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IMPACT OF INSPIRATORY MUSCLE TRAINING ON PULMONARY FUNCTION PARAMETERS IN ENDURANCE RUNNERS

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ABSTRACT

This research explores how respiratory muscle training affects lung function in marathon runners who regularly compete in long-distance events. Marathon running demands exceptional endurance, yet many training programs overlook the importance of strengthening respiratory muscles. We worked with forty-five competitive marathon runners over an eightweek period, implementing a structured respiratory training program using specialized breathing devices. The participants showed remarkable improvements in their breathing capacity and muscle strength. Maximum inspiratory pressure increased by 28.4%, maximum expiratory pressure improved by 21.7%, and forced vital capacity enhanced by 12.3%. These changes were statistically significant and substantially better than the control group who continued their regular training without respiratory exercises. Our findings suggest that marathon runners could benefit considerably from incorporating respiratory muscle training into their preparation routines. This relatively simple intervention appears to strengthen the breathing muscles, improve lung capacity, and potentially enhance overall running performance. The study contributes practical insights for coaches and athletes seeking evidence-based methods to optimize endurance training programs.
Keywords: respiratory muscle training, pulmonary function, marathon runners, endurance athletes, inspiratory muscle training, sports performance, exercise physiology

INTRODUCTION

Marathon running has become increasingly popular worldwide, with millions of people training for and completing these grueling 42.195-kilometer races each year. The physical demands placed on marathon runners are extraordinary, requiring not just strong legs and cardiovascular fitness, but also highly efficient respiratory systems. Yet when we look at typical marathon training programs, there's a curious gap. Runners spend countless hours building their leg strength, perfecting their running form, and developing cardiovascular endurance, but rarely do they specifically train the muscles responsible for breathing.[1]

This oversight seems particularly significant when we consider what happens to the respiratory system during a marathon. As runners push through the miles, their breathing muscles work continuously and intensely for several hours. The diaphragm, intercostal muscles, and accessory breathing muscles are constantly contracting and relaxing, facilitating the oxygen intake and carbon dioxide removal that keeps the runner moving forward. These muscles can fatigue just like leg muscles, and when they do, the consequences ripple through the entire body.[2-4]

Recent research in exercise physiology has begun exploring an intriguing question: what if we could train these breathing muscles to become stronger and more fatigue-resistant? Respiratory muscle training, or RMT, involves using specialized devices that create resistance during inhalation or exhalation, essentially providing a workout for the breathing muscles. While this approach has been studied in clinical populations with respiratory diseases, its application to healthy endurance athletes represents a relatively new frontier.[4-9]

The rationale for respiratory muscle training in marathon runners stems from understanding what happens during prolonged endurance exercise. When breathing muscles work hard, they require increased blood flow. This creates competition between the respiratory muscles and the working leg muscles for the available blood supply. Scientists call this the respiratory muscle metaboreflex. Essentially, when breathing muscles fatigue, the body redirects blood flow away from the legs to support continued breathing, which can contribute to the overwhelming fatigue that runners experience in the later stages of a marathon.[10-13]

If we could make the breathing muscles stronger and more resistant to fatigue through targeted training, theoretically they would require less blood flow during exercise. This could potentially leave more oxygen-rich blood available for the leg muscles, delaying fatigue and improving performance. Additionally, stronger respiratory muscles might improve overall lung function, enhance oxygen uptake, and reduce the perception of breathing difficulty during intense exercise.[14-15]

Despite the logical appeal of this approach, several questions remain unanswered. How much improvement in pulmonary function can realistically be achieved through respiratory muscle training? Do these physiological changes translate into better marathon performance? What type of training protocol works best for endurance athletes? How long do the benefits persist after training stops?

This research addresses these questions by implementing a controlled respiratory muscle training intervention with competitive marathon runners. We measured various aspects of pulmonary function before and after an eight-week training period to quantify the effects. Our study contributes to the growing body of evidence about respiratory muscle training while providing practical guidance for athletes and coaches considering this approach.

The significance of this research extends beyond just marathon running. Understanding how respiratory muscle training affects pulmonary function in healthy, highly trained athletes could inform training practices across many endurance sports. If breathing muscles can be strengthened like any other muscle group, this opens new avenues for performance enhancement that don't rely on controversial methods or expensive technologies.

OBJECTIVES

The primary and secondary objectives guiding this research investigation are:

Primary Objective: To determine whether an eight-week respiratory muscle training program produces measurable improvements in pulmonary function parameters among competitive marathon runners, specifically evaluating changes in maximum inspiratory pressure, maximum expiratory pressure, and forced vital capacity.

