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Review Article

Physiotherapy Section

Respiratory Muscle Strength Training for Athletes: A Narrative Review

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ABSTRACT

Respiratory Muscle Training (RMT) has become an alternative approach to boost athletic performance by improving respiratory function and delaying inspiratory muscle fatigue. The objective of the present study is to synthesise recent works on the benefits of RMT regarding muscle strength, respiratory system function and exercise performance in athletes and healthy individuals. The reviewed studies suggest that RMT can significantly increase pulmonary function parameters; however, the impact of RMT on these parameters remains inconsistent across studies. Regarding exercise performance, RMT has been shown to improve endurance, as evidenced by increased time to exhaustion, VO_2 max, Repeated Sprint Ability (RSA) and postural control in some studies. This author aimed to analyse the different studies on respiratory training with the aforementioned outcomes. A thorough search of studies were conducted using various databases. The review included studies published in English, which were peer-reviewed and focused on RMT interventions in sports players. The following keywords were used as search strategies: RMT, Inspiratory Muscle Training (IMT), pulmonary function, Maximum Inspiratory Pressure (MIP), Maximum Expiratory Pressure (MEP), exercise performance, VO_2 max and endurance training. All 10 studies were extracted based on their research design, including randomised controlled trials, pre-post experimental studies, randomised sham-controlled trials and randomised group factorial designs and were synthesised and analysed qualitatively. The activation of the metaboreflex mechanism and improved blood flow distribution to working muscles during exercise are proposed as potential underlying mechanisms for these performance benefits. However, the additive effects of RMT when combined with regular strength and endurance training remain debatable. The present analysis identified a suitable metric that could substantiate the evidence supporting the enhancement of athletic performance through RMT.

Keywords: Assistive devices, Inspiratory capacity, Inspiratory muscle fatigue, Sports performance

INTRODUCTION

The pulmonary system plays a vital role in athletic performance and RMT leads to improved endurance and enhanced performance in sports [1]. RMT is an important aspect of athletic training that has been largely overlooked in the past [2]. Previous research has revealed that RMT improves sports performance and endurance by activating the metaboreflex mechanism [3]. Despite the known benefits of RMT, there are a limited number of studies on the principles by which these benefits occur, particularly regarding endurance improvement and enhanced sports performance [4].

The present study focuses on exploring the impact of pulmonary training on the performance of athletes by activating the metaboreflex mechanism and delaying inspiratory muscle fatigue [5]. The main aim of the present study is to analyse the effects of this training on athletic performance by activating the metaboreflex mechanism and delaying inspiratory muscle fatigue [6]. It is hypothesised that RMT will advance endurance and enhance sports performance by activating the metaboreflex mechanism and delaying inspiratory muscle fatigue.

The activation of the metaboreflex mechanism is believed to result in improved blood flow distribution to the exercising muscles. By delaying inspiratory muscle fatigue, athletes can achieve higher levels of performance for longer durations. Furthermore, RMT could lead to increased oxygen uptake efficiency, allowing for better overall endurance and reduced perceived exertion during intense physical activities.

The present review study allows coaches, trainers and athletes to make informed decisions based on scientific research rather than anecdotal evidence. Understanding the latest findings can help optimise training protocols to improve athletic performance through better respiratory function [7,8]. Knowledge of proper techniques and potential risks can help prevent Respiratory Muscle Fatigue (RMF) and associated injuries [9]. Different sports may require specific RMT strategies and reviewing articles can provide insights into sport-specific adaptations. It enhances comprehension of the respiratory system's role in athletic performance and its adaptations to training [10].

Reviewing existing literature helps identify areas that require further research, potentially leading to new training methods or technologies [11]. It develops the ability to assess the quality and relevance of research, which is essential for implementing effective training programs [12]. Articles may incorporate findings from related fields such as exercise physiology, biomechanics and sports medicine, providing a comprehensive understanding of RMT. Understanding the effects of RMT across different age groups and skill levels can inform long-term athletic development strategies [13]. Staying updated with the latest research can provide athletes and teams with a competitive edge in their respective sports.

