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Effects of a 4-Week Respiratory Muscle Training Proposal for Semi-Professional Athletes

Efectos de una propuesta de entrenamiento de los músculos respiratorios de 4 semanas para atletas semiprofesionales

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Abstract

Objective: This study evaluated the effect of a novel respiratory muscle training protocol on the running performance of semiprofessional endurance athletes. Methods: The sample consisted of 11 endurance athletes (aged 25.5 ± 5.7 years; BMI 22.6 ± 3.4 kg·m2), who performed a test of incremental respiratory endurance to design an inspiratory muscle training protocol. Using a spirometer, the following variables were calculated: Muscle Inspiratory Pressure, Peak Inspiratory Flow, and S-INDEX (cm H2O), which is understood as a stress index or the relationship between pressure and volume. The performance of a 12-minute running test was also evaluated with the assessment of heart rate. The training protocol consisted of 12 sessions with a frequency of 3 times per week for 4 weeks of (6 x 80% of Muscle Inspiratory Pressure). A t-student ($p < 0.05$), the magnitude of change (Δ), and effect size were applied. Results: Improvements in the athletes' respiratory function were found in muscle inspiratory pressure (Effect Size 1.91; Δ= +44%), peak inspiratory flow (Effect Size 1.37; Δ= +22%), and S-INDEX (Effect size 1.37; Δ= +25%). The distance covered in the 12-minute test (Effect Size 0.11; Δ= +7%) also improved after the respiratory muscle training protocol. Conclusions: This novel proposal for respiratory muscle training produces improvements in respiratory muscle function and can be used as a competition strategy prior to a running event in semi-professional endurance athletes.

Keywords: Muscle Inspiratory Pressure; Peak Inspiratory Flow; Aerobic training; Running performance.

Resumen

Objetivo: Este estudio evaluó el efecto de un nuevo protocolo de entrenamiento de los músculos respiratorios sobre el rendimiento de carrera de atletas de resistencia semiprofesionales. Métodos: La muestra estuvo compuesta por 11 atletas de resistencia (edad 25,5 ± 5,7 años; IMC 22,6 ± 3,4 kg·m2), quienes realizaron una prueba inicial de resistencia respiratoria incremental, posteriormente se aplicó un protocolo de entrenamiento de los músculos inspiratorios. Mediante un espirómetro se calcularon las siguientes variables: Presión Inspiratoria Muscular, Flujo Inspiratorio Máximo y S-INDEX (cmH2O), que se entiende como un índice de estrés o la relación entre presión y volumen. También se evaluó la realización de una prueba de carrera de 12 minutos con la valoración de la frecuencia cardíaca. El protocolo de entrenamiento constó de 12 sesiones con una frecuencia de 3 veces por semana durante 4 semanas de (6 x 80% de la Presión Inspiratoria Muscular). Se aplicó una t de Student ($p < 0,05$), la magnitud del cambio (Δ) y el tamaño del efecto (TE) para identificar los cambios en el tiempo. Resultados: Se encontraron mejoras en la función respiratoria de los atletas en la presión inspiratoria muscular (TE 1,91; Δ= +44%), el flujo inspiratorio máximo (TE 1,37; Δ= +22%) y el S-INDEX (TE 1,37 Δ= +25%). La distancia recorrida en la prueba de 12 minutos (TE 0,11; Δ= +7%) también mejoró después del protocolo de entrenamiento de los músculos respiratorios. Conclusiones: Esta es una novedosa propuesta de entrenamiento de los músculos respiratorios para producir mejoras en la función de los músculos respiratorios y puede usarse como estrategia de competición previo a una prueba de carrera en deportistas de resistencia semiprofesionales.

Palabras clave: Presión inspiratoria muscular; Flujo inspiratorio máximo; Entrenamiento aeróbico; Rendimiento en carrera.

Introduction

The main function of the respiratory system is to facilitate the exchange of gases between air and blood. This involves the entry of oxygen (O2) and the removal of carbon dioxide (CO2) from the body (Weibel, 1984). During physical activity, the metabolic demands on the body increase, which means more O2 is needed to produce energy. The respiratory system responds to this increased demand by increasing the rate and depth of respiration, a process known as ventilation (Sheel & Romer, 2012). This allows more O2 to be taken in and more CO2 to be removed, which helps maintain gas balance in the body.