Secondary Objectives:

- To compare pulmonary function outcomes between marathon runners who complete respiratory muscle training versus those who continue standard training protocols without specific respiratory interventions.
- To examine the relationship between respiratory muscle training compliance rates and the magnitude of pulmonary function improvements achieved by individual participants.
- To assess whether improvements in respiratory muscle strength correlate with subjective reports of breathing comfort and perceived exertion during marathon training runs.
- To evaluate the sustainability of pulmonary function improvements four weeks after completing the respiratory muscle training intervention period.

SCOPE OF STUDY

- **Participant Scope:** This research focuses exclusively on competitive marathon runners who have completed at least three full marathons within the past two years and maintain weekly training volumes between 70-100 kilometers. Recreational joggers, ultra-marathon runners, and athletes with pre-existing respiratory conditions were excluded from participation.
- **Geographical Scope:** The study was conducted in metropolitan training facilities across three major cities, capturing diverse training environments while maintaining consistency in intervention protocols and measurement techniques.
- **Temporal Scope:** Data collection occurred over a six-month period from March through August 2025, encompassing an eight-week intervention phase, pre- and post-testing periods, and a four-week follow-up assessment phase.
- **Methodological Boundaries:** This research employs standardized pulmonary function testing equipment and validated respiratory muscle training devices. The study does not examine biochemical markers, genetic factors, or nutritional variables that might influence respiratory function.
- **Variables Included:** Maximum inspiratory pressure (MIP), maximum expiratory pressure (MEP), forced vital capacity (FVC), forced expiratory volume in one second (FEV1), training compliance rates, subjective breathing comfort ratings, and marathon completion times.
- **Variables Excluded:** The study does not measure maximal oxygen consumption (VO2max) through metabolic testing, does not include altitude training effects, and does not examine psychological factors beyond basic perceived exertion ratings related to breathing effort.

LITERATURE REVIEW

The intersection of respiratory physiology and endurance performance has fascinated exercise scientists for decades, yet systematic respiratory muscle training represents a relatively recent addition to athletic preparation strategies. Understanding this relationship requires examining how the respiratory system functions during prolonged exercise and why it might benefit from targeted strengthening interventions.

Respiratory Demands During Marathon Running

Marathon running places extraordinary demands on the respiratory system that extend far beyond normal daily breathing requirements. At rest, a typical adult breathes approximately twelve to fifteen times per minute, moving about six liters of air. During marathon running, ventilation rates can increase fifteen-fold or more, with elite runners moving over one hundred liters of air per minute through their lungs (McConnell, 2021). This dramatic increase requires sustained, powerful contractions of the diaphragm and intercostal muscles for two to six hours depending on the runner's pace.

What makes this particularly challenging is that respiratory muscles, like all skeletal muscles, are susceptible to fatigue. Research by Dempsey and colleagues (2022) demonstrated that respiratory muscle fatigue occurs regularly during prolonged endurance exercise, even in well-trained athletes. This fatigue doesn't just affect breathing; it triggers a cascade of physiological responses that can impair overall performance. When breathing muscles fatigue, mechanoreceptors within these muscles detect the metabolic stress and activate a reflex that causes blood vessels in the working limbs to constrict, redirecting blood flow to support continued respiratory function.

This phenomenon, termed the respiratory muscle metaboreflex, was elegantly demonstrated through studies where researchers mechanically supported breathing during exercise, reducing the work required by respiratory muscles. When breathing work decreased, leg blood flow improved, and time to exhaustion increased (Romer & Polkey, 2023). These findings suggest that respiratory muscle fatigue genuinely limits endurance performance, not through compromised oxygen delivery to the lungs, but through the reflexive redistribution of blood flow away from working muscles.

Respiratory Muscle Training Foundations

The concept of training respiratory muscles follows the same fundamental principles that govern all resistance training. When muscles work against resistance repeatedly, they adapt by becoming stronger and more fatigue-resistant. Respiratory muscle training typically involves breathing through devices that restrict airflow, creating resistance during inhalation, exhalation, or both (Illi et al., 2023).

Two primary approaches dominate the respiratory muscle training landscape. Inspiratory muscle training focuses on strengthening the muscles used for breathing in, primarily the diaphragm and external intercostals. This usually involves breathing in through a device with an adjustable valve that requires the athlete to generate substantial negative pressure to draw air through. Expiratory muscle training targets the muscles used for breathing out, including the internal intercostals and abdominal muscles, using devices that resist airflow during exhalation.

The physiological adaptations resulting from respiratory muscle training mirror those seen with limb muscle strength training. Studies using muscle biopsy techniques have shown that respiratory muscle training increases the proportion of fatigue-resistant muscle fibers in respiratory muscles and enhances their oxidative capacity (Verges et al., 2022). Additionally, respiratory muscle training appears to improve the neural control of breathing, making the respiratory pattern more efficient during exercise.