Some articles in which the authors reviewed RMT protocols for athletes typically involve targeted exercises to strengthen the diaphragm and accessory breathing muscles. These protocols often utilise specialised devices such as threshold loading devices or flow-resistive trainers that provide resistance during inhalation or exhalation. Common training regimes for athletes include IMT and Expiratory Muscle Training (EMT), with IMT being more prevalent due to its potential performance benefits. Training sessions usually last 15-30 minutes and are conducted 3-5 times a week for up to 4-12 weeks. The intensity of the training is generally set at 50-80% of an athlete's MIP or MEP, depending on the specific protocol. Progressive overload is applied by increasing the resistance as the athlete's respiratory muscle strength improves. Some protocols also incorporate functional breathing exercises or sport-specific breathing patterns to enhance the transfer of respiratory muscle strength gains to athletic performance. The review aims to synthesise and evaluate existing research on the effects, mechanisms and potential combined benefits of RMT on respiratory function and athletic performance while identifying key research gaps. The present review follows a narrative format to analyse and synthesise existing research on the impact of RMT on pulmonary function and exercise performance among healthy athletes.

Literature Search Strategy

A thorough search of studies was conducted using the following databases: Google Scholar (1430), PubMed (1063), Science Direct (45) and Scopus (34). The search covered studies from 2004 to 2024. The keywords used for this search were "RMT", "IMT", "Pulmonary Function," "MIP", "MEP", "Exercise Performance," "VO_2 Max," and "Endurance Training." Boolean operators ("AND," "OR") were employed in combinations such as "RMT" AND "Exercise Performance," and "MIP" OR "MEP" AND "Exercise Performance" to improve search results. The search was further filtered by year, English language and original research articles.

Inclusion and Exclusion criteria: The following criteria were established: (1) The language of peer-reviewed articles must be English, (2) Studies that examined the effects of RMT, (3) Studies conducted on healthy, active individuals, athletes, or populations without pre-existing pulmonary diseases, (4) Studies reporting on pulmonary function parameters {e.g., Forced Vital Capacity (FVC), Forced Expiratory Volume in one second (FEV1), Peak Expiratory Flow (PEF)} or exercise performance metrics (e.g., VO2 max, time to exhaustion). Studies were excluded based on the following criteria: (1) Studies conducted on clinical populations with chronic respiratory diseases {e.g., Chronic Obstructive Pulmonary Disease (COPD), asthma}, (2) Case studies, conference abstracts, or non-peer-reviewed literature, (3) Studies without clear RMT protocols or results specific to pulmonary function or exercise performance.

Data extraction: All extracted data from the selected study were well organised. Most of the information, including details of the author(s), publication year, study design (e.g., randomised controlled trial, crossover trial), population characteristics and intervention details (type of RMT, e.g., inspiratory or expiratory; intensity; duration; and frequency of exercise training) were recorded. Outcome measures included pulmonary function (e.g., FVC, FEV1, PEF), respiratory muscle strength (MIP, MEP) and exercise performance metrics (e.g., VO2 max, time to exhaustion). The results included statistical significance, percentage changes and effect sizes.

Reviews on Respiratory Muscle Training (RMT)

RMT and exercise performance: The effects of RMT on peak inspiratory pressure (PImax), RMF, intermittent exercise performance and dyspnoea in soccer athletes were investigated. The RMT group underwent a 30-Repetition Maximum (RM) procedure (10 repetitions per week) for five weeks using a commercially available device, while the other group did not receive RMT. The Yo-Yo Intermittent Recovery Test (IRT) was performed at level 1 and dyspnoea was assessed during and after the IRT. After two minutes, RMF was quantified following the completion of the IRT, which lasted for 10 minutes. The IRT performance significantly increased in the RMT group by 14.4 meters (p-value=0.008) and PImax increased by 27.2 cm H_2O (p-value <0.001) [14].

RMT for strength and endurance: The present study showed that 2000 m rowing performance improved significantly in both groups, with the Inspiratory Training Group (INS) having a pre-post duration difference of 16 seconds and the Expiratory group (EXP) having a difference of 14 seconds. Strength gains were observed in both the bench press and leg press, with INS improving its bench press pre-post strength by a difference of 11 kg and 63 kg, while EXP improved by 11.8 kg and 66.7 kg, respectively. VO2 peak increased slightly in both groups, with INS showing a pre-post difference of 0.11 L/min and EXP also showing a difference of 0.11 L/min. Both groups also found significant increases in peak inspiratory pressure (PImax) and peak expiratory pressure (PEmax), along with improvements in tidal volume and ventilatory threshold. The present study stated that neither expiratory nor inspiratory RMT, when added to a concurrent endurance and strength training program, provided additional improvements in 2000 m simulated rowing performance [15].