Respiratory muscles primarily work against airway resistance, constituting approximately 80% of total resistance, while the remaining 20% arises from the elastic resistance of lung tissue and the chest wall (Crosfill & Widdicombe, 1961). During intense exercise, the respiratory metaboreflex is triggered—a reflex mechanism that redirects blood flow from locomotor muscles (e.g., legs) to the respiratory muscles to sustain their vital function (Dempsey et al., 2006). This response is mediated by metabolic receptors (metaboceptors) in the diaphragm and intercostal muscles, which detect elevated levels of metabolites such as lactate, hydrogen ions (H+), and carbon dioxide (CO2) (Dominelli et al., 2017). When these metabolites accumulate due to sustained or intense effort, the receptors activate, sending signals to the central nervous system. This triggers peripheral vasoconstriction and increases blood flow to the respiratory muscles, ultimately impairing the ability to sustain high-intensity or prolonged exercise (Dominelli et al., 2017).

Growing interest is in strengthening respiratory muscles through forced breathing exercises, which may provide significant advantages for athletes (Fabero-Garrido et al., 2022). To this end, various devices, known as spirometers, have been developed to train these muscles. These devices create resistance during inhalation, overloading the inspiratory muscles and forcing them to work harder than usual. This type of training, called Inspiratory Muscle Training (IMT), targets key respiratory muscles such as the diaphragm, external intercostals, scalenes, and sternocleidomastoid (Ando et al., 2020; Derbakova et al., 2020; Volianitis et al., 2001). The primary objective of IMT is to enhance the strength and endurance of these muscles, potentially improving respiratory function and athletic performance.

Endurance sports require sustained aerobic efforts, which place high demands on the respiratory system (Edwards & Walker, 2009). IMT can be incorporated into the training program as an ergogenic aid because improving respiratory capacity can delay respiratory muscle fatigue, improve oxygen delivery to working muscles, and reduce the sensation of exertion during exercise. In addition, athletic performance, especially in endurance sports such as cycling, running and swimming may be improved (Romer et al., 2002). The IMT improves the metaboreflex adaptation of the respiratory muscles (Dominelli et al., 2017; Sheel et al., 2018; Witt et al., 2007). These mechanisms include diaphragmatic hypertrophy, increased blood flow to locomotor muscles, decreased subjective blood flow, reduced fatigue, decreased dyspnea, increased respiratory efficiency and resistance, an alteration in the composition of muscle fibers to type I, and an increase in type II fibers in intercostal muscles. IMT also optimizes neuromotor control in respiratory muscles, maintaining pressure production with a lower motor drive and greater economization of the respiratory muscles (Ramsook et al., 2017; Sadek et al., 2018; Sheel, 2002). IMT improves also the respiratory pattern during exercise hyperpnea (Charususin et al., 2016) and reduces the release of cytokines (Mills et al., 2013, 2014). Finally, IMT has the potential to minimize and/or delay respiratory fatigue and blood lactate concentration (Brown et al., 2008), which affects energy metabolism in athletes.

While IMT may benefit endurance athletes, it should be considered only as a complement to regular aerobic exercise training programs (Johnson et al., 2007). This innovative training method does not appear to significantly influence VO2max, apparent due to its reduced perceived exertion at high ventilatory rates—an effect more impactful in longer trials than in incremental VO2max tests (Edwards et al., 2008). However, the evidence remains inconsistent. For instance, although IMT has shown effectiveness in team sports (HajGhanbari et al., 2013), its efficacy in runners is less clear, with some studies failing to demonstrate significant benefits (Kwok & Jones, 2009; Tong et al., 2008) and only a few reporting positive outcomes. These discrepancies may stem from variations in training protocols (e.g., intensity and duration) and the athletes' experience level. For example, Enright and Unnithan, (2011) observed performance and ventilatory parameters improvements when the training protocol was tailored to the specific context. However, the study highlighted that the protocol's duration—eight weeks before competition—was excessive for semi-professional athletes, who face additional challenges such as academic commitments and limited budgets for advanced respiratory training technologies. This underscores the need for further research to develop more time-efficient approaches that support athletes.

Accordingly, this study aims to evaluate the effects of IMT on running performance in endurance semi-professional athletes. It hypothesizes that a shorter IMT protocol—12 sessions over four weeks—can also provide an ergogenic benefit during a running race in semi-professional athletes.