Applications in Endurance Athletes

While respiratory muscle training initially gained attention for treating patients with chronic respiratory diseases, researchers gradually recognized its potential applications for healthy athletes. Early studies with cyclists and rowers showed promising results, with athletes demonstrating improved time trial performance after several weeks of respiratory muscle training (Brown et al., 2023).

The translation to running presented interesting questions. Unlike cycling, where the upper body remains relatively stable, running involves rhythmic movement that affects breathing mechanics. Each foot strike creates vibrations that travel through the body, and breathing patterns typically synchronize with stride patterns. Would respiratory muscle training produce similar benefits for runners as it did for cyclists?

Initial research suggested it would. A landmark study by HajGhanbari and colleagues (2020) found that highly trained runners who completed respiratory muscle training improved their time trial performance and reported reduced breathing effort during intense exercise. However, the mechanisms behind these improvements remained somewhat unclear. Were runners performing better because of stronger respiratory muscles, improved breathing efficiency, reduced respiratory muscle metaboreflex activation, or some combination of these factors?

Measurement Approaches and Challenges

Assessing pulmonary function and respiratory muscle strength requires precise measurement techniques. The most common approach involves spirometry, which measures lung volumes and airflow rates. Key parameters include forced vital capacity (the total volume of air that can be forcefully exhaled after maximum inhalation) and forced expiratory volume in one second (the volume of air exhaled in the first second of forced exhalation). These measurements provide valuable information about lung capacity and airway function.

Respiratory muscle strength is typically assessed by measuring maximum inspiratory pressure and maximum expiratory pressure. These tests involve breathing against a blocked valve to generate maximum pressure, providing a direct indication of respiratory muscle force-generating capacity (Laveneziana et al., 2023). While these measurements are well-standardized in clinical settings, their application to athletes presents challenges. Athletes may have difficulty understanding the testing procedures, breathing patterns during testing may differ from those used during running, and day-to-day variability can be substantial.

Gaps in Current Understanding

Despite growing research interest, several important questions about respiratory muscle training for marathon runners remain incompletely answered. Most studies have focused on shorter-duration activities like cycling time trials or middle-distance running. Whether respiratory muscle training provides similar benefits for the multi-hour effort of marathon running is less clear. Additionally, the optimal training protocol remains debated. How much resistance should be used? How many breaths per session? How many sessions per week? For how many weeks?

Furthermore, the relationship between measurable improvements in pulmonary function tests and actual marathon performance requires clarification. An athlete might show improved maximum inspiratory pressure in the laboratory, but does this translate to better performance on the roads? Understanding this connection is crucial for determining whether respiratory muscle training deserves a place in marathon preparation programs.

The current research addresses these gaps by focusing specifically on marathon runners, employing a rigorous training protocol, and measuring both laboratory parameters and real-world performance indicators. By doing so, we aim to provide evidence-based guidance for athletes and coaches considering respiratory muscle training as part of comprehensive marathon preparation.

RESEARCH METHODOLOGY

Research Design and Philosophical Approach

This investigation employed a mixed-methods experimental design, combining quantitative measurements of pulmonary function with qualitative feedback from participants regarding their subjective experiences. The research philosophy follows a pragmatic approach, prioritizing practical outcomes and real-world applicability over purely theoretical considerations. We believe that sports science research should ultimately provide actionable guidance for athletes and coaches, which shaped our methodological decisions throughout the study.

The experimental design included random assignment of participants to either an intervention group receiving respiratory muscle training or a control group continuing their normal training routines. This randomized controlled trial structure allows us to isolate the effects of respiratory muscle training from other factors that might influence pulmonary function, such as general improvements in fitness from ongoing marathon training.

Participant Selection and Characteristics

We recruited forty-five competitive marathon runners through local running clubs, marathon training groups, and social media outreach within the running community. To be eligible, runners needed to meet several criteria: completion of at least three full marathons within the previous twenty-four months, current weekly training volume between seventy and one hundred kilometers, no diagnosed respiratory conditions like asthma, no smoking history, and no previous experience with structured respiratory muscle training.

The recruitment process yielded fifty-three interested runners, but eight did not meet the eligibility criteria after screening. The forty-five participants who entered the study ranged in age from twenty-four to forty-eight years, with a mean age of thirty-four years. The group included twenty-seven males and eighteen females, reflecting the gender distribution commonly seen in competitive marathon running. Their marathon personal best times ranged from two hours forty-eight minutes to three hours fifty-two minutes, indicating a relatively homogenous group of serious recreational to sub-elite runners.

We randomly assigned twenty-three participants to the intervention group and twenty-two to the control group using a computer-generated randomization sequence. This random assignment helps ensure that any differences between groups at the end of the study can be attributed to the intervention rather than pre-existing differences between participants.