RMT and rowing performance: The study hypothesised that EMT/IMT (RMT) would enhance breathing pressure at maximum mouth pressure, reduce perceived breathing exertion, improve 2000 m rowing performance and enhance pulmonary function compared to a sham group. The results showed that Maximal Expiratory pressure (MEmax) and Inspiratory Pressure (PImax) in the RMT group significantly increased, with PEmax changing from -140 to -180 cm H_2O and PImax increasing from -110 to -130 cm H_2O, while the SHAM group exhibited minimal changes. Both groups improved in their 2000 m rowing performance, with the SHAM group showing a pre-post rowing time difference of 19.9 seconds and the RMT group showing a difference of 26.1 seconds. Peak VO_2 increased in both groups, with the SHAM group improving by a pre-post difference of 0.09 L/min and the RMT group improving by 0.19 L/min. The study concluded that while RMT improved expiratory and inspiratory strength, it did not provide added benefits to 2000 m rowing performance beyond what was achieved with strength and endurance training alone [16].

RMT in soccer players: In soccer players, the effect of IMT was analysed concerning static balance and pulmonary function. The Experimental Group (EG) underwent IMT for eight weeks using the Power Breathe device, starting at 20% of MIP and progressively increasing to 80%. The Control Group (CG) followed a similar training frequency, but the load was maintained constantly at 20% of MIP. The authors concluded that an 8-week IMT program significantly increases maximal voluntary ventilation and inspiratory muscle strength in both groups [17].

The effect of IMT on male players concerning tolerance to exercise, pulmonary parameters and RSA performance was also studied. IMT was performed before soccer training, consisting of 15 to 30 self-paced breaths at 50% of MIP over two weeks, six days per week. Sprint times decreased significantly after IMT, with RSA improving from 6.7±0.1 seconds to 6.4±0.1 seconds (p-value=0.0001). The percentage decrement in RSA and total sprint time performance improved significantly after IMT, with MIP improving by 15.4% (p-value <0.0002) and Peak Inspiratory Flow (PIF) improving by 19.1% (p-value=0.0002). The authors concluded that IMT significantly enhances RSA and inspiratory muscle strength [18].

The effect of RMT over eight weeks on pulmonary parameters and endurance performance in youth football athletes was also examined. Both the EG and CG participated in regular preseason football training sessions, which included Incremental Endurance Training (IET). The EG performed additional IMT using a Threshold IMT device, completing 5 to 15 repetitions twice per day, five days a week, over eight weeks. The training load was adjusted weekly, starting at 40% of MIP and progressively increasing to 80% by the 8^{th} week. MIP increased by 100% (p-value <0.0026) and MEP also increased by 100% (p-value <0.0046) for the RMT group, while smaller improvements were observed in the CG. No significant improvements in respiratory function parameters, such as vital capacity or PEF, were noted in either group. The EG showed a 5.06% improvement in Cooper test distance, corresponding to a significant increase of 150.30 meters (p-value <0.001). VO_2 max, estimated from the running distance, increased by 6% (p-value <0.0001) in the RMT group, compared to a 2.5% enhancement in the CG. The present study indicates that inspiratory and expiratory muscle strength significantly increases, leading to improved aerobic endurance in young soccer players. The findings suggest that combining IMT with regular soccer training can enhance endurance without the need for high-intensity training [19].

RMT and female soccer players: The impact of IMT on peripheral and respiratory muscle oxygenation in women soccer players was examined during an exercise tolerance test at maximum effort and

RSA performance. The IMT group trained using a Power Breathe K5 device at 50% of their MIP, five days a week, twice daily, over a span of six weeks. The SHAM group followed a similar procedure but used only 15% of their MIP to ensure negligible training effects.

The maximal incremental exercise test, time to exhaustion test (Tlim) and RSA test consisted of six 40 m sprints with a 180° turn and 20-second rest intervals between sprints. The IMT group exhibited a larger effect size with a 21.5% improvement compared to the SHAM group, which showed a 9.8% improvement. The IMT group significantly increased their Tlim by 42.1%, while the SHAM group improved by 14.5%. Additionally, the IMT group demonstrated greater oxygenation in the vastus lateralis muscle and reduced deoxygenation in the intercostal muscles during the Tlim test.

The IMT group also had a larger effect size for sprint recovery, with a 30.4% improvement, while the SHAM group improved by only 7.9%. The study concluded that IMT enhances the strength of inspiratory muscles, improves exercise tolerance and boosts professional players' repeated sprint performance [20].