Material and Methods

The participants in this study were 11 endurance athletes (age: 25.5 ± 5.7 years; weight 67.5 ± 13.7 kg; height 1.72 ± 0.05 m; Body Mass Index (BMI) 22.6 ± 3.4 kg/m2 and Body Fat 15.9 ± 7, 5%), which competed in different endurance modalities (half marathon, trail running) at the regional level of the Extremadura region. The sample was chosen by convenience. Participants were informed of the study procedure and were asked to sign an informed consent. The study followed biomedical guidelines based on the Declaration of Helsinki.

Design and Procedure

This study was developed using a quantitative observational design. Before the initial assessment and the intervention phase, the participants were informed about the benefits of respiratory muscle training, and they had the opportunity to ask questions and discuss any issues related to the training process. To minimize learning effects, participants completed a familiarization session with the PowerBreather instruments one week before the assessments. The assessment included the specific tests of respiratory muscles and the sport performance, through the maximal 12-minute race test. The intervention consisted of 12 training sessions, conducted at a frequency of three sessions per week over a total period of four weeks (Figure 1). Sessions were held on Mondays, Wednesdays, and Fridays, ensuring a 24-hour recovery period between each session. Upon completing the training program, the same initial tests were repeated to evaluate the effects of the intervention. Throughout the study, participants maintained their usual levels of physical activity and dietary habits, while their coaches continued to oversee and plan their regular sports training routines.

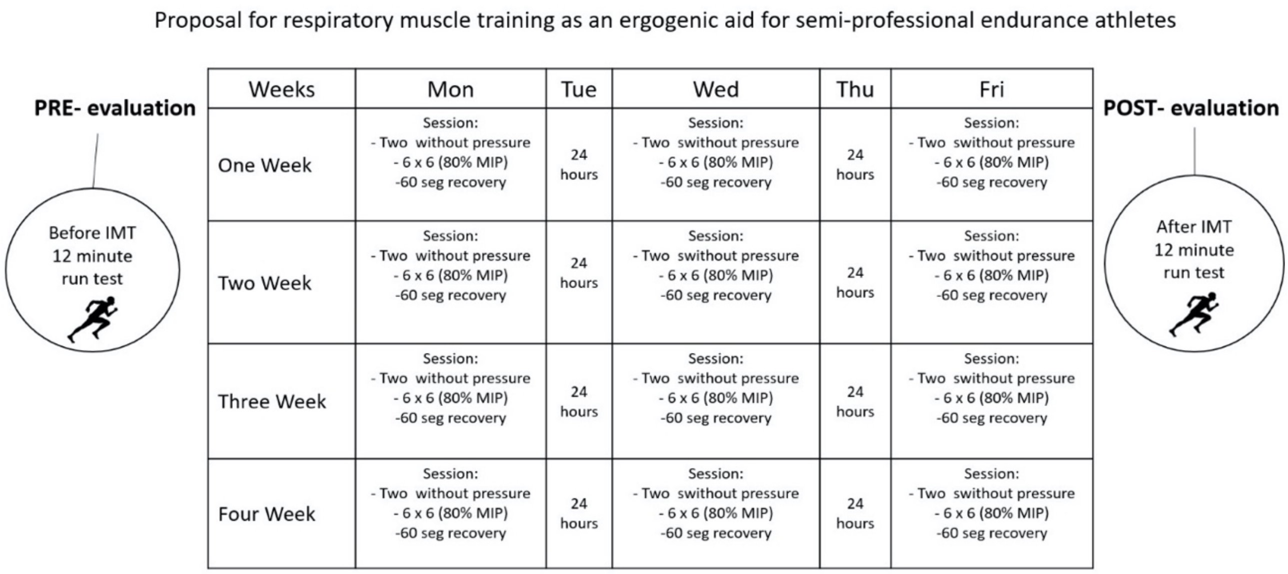

Figure 1. Proposal for respiratory muscle training as an ergogenic aid for endurance athletes.

Test of Incremental Respiratory Endurance (TIRE)

A Test of Incremental Respiratory Endurance was used to guide the training protocol. It establishes an inspiratory pressure level based on the subject's maximum inspiratory power and provides feedback through a reference template

(Cahalin & Arena, 2015). During the TIRE test, the subject inhales against resistance, usually at an intensity of 80% of the maximum sustained inspiratory pressure (MIP). The relationship between effort and recovery is progressively reduced from 60 seconds to 5 seconds (Cahalin & Arena, 2015). According to these authors, each session is preceded by sustained Peak Inspiratory Flow (PIM) tests, and the best one is used as a reference for training. This ensures that the training intensity is correct and individualized for each subject, and that the load is at a realistic level for that session while ensuring optimal performance. The device used for the IMT was the Power Breathe KH2 (Hab International Ltd., Southam, UK). This device provides valid and automatically processed estimates of the physical units of energy that are essential to quantify the load on inspiratory muscles during resistive breathing tasks (Langer et al., 2013). The reliability of the TIRE test was ICC=0.978 compared to familiarization session.