Intervention Protocol

The intervention group received respiratory muscle training devices (PowerBreathe KH2) and detailed instructions on their use. The training protocol consisted of two daily sessions, morning and evening, each involving thirty breaths against inspiratory resistance. The device provides adjustable resistance using a spring-loaded valve, and we set initial resistance at approximately fifty percent of each participant's maximum inspiratory pressure as measured during baseline testing.

Participants increased the resistance by small increments each week following a progressive overload principle, similar to increasing weights in strength training. By week four, most participants were training at approximately seventy percent of their initial maximum inspiratory pressure, and by week eight, many had progressed beyond their initial maximum, demonstrating clear strength gains.

To monitor compliance, we provided training logs and asked participants to record each completed session. Additionally, we scheduled weekly check-in calls to address questions, provide encouragement, and reinforce proper technique. The respiratory muscle training was supplementary to participants' ongoing marathon training; we specifically instructed them not to alter their running training during the eight-week intervention period.

The control group continued their normal marathon training without any respiratory muscle training component. We asked them to maintain their typical training patterns and avoid beginning any new training modalities during the study period. Both groups received the same pre- and post-intervention testing protocols.

Data Collection Procedures

We conducted comprehensive pulmonary function testing at three time points: baseline (before beginning the intervention), immediately post-intervention (after completing eight weeks of training), and follow-up (four weeks after completing the intervention). All testing occurred in a university exercise physiology laboratory using calibrated equipment and following standardized protocols.

Spirometry measurements were obtained using a portable spirometer (MicroLab ML3500) following American Thoracic Society guidelines. Participants performed the maneuvers in a seated position wearing a nose clip. After normal breathing, we instructed them to inhale as deeply as possible, then exhale forcefully and completely into the spirometer mouthpiece. We recorded the best result from three acceptable trials, with forced vital capacity and forced expiratory volume in one second as the primary variables of interest.

Respiratory muscle strength testing used a handheld respiratory pressure meter (MicroRPM) to measure maximum inspiratory and expiratory pressures. For maximum inspiratory pressure, participants exhaled completely, then inhaled as forcefully as possible through the device against a blocked valve for approximately two seconds. For maximum expiratory pressure, the process reversed—participants inhaled completely, then exhaled maximally against the blocked valve. We repeated each test at least five times with adequate rest between attempts, recording the highest pressure achieved as the participant's maximum.

Beyond these objective measurements, we collected subjective data through questionnaires administered at each testing session. Participants rated their perceived breathing comfort during recent training runs using a ten-point scale and provided open-ended comments about any changes they noticed in their breathing during exercise.

Statistical Analysis Approach

We analyzed the quantitative data using appropriate statistical techniques for pre-post intervention designs with control groups. The primary analysis involved repeated measures analysis of variance (ANOVA) to examine changes in pulmonary function parameters across time (baseline, post-intervention, follow-up) and between groups (intervention vs. control). This analytical approach allows us to determine whether the intervention group showed significantly greater improvements than the control group.

For each pulmonary function parameter, we calculated the percent change from baseline to post-intervention within each group. We then compared these change scores between groups using independent t-tests. Statistical significance was set at $p<0.05$, meaning we considered results statistically significant if they would occur by chance less than five percent of the time.

We also examined correlations between training compliance (percentage of prescribed sessions completed) and the magnitude of improvement in pulmonary function parameters. This analysis helps determine whether dose-response relationships exist—in other words, whether participants who completed more training sessions achieved greater improvements.

Ethical Considerations

The research protocol received approval from the university institutional review board before any data collection began. All participants provided written informed consent after receiving detailed explanations of the study procedures, potential risks, and their right to withdraw at any time without penalty. We protected participant confidentiality by assigning identification numbers and storing all data in password-protected electronic files.

The respiratory muscle training intervention carries minimal risk for healthy athletes, but we monitored participants for any adverse effects through weekly check-ins. We instructed participants to contact us immediately if they experienced any concerning symptoms like dizziness, chest pain, or unusual breathing difficulties. No serious adverse events occurred during the study period, though a few participants reported minor jaw soreness during the first week of training, which resolved with continued practice.

Limitations

Several methodological limitations warrant acknowledgment. First, the study duration of eight weeks, while sufficient to induce training adaptations, may not capture longer-term effects or optimal training duration. Second, we did not measure actual marathon performance as a primary outcome due to logistical challenges of having all participants race during specific time windows. Third, the study sample, while appropriate for detecting significant effects, was relatively small and drawn from a specific geographic region. Fourth, we could not implement true blinding—participants necessarily knew whether they were performing respiratory muscle training. This creates potential for placebo effects, though the objective nature of pulmonary function measurements somewhat mitigates this concern.

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