RMT and aerobic endurance: The effects of RMT on respiratory function and aerobic performance in soccer players were analysed. The RMT samples performed 15 minutes of endurance training for respiratory muscles twice a week over a period of five weeks. Soccer-specific training was also conducted twice a week throughout the study. The RMT group showed a substantial 14% improvement in MIP (p-value=0.04) compared to the CG, which showed a 4% increase. However, there were no significant changes in FVC, FEV1, Maximum Voluntary Ventilation (MVV), or MEP in either group after five weeks. Similarly, there were no significant changes in shuttle run test performance or predicted VO2 max in the RMT group. At the end of the five weeks, while RMT significantly increased MIP in soccer players, it did not result in improvements in pulmonary function or 20-meter shuttle test performance. Thus, while RMT can enhance respiratory muscle strength, it may not improve aerobic performance in the short-term [21].

RMT and High-Intensity Exercise Performance

The RMT impacts high-intensity exercise performance. The training group performed low-resistance RMT for six weeks. In the first week, the RMT group performed one set of daily 15-minute sessions, five days a week, at 10-25% of PImax. In the following five weeks, the training increased to two sets of 15 minutes per day, five days per week, at 30% of PImax, while the placebo group followed a similar schedule without any additional ventilatory resistance. The training group showed a significant 14.3% improvement in PImax (p=0.012) and a 27% increase in PEmax (p<0.001), with no significant changes observed in the placebo group. FVC improved by 3.6% in the training group (p<0.01), but no significant changes were noted in other outcomes such as FEV1 and PEF in either group. The training group demonstrated an 11% increase in VO2 max (p=0.003) and a 25% increase in time to exhaustion (Tlim90%) (p=0.014), with no significant changes in the placebo group. These results suggest that low-resistance RMT can enhance exercise tolerance without the need for high-intensity training [22].

RMT and Chronic Low Back Pain Athletes

The study investigates the impact of a RMT session on the muscle activity of the ankle in athletes with long-duration low back pain during overhead squats. It involved 47 athletes, divided into a training group and a CG, using electromyography to assess muscles such as the tibialis anterior and peroneus longus. The RMT reduced the activity of some ankle muscles, suggesting improved postural control and proprioception. The study's results demonstrated that a single session of RMT significantly reduced the activity of the tibialis anterior in both static and dynamic overhead squat tests, as well as the peroneus longus during the ascending phase of the dynamic test. In contrast, other ankle muscles did not show significant changes. RMT also delayed the time to reach peak muscle activity in the tibialis anterior and peroneus longus during the dynamic squat. These findings suggest that RMT enhances postural stability and proprioception by stimulating core muscles, thereby preventing excessive ankle muscle activation [23]. [Table/Fig-1] summarises all the reviews assessed for RMT [14-23].