Training Protocol

The session started with 2 maximum breaths, without the application of pressure by the spirometer. These breaths were used to calculate 80% of the MIP. Then, the subject performed 6 blocks of 6 breaths at 80% MIP with progressively reduced recovery periods between series (60s - 45s - 30s - 15s - 5s). The entire protocol was developed using the same PowerBreathe KH2 spirometer as for TIRE. All training sessions took place in a quiet room with no distractions, and the same instructions were given to all participants to ensure their motivation during the training period.

Respiratory Muscles Assessment

Spirometry measurements were carried out by the recommendations of the European Respiratory Society, as outlined in the article 'Standardization of Spirometry' (Miller et al., 2005). The assessment of the respiratory muscles involved measuring PIF and MIP using the same spirometer as for training.

Peak Inspiratory Flow: Is the maximum measure at which the patient can inhale air into the lungs (Quanjer et al., 1993). This measurement is based on the peak flow rate measured during the respiratory test, which indicates the speed at which the athletes' muscles are contracting. The protocol involves the participant standing relaxed with the nose covered to ensure that all air is taken in through the mouth. Then, as much air as possible is exhaled and, to ensure complete exhalation, the subject is advised to sit forward and exhale completely. Once all air is expelled, the subject takes a quick and deep breath, trying to inhale as much air as possible. In the PIF test, the S-Index (cmH2O) is calculated, which is the stress index or the relationship between pressure and volume (RPV). PIF is measured in liters per second (L/s), and volume in liters (L).

Maximum Inspiratory Pressure: This is used to observe variations in the strength of the inspiratory muscles before and after carrying out the training protocol. The protocol for this test is similar to the PIF test, with the only difference being that the spirometer provides resistance that the subject has to try to overcome while taking the maximum possible inspiration. The parameter calculated during the MIP test is the Inspiratory Pressure (cmH_2O).

Endurance Performance Assessment

Aerobic performance was evaluated through the 12-minute run test. The assessment was conducted on the athletics track in Caceres (Technification Center). The evaluation was individually developed, starting with a free warm-up for approximately 10 minutes. Participants had a Garmin Forerunner 735XT GPS device (Garmin Ltd., Liberty House, Hounsdown Business Park, Southampton, Hampshire, SO40 9LR, U.K.) to record the average and maximum heart rate (HR), as well as the distance covered at all times. The test is based on covering the longest possible distance in 12 minutes at a constant intensity and speed (Aparicio et al., 2013).

Statistical Analysis

The statistical analysis was conducted using the SPSS v.20 statistical software. The results are presented with descriptive statistics such as the mean and standard deviation. Firstly, the Kolmogorov-Smirnov and Levene tests were conducted to assess the distribution and homogeneity of variance. The magnitude of absolute change (%) was then calculated using the following formula: Δ% = (pre-post)/pre*100. Subsequently, a t-test was performed to determine whether there were any significant changes between the two evaluation moments (PRE vs POST). When the P-value was less than 0.05, the changes were considered statistically significant. The interpretation of effect sizes was based on the calculation of partial omega squared (ωp2) as follows: < 0.02 very low, <=0.02 but <0.13 low, <=0.13 but <0.26 moderate, and >=0.26 high (Cohen, 1988). In addition, an analysis of the individual response was carried out based on the typical error (TE=SDIR÷√2) (Bonafiglia et al., 2021; Hopkins, 2000; Walsh et al., 2020) where the individual results are presented with the percentage of participants with a beneficial effect (a change >TE), Uncertain (does not exceed the TE) and a non-beneficial effect (a change <TE) (Bonafiglia et al., 2021). To reproduce the a-priori power analyses reported in the set of studies, we used G*Power (Version 3.1.9.6).

Results

Table 1 shows the results obtained before and after IMT in the respiratory muscles assessment and sports performance tests. An increase of 25% in SINDEX, 22% in peak flow, and 44% in MIP was observed after 4 weeks of respiratory muscle training. Similarly, an increase of 7% in covered distance was observed in the 12-minute run test. No significant changes were observed in Heart Rate (HR).

