Loturco, I., & Esco, M. (2016). Ultra-short-term heart rate variability is sensitive to training effects in team sports players. *Journal of Sports Science & Medicine*, 3(14), 602–605.
- Ogawa, T., Nagao, M., Fujii, N., & Nishiyasu, T. (2020). Effect of inspiratory muscle loaded exercise training on peak oxygen uptake and ventilatory response during incremental exercise under normoxia and hypoxia. *BMC Sports Science, Medicine and Rehabilitation*, 12(1), 25. <https://doi.org/10.1186/s13102-020-00172-1>
- Ogoh, S. (2025). Cardiac output-mediated regulation of cerebral blood flow during exercise: Clinical perspectives on the indirect impact of muscle metaboreflex. *Experimental Physiology*, 110(5), 686–693. <https://doi.org/10.1113/EP091591>
- Okrzymowska, P., Mackala, K., Kucharski, W., & Rożek-Piechura, K. (2025). Inspiratory muscle training included in therapeutic and training regimens for middle-distance runners. *Journal of Clinical Medicine*, 14(9), 3180. <https://doi.org/10.3390/jcm14093180>
- Phillips, D. B., Collins, S. É., & Stickland, M. K. (2020). Measurement and interpretation of exercise ventilatory efficiency. *Frontiers in Physiology*, 11. <https://doi.org/10.3389/fphys.2020.0659>
- Ren, Z., Guo, J., He, Y., Luo, Y., & Wu, H. (2025). Effects of inspiratory muscle training on respiratory muscle strength, lactate accumulation and exercise tolerance in amateur runners: A randomized controlled trial. *Life*, 15(5), 705. <https://doi.org/10.3390/life15050705>
- Riboli, A., Coratella, G., Rampichini, S., Limonta, E., & Esposito, F. (2022). Testing protocol affects the velocity at VO2max in semi-professional soccer players. *Research in Sports Medicine*, 30(2), 182-192. <https://doi.org/10.1080/15438627.2021.187840>
- Rodrigues, G. D., Dal Lago, P., & da Silva Soares, P. P. (2021). Time-dependent effects of inspiratory muscle training and detraining on cardiac autonomic control in older women. *Experimental Gerontology*, 150, 111357. <https://doi.org/10.1016/j.exger.2021.111357>
- Romer, L. M., & Polkey, M. I. (2008). Exercise induced respiratory muscle fatigue : implications for performance. *Journal of Applied Physiology*, 104(3), 879–888. <https://doi.org/10.1152/japplphysiol.01157.2007>
- Rożek-Piechura, K., Kurzaj, M., Okrzymska, P., Kucharski, W., Stodółka, J., & Maćkała, K. (2020). Influence of Inspiratory Muscle Training of Various Intensities on The Physical Performance of Long-Distance Runners. *Journal of Human Kinetics*, 75(1), 127–137. <https://doi.org/10.2478/hukin-2020-0031>
- Shei, R.-J. (2018). Recent advancements in our understanding of the ergogenic effect of

- respiratory muscle training in healthy humans: A systematic review. *Journal of Strength and Conditioning Research*, 32(9),26652676.<https://doi.org/10.1519/JSC.0000000000002730>
- Tarvainen, M. P., Niskanen, J.-P., Lipponen, J. A., Ranta-aho, P. O., & Karjalainen, P. A. (2014). Kubios HRV – Heart rate variability analysis software. *Computer Methods and Programs in Biomedicine*,113(1),210–220.
<https://doi.org/10.1016/j.cmpb.2013.07.024>
- Tiller, N. B. (2019). Pulmonary and respiratory muscle function in response to marathon and ultra-marathon running : A review. *Sports Medicine*,49(7), 10311041.<https://doi.org/10.1007/s40279-019-01105-w>
- Torres-Castro, R., Caicedo-Trujillo, S., Gimeno-Santos, E., Gutiérrez-Arias, R., Alsina-Restoy, X., Vasconcello-Castillo, L., Seron, P., Spruit, M. A., Blanco, I., & Vilaró, J. (2025). Effectiveness of inspiratory muscle training in patients with a chronic respiratory disease: an overview of systematic reviews. *Frontiers in Sports and Active Living*,7.<https://doi.org/10.3389/fspor.2025.1549652>
- Witt, J. D., Guenette, J. A., Rupert, J. L., McKenzie, D. C., & Sheel, A. W. (2007). Inspiratory muscle training attenuates the human respiratory muscle metaboreflex. *The Journal of Physiology*, 584(3), 1019–1028.<https://doi.org/10.1113/jphysiol.2007.140855>