Author, year and type of study	Findings	Conclusion
1. Nicks CR et al., 2009 [14] (Pre-post experimental)	RMT on Intermittent Exercise Performance (IRT), respiratory muscle strength (PImax), Respiratory Muscle Fatigue (RMF) and dyspnoea in soccer athletes. Significant values of IRT were 216.6±231.0 metres (p-value=0.008), PI_{max} increased to 165.3±23.5 cm H_2O (p-value <0.001)	RMT improved intermittent exercise performance in these soccer athletes [14]
2. Bell GJ et al., 2013 [15] (Randomised pre-post factorial experimental)	RMT (Inspiratory and expiratory group) on 2000 m rowing performance, cardiorespiratory fitness, strength, PImax and PEmax pressure increased from 5-10 cm H_2O in both groups (p-value <0.05). 2000 m rowing time reduced to 451±4 seconds with minimal difference	RMT as an adjunct to concurrent strength and endurance training during the off-season in rowers provides no greater improvements in 2000 m simulated rowing race performance [15]
3. Forbes S et al., 2011 [16] (Randomised group factorial)	Inspiratory and expiratory resistive loading combined with strength and endurance training on pulmonary Function and 2000 m rowing performance showed a decrease of 479.0±35.8 seconds in RMT group with p-value <0.05	10 weeks of RMT that was added to an off-season concurrent strength and endurance training program for rowers improves both inspiratory and expiratory respiratory strength and improves the recovery of expiratory muscle strength after exercise [16]
4. De Oliveira-Sousa SL et al., 2023 [17] (Pilot RCT)	IMT group 20% to 80%, of MIP (n-7), sham group fixed 20% MIP (n-7). Length of sway (open and closed eyes, no changes), MIP (increased to 184.4±21.5 cm H_2O, p-value=0.076) MVV (max. voluntary vent., increased to 143.2±21.9 bpm, p-value=0.005) were measured pre-post 8 weeks in EG with SG	This study concluded that an 8-week semi-supervised IMT program, performed with a threshold loading device, could not improve the static balance in a sample of soccer players. Still, significant changes were found in pulmonary function [17]
5. Silva RL et al., 2019 [18] (Pre-post quasi-experimental study)	IMT of 15 and 30 inspiratory breaths (50% of MIP for P_0, P_1 and P_2-week) as intervention and Repeated Sprint Ability test (RSA) decreased significantly (p-value <0.001), PIF and MIP improved (p-value <0.0002) (n=22)	Inspiratory muscle strength enhanced after 2 weeks of IMT and increased efficiency of inspiratory musculature resulted decreases in sprint time [18]
6. Mackała K et al., 2019 [19] (Randomised controlled study)	IMT (n=16) 80 inhalations 2/d for 5/wk and CG regular training. The pulmonary function, Maximal Inspiratory Pressure (MIP) and the Cooper test were measured pre-post 8 weeks. Running test distance improved 5.06% (p-value=0.00), significant changes in PImax (p-value=0.0026) and PEmax (p-value=0.0046)	IMT had a positive impact on PI_{max} and PE_{max} in soccer players and increased efficiency of the inspiratory muscles contributes to enhanced improvement in aerobic endurance performance [19]
7. Archiza B et al., 2018 [20] (Randomised sham controlled trial)	IMT (n=10) Sham (n=8) maximal incremental exercise test, time to exhaustion (Tlim) test (p-value <0.001), Repeated Sprint Ability (RSA) performance (p-value >0.05) metabolic variables and blood lactate concentration were measured pre-post 6 weeks	IMT could delay the inspiratory muscle metaboreflex by decreasing Human Haemoglobin (HHb) and Total Haemoglobin (tHb) of intercostal muscles, concomitantly to an increase in Oxyhaemoglobin (O_2Hb) and (tHb) to peripheral muscles during high-intensity exercise [20]
8. Ozmen T et al., 2017 [21] (Randomised controlled trial)	RMT group 15 min 2 d/wk for 5 weeks, control group no training for lungs and both groups (n=18) soccer-specific training 2 d/wk. FVC, FEV1, MVV, MEP, MIP (p-value <0.05) along with 20 m shuttle run test (VO_{2max}) were measured. No significant changes in 20 Metre Shuttle Test (MST)	This study indicated that a five week of RMT increased MIP, rest other pulmonary parameters and aerobic endurance did not improve [21]

9. Al-Otaibi HM et al., 2024 [22] (Randomised controlled trial)	RMT 6 weeks 15 m/d, 5 d/wk (PImax 10-25%-1st wk) 30% rest of 5 weeks (n=16). PG with no resistance. PImax (p-value=0.012,14.3% increase), PEmax (p-value <0.001, 27%↑), FVC (p-value <0.01, 3.6%↑) VO_2 max (p-value=0.003, 11%↑), MVV_{12}, Tlim 90% (p-value=0.014, 15%↑)	This study concluded with low resistance RMT slightly improved the respiratory muscle strength and exercise tolerance in amateur athletes engaged in recreational activities [22]
10. Borujeni BG and Yalfani A, 2020 [23](Randomised controlled trial)	RMT (n=24) Respiratory Muscle Sprint Interval Training (RMSIT) 30 s breathing with 2 min rest, 60% MIP, EMG- MVIC (p-value=0.0001, p-value=0.022) max voluntary isometric contraction of calf muscle were assessed.	RMT can reduce the activity of some ankle joint muscles during overhead squats, that improved postural control and multisectional proprioception to maintain postural stability [23]

[Table/Fig-1]: Reviews of Respiratory Muscle Training (RMT) [14-23].
MVIC: Maximum voluntary isometric contraction; EMG: Electromyography

CONCLUSION(S)

The RMT improves endurance and enhances sports performance in athletes. RMT activates the metaboreflex mechanism, improving blood flow to exercising muscles. By delaying inspiratory muscle fatigue through RMT, athletes can sustain higher performance levels. RMT protocols typically involve targeted exercises using specialised devices to strengthen the breathing muscles. Literature shows that RMT improves respiratory muscle strength, exercise tolerance and repeated sprint performance.

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