Also, shows the effect size of the different variables of respiratory function and sports performance. A large effect is observed in MIP (ES=1.91), PIF (ES= 1.37), and SINDEX (ES= 1.37). A moderate effect was also observed on HR maximum (0.67) and HR mean (0.72) during the run test. Inspirated volume (0.01) and covered distance (0.11) did not show a significant effect size.

Table 1. Results obtained in respiratory function variables and running in semi-professional athletes.

Variables	Pre-	Post-	Δ (%)	p-value	ES	Statistical Power
Test PIF						
SINDEX (cmH_2O)	108.9 ± 18.4	132.7 ± 16.3	25.0	<0.01	1.37	0.74
Peak Inspiratory Flow (L/s)	6.0 ± 1.1	7.3 ± 0.8	22.5	<0.01	1.37	0.76
Volume (L)	3.7 ± 0.7	3.7 ± 0.6	24.3	NS	0.0	0.40
Test MIP						
Muscle Inspiratory Pressure (cmH_2O)	100.9 ± 28.9	143.1 ± 15.1	44.4	<0.01	1.91	0.80
12 Minute Run Test						
Distance (m)	3025 ± 586	3087 ± 531	7	<0.01	0.11	0.67
Heart Rate maximun (bmp)	189 ± 8	190 ± 7	0.50	NS	0.67	0.85
Heart Rate mean (bmp)	180 ± 3	183 ± 5	2.20	NS	0.72	0.85

Note: Pre- indicates results obtained before the application of the training protocol; Δ represents absolute change calculated as (Post-Pre/Pre)*100; Post- indicates results obtained after the application of the training protocol. ES= Effects Size. S-INDEX refers to stress index, PIF to peak inspiratory flow rate, MIP to maximum inspiratory pressure, HR to heart rate, and NS to non-significant differences.

Table 2 presents an analysis of the individual response based on the change in the IMT intervention in the athletes. The TE was 0.62 PIF (L/s), 23.8 MIP (cmH2O), 328 distance (m) running tests. Also, a positive benefit was observed in PIF in 9/11 athletes (81.8%), in IMT and distance covered in 8/11 athletes (72.7%).

Table 2. Analysis of individual response to the effect of 4-Week Respiratory Muscle Training in semi-professional athletes.

Athletes	Δ PIF (L/s)	Δ MIP (cmH2O)	Δ Running Distance (m)	inferential statistics PIF (L/s)	Inferential statistics MIP (cmH_2O)	inferential statistics. Running Distance (m)
Athlete 1	1.86	49.59	329			
Athlete 2	2.91	66.79	50.63	TE= 0.62 L/s	TE= 23.8 cmH_2O	TE= 328 m
Athlete 3	-0.02	7.14	1056.96			
Athlete 4	2.41	16.29	187.09	Individual	Individual	Individual
Athlete 5	2.88	33.63	1062.17	response=	response=	response=
Athlete 6	2.31	36.74	291	Beneficial 81.8%	Beneficial 72.7%	Beneficial 72.7%
Athlete 7	2.1	34	1062.71	Uncertain	Uncertain	Uncertain
Athlete 8	-0.07	77.48	763.41	18.2%	27.3%	27.3%
Athlete 9	0.91	23.44	965.7	not beneficial	not beneficial	not beneficial
Athlete 10	1.68	101.52	575	0%	0%	0%
Athlete 11	4.48	36.91	356			

Note. Δ PIF (L/s)= Change of Peak Inspiratory Flow (L/s), Δ MIP (cmH2O)= change of Muscle Inspiratory Pressure (cmH_2O) and Δ Running Distance (m)= change of 12 Minute Run Test. TE= Typical Error ($SD_{IR}÷\sqrt{2}$)

Discussion

The aim of this study was to investigate the effect of a respiratory muscle training protocol on running performance in endurance athletes after 4 weeks. The results showed an increase in the strength of inspiratory muscles, as measured by the MIP and PIF variables. Additionally, a slight improvement was observed in the running race distance.

Numerous studies have investigated the efficacy of IMT in endurance athletes. A systematic review and meta-analysis by Karsten et al., (2018) analyzed 38 studies. They concluded that respiratory resistance devices, such as Powerbreathe, can improve running performance parameters and MIP lung function. Similarly, Chang et al., (2021) demonstrated that four weeks of IMT significantly improved inspiratory muscle strength, 800-meter running performance, and reduced lower limb blood flow. However, this study utilized a higher training frequency—twice daily, five days per week. Likewise, Romer et al., (2002) reported performance improvements in cyclists during a time trial after six weeks of IMT involving 84 sessions. These findings suggest that exhaustive training protocols tend to yield greater performance gains.

Likewise, Barnes & Ludge, (2021) observed performance improvements in a 3200-meter run after a warm-up, attributed to enhanced inspiratory muscle function that reduced dyspnea. In comparison, our study's lower frequency of 12 IMT sessions over four weeks may not be sufficient to significantly improve running performance. Still, it could help maintain performance while enhancing respiratory function. Regarding HRmax, some studies have not related IMT to direct cardiovascular improvements. The Powerbreathe KH2 device primarily targets the respiratory muscles, such as the diaphragm and intercostal muscles, enhancing their strength and endurance rather than directly influencing HR during exercise (Langer et al., 2018). The HRmax during exercise is determined by factors such as age, genetics, and overall cardiovascular fitness (Achten & Jeukendrup, 2003). Although IMT can indirectly improve cardiovascular fitness by enhancing breathing efficiency and oxygen consumption, it does not directly affect HR (Mackała et al., 2019). The changes in HRmax during exercise are largely influenced by sympathetic nervous system activation, which increases HR and blood flow to muscles—a process not directly modified by IMT (Langer et al., 2018). While the same aerobic training can improve the HR maximum (Duarte et al., 2015), it is difficult to distinguish the limiting factors of running without a more exhaustive analysis of the training control variables.

In the same context, after four weeks of training, significant improvements were observed in the S-index, muscle strength, and lactic acid metabolism, demonstrating the sensitivity of variables such as PIF, PIM and the S-index in detecting adaptations in respiratory muscle function among athletes (Rehder-Santos et al., 2021). Additionally, individual responses to IMT in parameters such as PIF, PIM, and the distance covered in a 12-minute run showed a beneficial effect in a high percentage of participants, further supporting the study's findings. The lack of performance improvement in two athletes may indicate an insufficient training stimulus or an adaptive overload of the IMT program. This could also explain the lack of change in HRmax, as IMT does not induce a sufficient cardiovascular workload to prompt cardiac adaptations (Segizbaeva & Aleksandrova, 2021). Nevertheless, physical improvements related to metabolism were identified in most athletes, highlighting the potential benefits of IMT for enhancing respiratory function and metabolic efficiency.

Limitations and recommendations

The main limitation of the study is the lack of a control group. However, it is already established that IMT has an ergogenic effect on performance compared to control groups (Fernández-Lázaro et al., 2021), which supports the results of this study. Furthermore, this is a pilot study as a protocol for future studies. Additionally, more physiological evaluations are needed to understand the relationship between respiratory muscle improvements and running performance, such as measuring peripheral muscle oxygen, core temperature, and glucose levels during physical tests. A more personalized approach should be applied to prescription Powerbreathe training based on the athlete's objectives, needs, and desired results. By integrating specific methods such as optimization, periodization, and personalization, future studies can overcome previous discrepancies within IMT research. It is also important to note that choosing sports modality may influence the overall training load and adaptations, which will inevitably affect the projected results.

Conclusion

In summary, a 4-week inspiratory muscle training protocol, consisting of three sessions per week at 80% of inspiratory capacity, effectively improves respiratory muscle function and has the potential to enhance running performance in semi-professional endurance athletes.

Practical applications

The findings of this study offer valuable recommendations for coaches working with semi-professional endurance athletes. Implementing a 4-week respiratory muscle training protocol, consisting of three sessions per week at 80% of inspiratory capacity, can serve as an effective strategy for improving respiratory muscle function. Coaches can incorporate this approach into their training programs to potentially enhance running performance and overall endurance. This targeted respiratory training can complement traditional endurance training, providing athletes with an edge in both performance and recovery.

Author Contributions: En los artículos con varios autores deberían indicarse, brevemente, las contribuciones individuales de cada co-autor: “Conceptualización, M.C-C, J.R.S.B and G-O.; metodología, M.C-C, A.C-C, R.T and G.O.; software, J.R.S.B; validación, J.R.S.B and R.T; análisis estadísticos, A.V-B, and M.C-C.; investigación, A.V-B, M.C-C and G.O.; recursos, R.T, and G.O.; preparación de datos, A.V-B, M.C-C and A.C-C.; preparación del manuscrito, A.V-B and M.C-C.; redacción - revisión y edición, A.C-C., R.T., and G.O.; visualización, A.V-B.; supervisión, G.O.

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